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A remote monitor of bed patient cardiac vibration, respiration and movement

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Abstract— **We have developed a remote system for monitoring heart rate, respiration rate and movement behavior of at-home elderly people who are living alone. The system consists of a 40 kHz ultrasonic transmitter and receiver, linear integrated circuits, a low-power 8-bit single chip microcomputer and an Internet server computer. The 40 kHz ultrasonic transmitter and receiver are installed into a bed mattress. The transmitted signal diffuses into the bed mattress, and the amplitude of the received ultrasonic wave is modulated by the shape of the mattress and parameters such as respiration, cardiac vibration and movement. The modulated ultrasonic signal is received and demodulated by an envelope detection circuit. Low, high and band pass filters separate the respiration, cardiac vibration and movement signals, which are fed into the microcontroller and digitized at a sampling rate of 50 Hz by 8-bit A/D converters. The digitized data are sent to the server computer as a serial signal. This computer stores the data and also creates a graphic chart of the latest hour. The person's family or caregiver can download this chart via the Internet at any time.**

I. INTRODUCTION

According to "World health report 2006" of WHO [1], in Japan elderly people over age sixty are 25.6% of the total population, and ten percent are not living with their daughters or sons and are living alone. Their children and other caregivers want frequent updates on the elderly person's health condition, so it is most important to monitor the health of the elderly people and provide a constantly-available status report. The elderly spend much of their time resting or sleeping on their bed, so numerous types of awareness recording systems [2]-[14] have been developed for monitoring their physiologic parameters such as heart and respiration rates, electrocardiogram and body movements. Sensors attached to the bed mattress or sheet are influenced by urinary incontinence and sheet changing and therefore cannot continuously record the physiological parameters.

In this study, a new monitoring system has been developed for measuring the physiological parameters of heart and respiration rate and movement behavior while elderly people are in bed. Moreover, the system can also detect if the patient has left the bed, which makes it useful for many clinical applications, with patients of any age. Ultrasonic transmitter and receiver units are installed in the mattress and the physiological parameters are detected from the received ultrasonic signal. A server computer stores the data and makes a latest one-hour graphic chart. When the family or caregiver calls from an Internet mobile phone to the server computer, the server computer sends the graphical chart via Internet. The family or caregiver therefore can monitor the elderly person's health condition and behavior at any time.

II. METHOD

Fig. 1 shows the principle of the monitoring system which employs a 40 kHz ultrasonic transmitter and receiver.

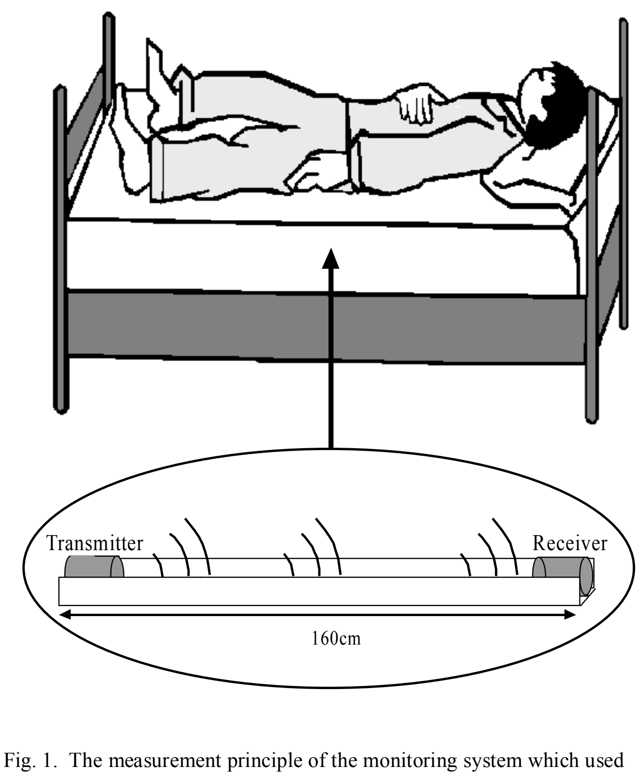

Fig. 1. The measurement principle of the monitoring system which used 40 kHz ultrasonic transmitter and receiver

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However, the mattress has 540 pocket spring coils, which obstruct the diffusion of the 40 kHz ultrasonic signal. So the ultrasonic transmitter and receiver were installed in both sides of the aluminum rail as shown in Fig. 1. The aluminum rail is installed between the pocket spring coils at the bottom of the bed mattress. The 40 kHz transmitter sends ultrasonic energy to the receiver through the rail, and diffuses it into the bed mattress. The diffused ultrasonic wave is multiply reflected by the mattress cover, and diffuses into the mattress. The complexly-reflected signal within the mattress causes the amplitude of the received signal to vary with changes in mattress shape. When a person is lying in any position, on any bed area, then his/her physiological parameters alter the shape of the mattress and amplitude modulate the received signal. When the person is out of bed, the amplitude does not change, so the system also monitors in/out of bed status.

III. SYSTEM DESCRIPTION

Fig 2 shows the system block diagram. It consists of a 40 kHz ultrasonic transmitter and a 40 kHz ultrasonic receiver (Nippon Ceramic. T/R40-16), four amplifiers, high and band pass filters, an 8-bit microcontroller (Microchip Technology, PIC18F452) and an Internet server computer.

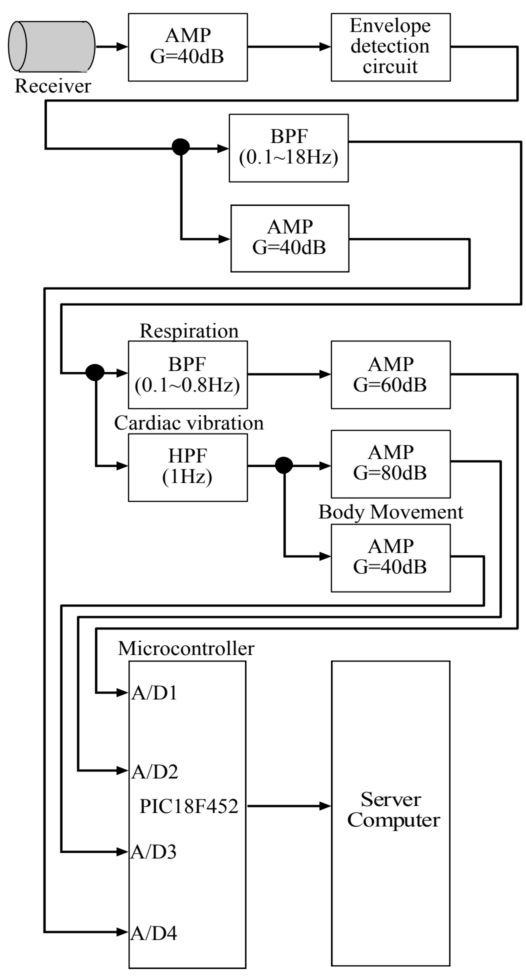

Fig. 2. The block diagram of the monitoring system

The ultrasonic transmitter is driven by a 40 kHz sinusoidal oscillator (418B, Kikusui Electronics). This low frequency is used because it diffuses wider into the mattress than higher frequencies. The received ultrasonic signal is applied to a 40 dB gain non-inverting amplifier. The amplified signal is demodulated by an envelope detection circuit, which consists of two diodes and two capacitors. The envelope detection circuit output, whose output contains the three physiological parameters, is fed into a 0.1 Hz-18 Hz band pass filter BPF. Respiration is detected by a 0.1 Hz to 0.7 Hz band pass filter and amplified by a 60 dB gain amplifier. Cardiac vibration and body movements are detected by a 1 Hz high-pass filter. The cardiac vibration signal is amplified by an 80 dB gain amplifier. The body movement signal is amplified by a 40 dB gain amplifier. Each physical parameter and the envelope detector output are fed into a microcontroller, which is an 8-bit CMOS RISC-like CPU with eight 8-bit analog to digital converters. Four of these are used, to digitize at a sampling rate of 50 Hz. The microcontroller sends the digitized signals as serial data to the internet server computer. The internet server computer stores the data and creates a latest one hour graphical chart. The family or caregiver can download the graphical chart via the Internet.

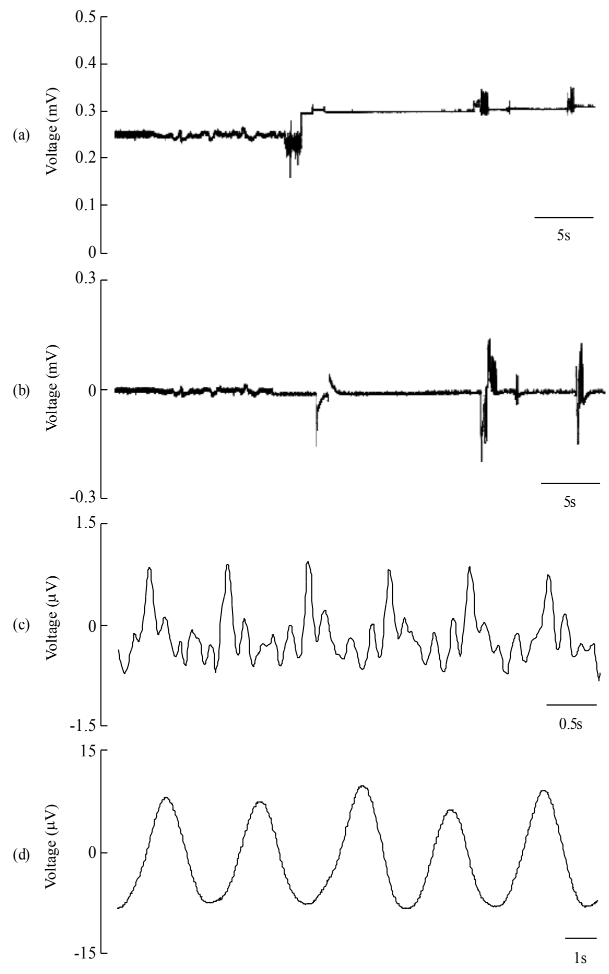

Fig.3 The envelope detection circuit output waveform(plot(a)), body movement(plot(b)), cardiac vibration(plot(c)) and respiration(plot(d))

Fig. 4 shows the Internet server computer flow chart. The server computer detects whether the elderly person is in or out of bed. When the elderly person is in bed, then the output of the envelope detection circuit increases as shown in Fig. 3(a). Behavior such as moving and resting is detected from the body movement signal, as shown in Fig. 3(b).

The cardiac pulse is detected from the amplified heart vibration, as shown in Fig. 3(c). The rising and falling edges of the cardiac vibration wave have steeper slopes than the other waves in the neighborhood of the baseline. The cardiac vibration wave is detected by sequentially comparing these slopes, which are calculated by the amplitude and duration from the pre-peak nadir to the peak. If the slope exceeds a set threshold, the signal is identified as a cardiac pulse. The detected cardiac pulses are is counted for one minute, and defined as heart rate.

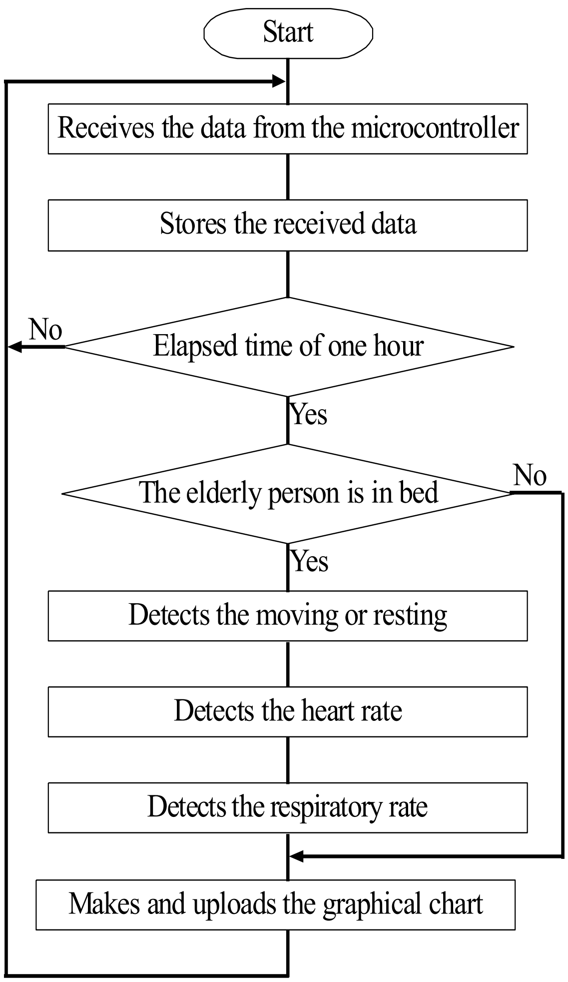

Fig.4 The Internet server computer flow chart

Respiration individual waveforms, as shown in Fig. 3(d), are detected when their amplitude exceeds a set threshold. The respiration cycles are counted for one minute and defined as respiration rate.

The server computer creates the graphical chart from the detected heart rate, respiration rate and behavior every one hour. The graphical chart is uploaded to the homepage and can be downloaded by the family or caregivers.

IV. Results and Conclusion

Measurements were performed on three normal age 21-61 male subjects in a bed with pocket spring coils (F-1-P, Dream Bed). Each subject provided measurements for two continuous hours, and the accuracies of heart and respiratory rates were verified by clinical instruments to be within +/- 3 %. Moving, resting and out of bed state detection was verified, by direct observation, be error-free for the entire two hours, for each subject.

When the subject is lying on the bed, the respiration rate, heart rate and behavior are detected and displayed on an Internet mobile telephone (W64S, au) as shown in Fig. 5.

The mean frequency of respiration and heart rates were 15/minute and 62 bpm, respectively. These results indicate that respiration rate and heart rate are closely influenced by each other and that the subject's general health condition and living patterns can be estimated from these data.

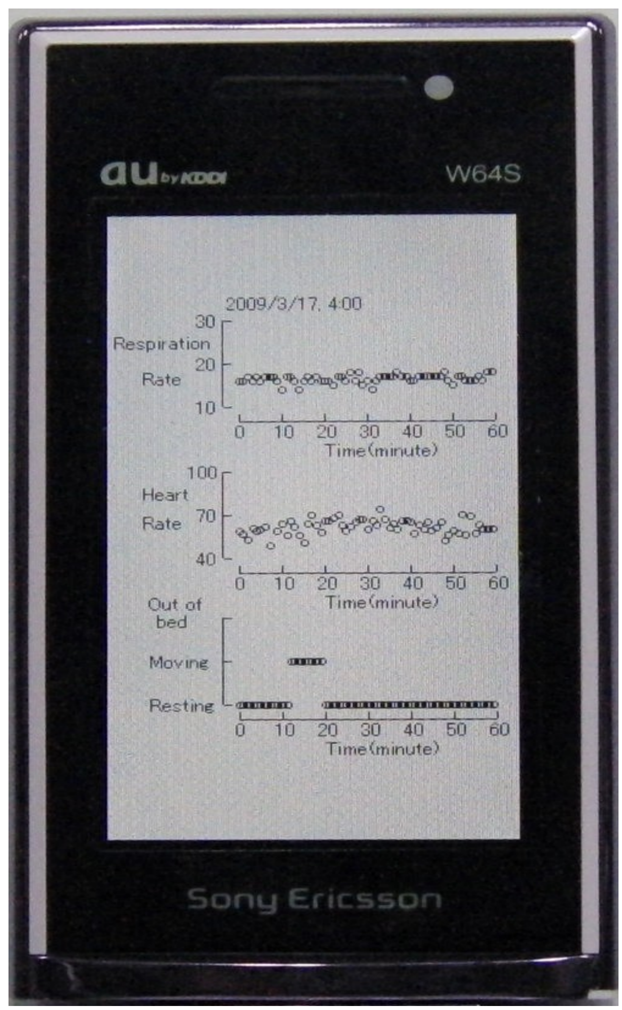

Fig. 5 Respiration rate, heart rate and behavior displayed on the Internet mobile telephone.

Although the system cannot detect respiration and heart rates while the patient is moving, solitary elderly people's general health condition and living patterns at home can be closely inferred. In conclusion, the 40 kHz ultrasonic remote monitoring system has been designed for heart rate, respiration rate and behavior measurement. These parameters are detected by ultrasonic energy transmitted into the bed mattress, when the subject is lying on the bed mattress. The system does not need any sensors to be attached to the subject.

The system is not intended to be used for clinical diagnostic purposes, although its resting heart and respiratory rates are exceedingly reliable and accurate, as is its monitoring of general in and out of bed status and schedule. Almost all caregivers and families of elderly people have sufficient knowledge of normal heart and respiration rate ranges to use the system to remotely check the solitary person's condition and behavior by Internet mobile telephone or personal computer at any time, especially during normal sleeping hours, and to call emergency personnel if they suspect a problem. Families often worry most intensely about their elderly relatives in the middle of the night, and non-obtrusive remote observation of normal sleep during this time, with good heart and respiratory rates, is most assuring, to say the least.

The system is not only applicable to at-home solitary elderly people, but could also be useful for monitoring welfare facility residents and hospital patients, especially in outlying hospitals.

ACKNOWLEDGMENT

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