A Biofeedback-based Breathing Induction System

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Abstract—we have developed a biofeedback-based breath training environment in which the user can easily relax his body and mind only by following the induction. The environment includes body relaxation video guide and breathing induction program. The body relaxation video guide helps relax the body with simple stretch motions in a seating posture. The breathing induction program is operated in two modes: biofeedback training mode and self training mode. In the biofeedback training mode, a visual breathing induction is provided and each breath following the induction is assessed by processing the change of pulse rates measured from photo-plethysmography. In self-training mode, voice and visual induction is provided to breathe consciously in a natural posture without any physical restrictions such as sensor contact and visual induction eye tracing. The environment is also equipped with a breathing test function. The breathing test evaluates current breathing habit to recommend an optimal breathing guide.

Keywords— breathing induction; biofeedback; mental health; pulse rate; breath rate; concentration; memory; creativity; stress relief

I. INTRODUCTION

Many studies in psychological fields have showed that breathing induction can get benefits of improving mental health [1][2]. This breathing induction can be incorporated into a program passively or actively [3]. In passive breathing induction, no conscious control is exerted over inhalation and exhalation and breathing is “natural.” In contrast, active breathing induction involves conscious control over inhalation and exhalation. This may involve controlling the breathing rate. From these facts, we implemented the breathing induction environment with two modes: biofeedback training mode and self training mode, each of which corresponds to active and passive breathing, respectively [4].

In addition, many researchers have proven that personally-tuned training program reflecting the person’s physiological status is more effective in health promotion than universally ready-made one [5]. Most of the recently developed mental training systems, however, harp on the same exercise prescription. These systems cannot provide biofeedback effects to the subject and thus have limitations in efficient health promotion [5]. To solve these problems, we proposed the biofeedback-based breathing induction system to effectively improve people’s mental health [5][6].

In order to evaluate subject’s breathing habit, an algorithm for estimation of breath wave is needed. There are several methods for evaluating breath signals: plethysmography technique, impedance pneumography technique, and nasal temperature technique [6]. Although these methods are relatively accurate, it may bring inconvenience and discomfort to the patients as well as to the physicians. In contrast to these traditional methods, pulse oximeter based breathing measurement has been developed without any attachment of sensors [6][7][10].

This paper presents a biofeedback-based breath training environment. In addition, we demonstrate methods for effective evaluation of subject’s breathing habit by using the pulse oximeter based algorithm [8][9].

II. SYSTEM SPECIFICATION

In order to solve the problems above, the breathing induction system requires the following specifications:
1) Contents for physical relaxation and physical awake both before and after exercise
2) Contents for breathing relaxation, which reflects subject’s physiological status
3) Pulse wave detection modules for analysis of subject’s physiological status
4) Algorithms for detection of pulse rate and estimation of breathing habit
5) Database for managing subject’s information and biofeedback results
6) Personalized exercise prescription based on physiological parameters, such as pulse rate and breath rate

III. SYSTEM DESIGN

A. System Overview

Our developed system can be divided into two modules: a hardware module, which offers physiological status measurement interface by using red LED type sensors, and a software module, which offers mental training program with the personalized breathing induction.
The system measures two physiological parameters from the subject: pulse rate and breath rate. Pulse rate can be obtained by using the red LED type sensors from subject’s index finger. The pulse data are transmitted to the microcontroller in hardware module. After digital filtering, such as low pass filtering, the microcontroller converts analog signal into digital signal (ADC) with a sampling frequency of 512Hz. From these sampled data, breath information can be extracted by pulse rate variability and envelope of pulse wave.

After this detection process, the system evaluates the target breath rate from the extracted information, especially breath rate. Using the evaluated data, the system provides biofeedback to the subject and serves the personalized induction program. By following the induction program, subjects can correctly change their breathing habits.

B. Usecase Diagram

In our system, there are four actors: an actor that performs the biofeedback training mode, an actor that performs the self training mode, personal computer, and device. The system detects subject’s physiological parameters from the unrestrained device, which includes biosensors.

Users can be provided with four mental training programs from the system: concentration, memory, creativity, and stress relief. Each program has three phases: warm-up phase—for physical relaxation, workout phase—for breath relaxation, and cool-down phase—for body awaking. In the test session, the system measure subject’s physiological parameters, such as inhalation period, exhalation period, and average pulse rate. After test, users will be provided personalized with optimal breath rate, which reflects their mental status.

C. Sequence Diagram

Fig. 3 shows how processes of the system operate with one another and in what order.

IV. SYSTEM IMPLEMENTATION

A. Hardware Implementation

The hardware module can be divided into two primary parts: analog part and digital part.

The analog part includes red LED type biosensors and analog low pass filtering module. The biosensors illuminate the skin and measure changes in light absorption [11]. To
eliminate a high frequency noise signal, we applied analog low pass filtering with a cutoff frequency of 10Hz.

The digital part has been implemented by microcontroller, MSP430FG437, which has an ADC resolution of 12bit. This part performs three main functions: analog to digital conversion with a sampling frequency of 512Hz, extraction of AC signal, which is actual pulse wave, from original raw data—including DC signal, and data communication through the USB protocol.

B. Breathing Induction Model

We have designed breathing induction model according to each training program. In order to provide personalized training program, we control two factors: different breathing pattern and breath rate.

We designed I:S:E:S ratio based on the relationship between heart beat interval oscillations and spontaneous breathing. The intervals between successive heart beats shorten during inspiration and lengthen during expiration, this phenomenon is known as “respiratory modulation” [7].

V. RESULTS

A. Hardware Part

Fig. 7 shows our designed pulse oximeter. In order to eliminate discomfort from test environment, we devised unrestrained pulse oximeter, which can induce meditative posture.

The device is equipped with two biosensors, which have same roles, and thus can detect pulse wave regardless of direction of subject’s index finger.

B. Software Part

Fig. 8 depicts a window-based breathing induction program. Each program has a different induction model and provides a user interface for measuring the physiological status, such as pulse rate.

| I:S:E:S ratio of “concentration program” | 6:3:4:3 |
| I:S:E:S ratio of “memory program” | 5:3:5:3 |
| I:S:E:S ratio of “creativity program” | 4:3:6:3 |
| I:S:E:S ratio of “stress relief program” | 5:3:5:3 |

Table 1. I:S:E:S Ratio of Breathing Induction Program

In order to design breathing induction model, we have adjusted inhalation : suspend : exhalation : suspend (I:S:E:S) ratio. The ratio of our designed model is presented in Table 1.
During the training, the system evaluates subject’s breathing habit by analyzing his breath information, such as inhalation to exhalation ratio. After one breathing, the system provides evaluated results to the subject as a biofeedback. In our system, this function can be done by playing different sound effects and visualizing the results.

In order to estimate optimal breath rate, we have implemented breathing test session. In this session, the system measures pulse wave and the breath wave, which is extracted from pulse wave. After test, the system analyzes the test results and provides personalized target breath rate to the subject.

VI. CONCLUSION

We have developed a biofeedback-based breathing induction system that offers efficient mental training environment. The system extracts breath information from subject’s pulse wave and evaluates an optimal breath rate. Using this optimal breath rate, the system provides custom-made induction program to the subjects. By following the induction, subjects can change their breathing habit and thus improve their mental health.

To do this job, we have proposed methods for effective evaluation of people’s breathing habit. Furthermore, we have designed breathing induction model that leads proper breathing habit by controlling target breath rate and inhalation to exhalation ratio. From the neurophysiological views, we believe that our developed system can provide an intelligent mental training environment through personalized exercise prescriptions, which reflect subject’s mental status.

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