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A Wireless Breathing-Training Support System for Kinesitherapy

Hiroki Tawa, Yoshiharu Yonezawa, Hiromichi Maki, Hidekuni Ogawa, Ishio Ninomiya, Kouji Sada
Shingo Hamada, and W. Morton Caldwell, *Member, IEEE*

Abstract— **We have developed a new wireless breathing-training support system for kinesitherapy. The system consists of an optical sensor, an accelerometer, a microcontroller, a Bluetooth module and a laptop computer. The optical sensor, which is attached to the patient's chest, measures chest circumference. The low frequency components of circumference are mainly generated by breathing. The optical sensor outputs the circumference as serial digital data. The accelerometer measures the dynamic acceleration force produced by exercise, such as walking. The microcontroller sequentially samples this force. The acceleration force and chest circumference are sent sequentially via Bluetooth to a physical therapist's laptop computer, which receives and stores the data. The computer simultaneously displays these data so that the physical therapist can monitor the patient's breathing and acceleration waveforms and give instructions to the patient in real time during exercise. Moreover, the system enables a quantitative training evaluation and calculation the volume of air inspired and expired by the lungs.**

I. Introduction

Chronic obstructive pulmonary disease (COPD) is now the fourth-most cause of death in the world [1]. COPD weakens Work of Breathing (WOB) by airway inflammation. Patients will finally weaken and die unless they have proper treatment [2]-[4]. Breathing-training is an important medical therapy because it improves WOB [5]-[6]. Breathing-training programs include pursed lips breathing and diaphragmatic breathing, as taught to COPD patients by hospital physical therapists. At first, the patients train mainly by pursed lips breathing, during a resting condition. The physical therapist directly monitors the patient's breathing and gives instructions to the patient during this training. The effect of training is evaluated subjectively for respiratory improvement. The patients who have learned the at-rest breathing methods are then trained with exercise, such as level walking, or up and down stairs. However, due to patient motion during exercise, physical therapists often have difficulty in visually evaluating the patient's breathing, which handicaps their ability to give breathing instructions in real time.

H. T. Author is with the Department of Health science, Hiroshima Institute of Technology, Hiroshima 731-5193, Japan. (e-mail: a204057@cc.it-hiroshima.ac.jp).
Y. Y. Author is with the Department of Health science, Hiroshima Institute of Technology, Hiroshima 731-5193, Japan. (e-mail: hityoshi@cc.it-hiroshima.ac.jp).
H. M. Author is with the Department of Health science, Hiroshima Institute of Technology, Hiroshima 731-5193, Japan (e-mail: hiromiti.maki@nifty.com).
H. O. Author is with the Department of Health science, Hiroshima Institute of Technology, Hiroshima 731-5193, Japan (corresponding author to provide phone: +81-82-921-6213; fax: +81-82-921-8978; e-mail: ogawa@cc.it-hiroshima.ac.jp)
I. N. Author is with the Department of Hiroshima International Univ., Hiroshima 724-0695
K. S. Author is with the Shakaihoken Shimonoseki Kousei Hospital, Yamaguchi 750-0061, Japan
S. H. Author is with the Shakaihoken Shimonoseki Kousei Hospital, Yamaguchi 750-0061, Japan
W. M. C. Author is with Caldwell Biomedical Electronics, Finleyville, Pennsylvania 15332, USA. (e-mail: caldbio@earthlink.net).

In response to this problem, we have developed a new wireless breathing-training support system for COPD kinesitherapy [7]-[11]. The system sequentially records and monitors the patient's breathing and body movement acceleration waveforms during exercise. Using this system, the physical therapist can accurately monitor breathing and exercise and give enhanced instructions, in real time, to the patient. Moreover, the system enables a quantitative evaluation of training, calculation of the volume of air inspired and expired by the lungs, and data recording of each breathing exercise session.

II. System Description

Figure 1 shows the overall wireless breathing-training support system, which employs a respiratory detection device (RDD) and laptop computer. The RDD is attached to a non-elastic belt encircling the chest and measures low frequency components of belt circumference change [12]. This length is measured by an optical sensor and outputted as serial digital data. The accelerometer measures dynamic acceleration force produced by exercise.

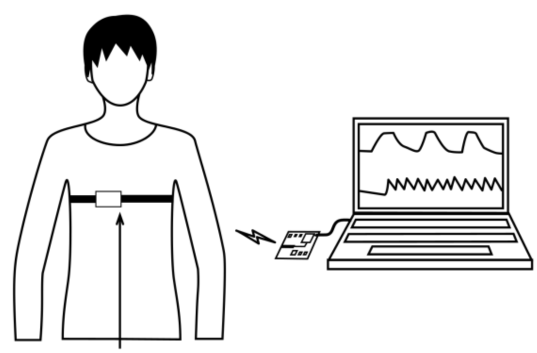

Figure 1. The overall description of the wireless breathing-training support system

The microcontroller sequentially samples the dynamic acceleration force and sends the acceleration force and chest circumference signals to the physical therapist's laptop computer, via a Bluetooth module. The computer receives and stores the data and both signals are simultaneously displayed on its screen.

Figure 2 shows the RDD designed for measuring chest circumference and dynamic body acceleration. Circumference is measured by an optical distance transducer made from a computer mouse (BUFFALO, BOMC2-USSP), which has its plastic cover removed. This sensor linearly measures belt perimeter length variations, which are produced by subject breath inspiration and expiration. It is used due to its inherent linearity, sensitivity, direct digital output, and simplicity of application. The accelerometer (Kionix, KXM52-1050), which is set vertical to the Earth's surface, measures body movements produced by level treadmill walking or going up/down stairs. These sensors and their electronics are mounted on a 60x40x2mm acrylic board. A Teflon sheet bonded to the mouse pad is placed between the acrylic board and a non-elastic belt and pulled by

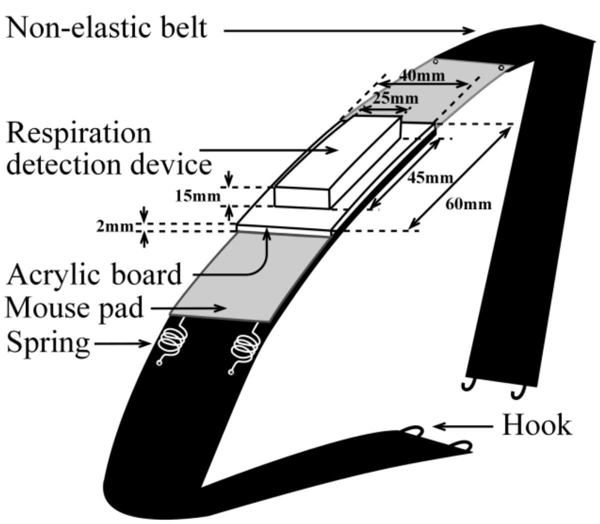

Figure 2. The RDD designed for measuring a chest circumference segment length and dynamic acceleration

two spring coils attached to the belt. The acrylic board is fixed to the belt. When the patient breathes, the optical sensor measures the Teflon sheet movement distance.

Although the accelerometer has three axis outputs, only the vertical is used, which is sufficient to indicate exercise speed and intensity, for treadmill or stairs, and also inactivity. At present, for system ease-of-use, only the vertical axis activity measurement has been requested by respiratory technicians and physicians.

Figure 3 is the RDD block diagram. The RDD consists of a high pass filter, non-inverting amplifier, RC integrator, microcontroller (Microchip Technology, PIC16F877), the distance sensor, and the Bluetooth module (ROVING NETWORKS, RN-41). These components, and a lithium polymer 3.7 volt, 300 mAh battery (# 62030, Hyper Power Co.) are contained in the RDD enclosure. The 6 x 20 x 20 mm battery operates the system for three hours per charge. The accelerometer output is fed into a high pass filter and

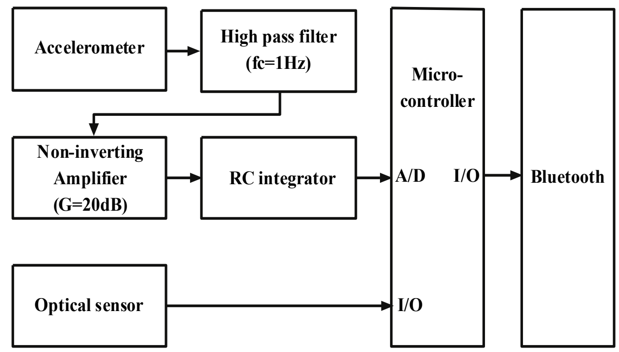

Figure 3. The block diagram of the RDD

amplified 20dB. The acceleration signal is then rectified, integrated by a simple RC integrator and inputted to the microcontroller, which samples it at 10 Hz. The 8-bit serial optical sensor output is fed to the microcontroller's digital input.

Figure 4 shows the flowchart of the RDD. When the RDD receives a start command signal from the computer, the microcontroller starts and checks if a movement signal is present. If detected, then the microcontroller calculates the latest position. If movement is not detected, position remains the same as the last calculated value

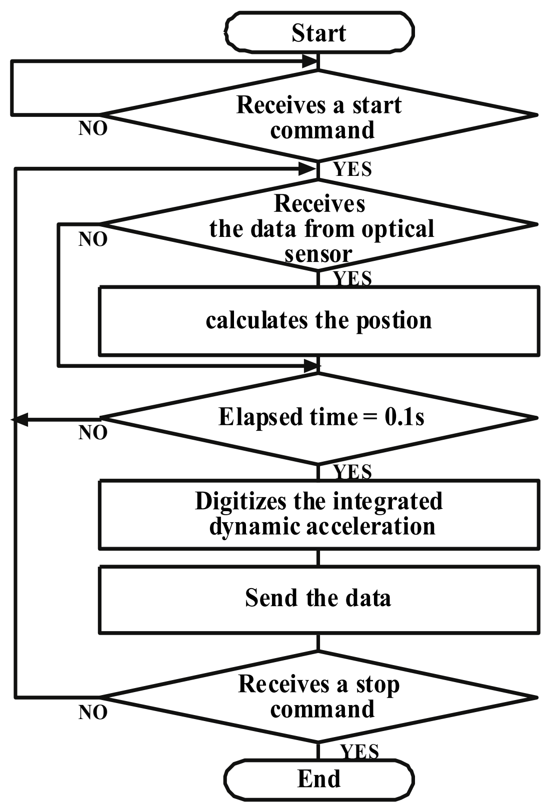

Figure 4. The flowchart of the RDD

Figure 5 shows the flowchart of the laptop computer. When the patient starts breathing training, the physical therapist sends a start command to the RDD, via a Bluetooth module.

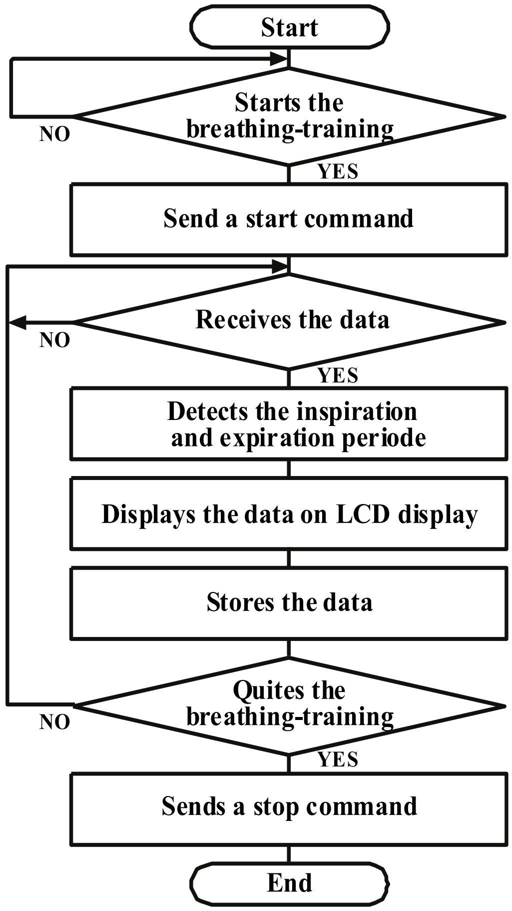

Figure 5. The flowchart of laptop computer

The laptop computer receives the chest circumference and acceleration signals from the RDD. These data are stored to the computer, which detects inspiration, expiration and walking periods. These periods, as well as chest circumference and dynamic acceleration are simultaneously displayed on the computer display, until a stop command signal is sent.

III. Results And Conclusion

The system was successfully evaluated by performing measurements on five normal 22 - 61 year-old male subjects. The RDD was positioned over the xiphoid process.

Figure 6 shows typical respiration waveforms simultaneously measured with the developed device and a spirometer.

These waveforms are synchronized; verifying that the developed system records the respiration waveform. The correlation coefficient is 0.95. These results indicate that chest instantaneous circumference is an excellent measurement of respiratory function, and, by use of this system, is easier to obtain than other chest distance dimensions, such as width and/or depth. Therefore, the system can be used to calculate the volume of air inspired and expired by the lungs. This requires obtaining the relationship between the measured circumference and lung air volume, as

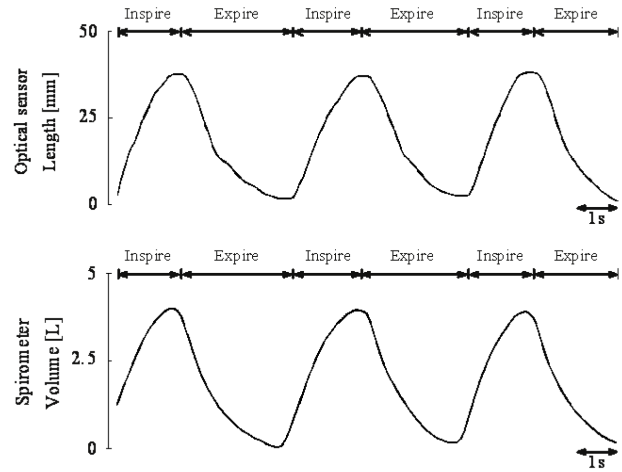

Figure 6. Typical respiration waveforms simultaneously measured by the developed device and a spirometer.

recorded by a spirometer, for each patient.

Figure 7(a) shows the chest circumference changes and the integrated dynamic acceleration during walking. One step of walking is shown by the peak of the integration waveform.

The physical therapist instructed the subject to inspire during two steps, and then expire during four steps for this breathing-training.

Figure 7(b) shows the chest circumference changes and

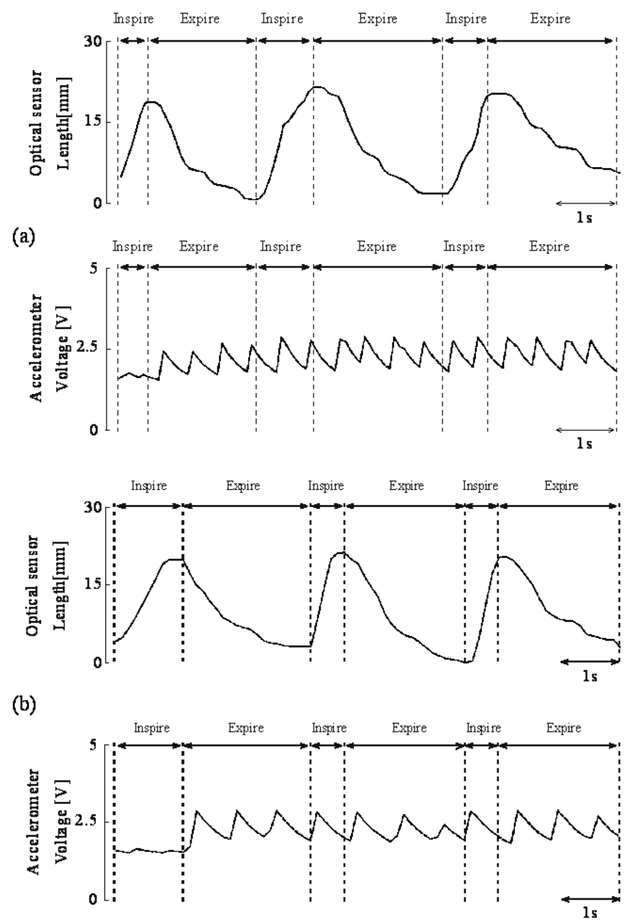

Figure 7. Chest circumference and dynamic acceleration during walking (plot (a)) and going up stairs (plot (b)).

dynamic acceleration measured during going up stairs. The physical therapist instructed the subject to inspire during one step, and then expire during three steps for this breathing-training. These results show that the subject did the breathing-training according to the physical therapist's instructions.

The developed system can monitor breathing and acceleration waveforms during exercise, and the physical therapist can give instructions to the patients in real time. The stored data enables a quantitative training evaluation and also calculation of air volume inspired and expired by the lungs [13]-[14].

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