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A Low Cost Vibrotactile Array to Manage Respiratory Motion

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ABSTRACT

We present a tactile Respiratory Management System (tRMS) to manage and control breathing patterns of cancer patients undergoing radiation therapy. The system comprises of an array of small vibrating motors and a control box that supplies power to and provides a control interface for up to twelve motors through the parallel port of a standard personal computer. The vibrotactile array can be fastened along the forearm, arm, thigh, leg or abdomen in any configuration using Velcro and fabric wraps. All motors are operated in a binary fashion, i.e. on or off, with quick response time and perceivable vibration magnitudes. The tRMS system is inexpensive and portable, providing spatiotemporal variations in tactile cues to regulate respiratory motion during radiotherapy. The system will also be used in future psychophysical studies to determine effective use of tactile cues to control human motor actions.

KEYWORDS: Tactile feedback, vibrotactile array.

INDEX TERMS: L.2.0.c [Haptics Technology]: Tactile display; L.3.0 [Haptics Applications]: Integrating touch-based interactions into various domains Assistive technology.

1 INTRODUCTION

Gated radiation therapy is used to treat cancer patients with tumors in the upper torso area where the location of the tumor varies due to breathing patterns [1]. In this technique, the radiation beam targeting the tumor is turned on during specific portions of the breathing cycle, only when the tumor is in-line with the beam orientation. Specifically with lung cancer patients, the magnitude of lung motion is highly non-uniform during free breathing (see Fig. 1). Such irregularity in respiratory motion results in elongated treatment time, increased cost, and additional inconvenience to the patients. In order to reduce the cost and duration of the therapy, regularity in both frequency and amplitude of breathing motion must be maintained during radiotherapy. Visual and auditory feedback had been used to reduce the inconsistency in breathing patterns, but these modalities were proven ineffective due to an increase in cognitive stress that patients experienced during therapy [1]. It is the goal of the present study to utilize tactile cues, possibly in addition to visual and auditory feedback, to maintain steady and consistent breathing rates without discomfort or burdensome cognitive demands on the patient.

In related research efforts, localized cues were presented via the tactile sense using spatially spaced vibrator placed along the skin.

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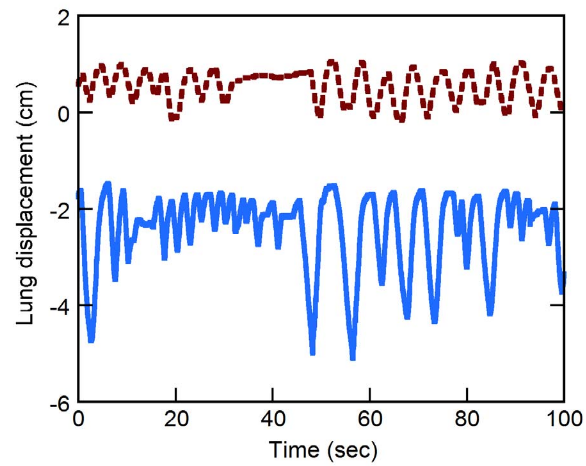

Figure 1. Typical lung motion profiles of two cancer patients

These cues provided attentional and directional information as well as information extracted from acoustical signals [2,3]. In contrast, the objective of the present study is to develop and investigate the effectiveness of spatially distributed tactile cues that command a human's internal control of their motor actions. Such cues will act as command inputs for healthy and affected participants (cancer patients) to maintain consistent breathing patterns. In this paper, we demonstrate the tactile Respiratory Management System (tRMS), its operation and use in a psychophysical study.

2 TACTILE RESPIRATORY MANAGEMENT SYSTEM

The tactile Respiratory Management System (tRMS) comprises of two main components: (i) an array of vibrating motors, and (ii) a small circuit box for control. Design requirements for the tRMS were to minimize cost, power consumption, and size, and to delivery a portable, and flexible system.

The tactile array consists of up to twelve small linear motors each with an unbalanced mass attached to the shaft (Jameco Electronics, Belmont, CA; model 256090) and housed in acrylic blocks as shown in Fig. 2. Each block along with the motor weighs approximately 3.5 grams and vibrates at constant frequency of about 180-200 Hz with perceivable amplitude. The blocks are wrapped with Velcro tape for attachment to a cloth and can be attached adjacent to any area of the skin so long as they don't interfere with the radiation beam. The motor wires are connected to the collector of two Darlington transistor arrays (ULN2803AN, eight channels capable of providing up to 500 mA) whose base current is controlled by digital outputs of the parallel (printer) port of a personal computer. Thus the "high" state of the parallel port output pin turns the corresponding motor on and the "low" state turns it off – controlling the binary state of each motor. The circuitry is placed in a small box (shown in Fig. 3). The system is powered with a 3V DC (1 A) power adapter and can run twelve motors simultaneously.

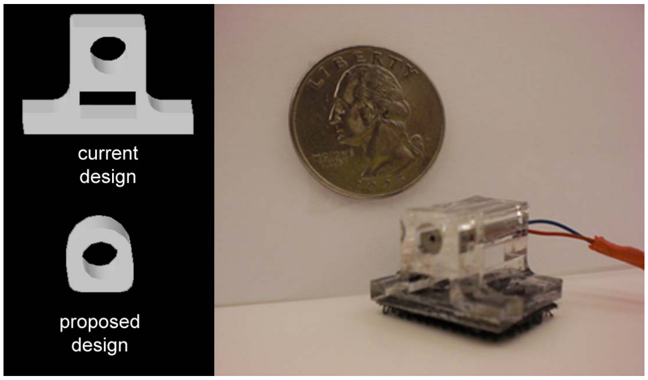

Figure 2. Vibrating motor in its housing

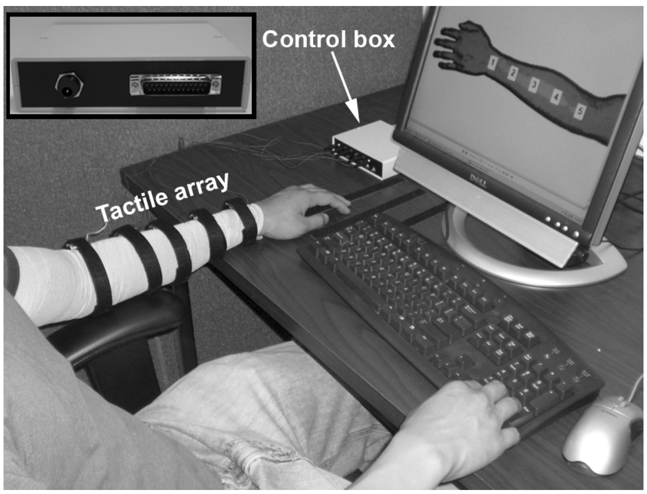

Figure 3. A participant with tRMS worn on the forearm during experiment. Inset shows the back side of the control box

A psychophysical evaluation of the tRMS was conducted by asking three healthy participants (two males, S1 and S2, and one female, S3, ages 32, 19 and 21 years old) to identify the location of the vibrators attached to their left forearm using a one-interval five-alternative forced-choice (1I-5AFC) absolute identification paradigm (see Fig. 3). Each participant completed two runs of 100 trials of 200 msec each. Results of the evaluation are shown in Table 1. Overall scores were generated by combining data for all three participants.

Table 1. Summary of psychophysical evaluation

Participant	Percentage correct	Information Transfer (IT)	IT rate (bits/sec)
S1	86.5%	1.75 bits	8.76
S2	76.5%	1.48 bits	7.42
S3	75.5%	1.39 bits	6.95
Overall	79.5%	1.49 bits	7.47

3 DEMONSTRATION

This demonstration will feature the tRMS system, and control algorithms developed in our lab for maintaining motor actions, attentional and directional queuing, and tactile representation of acoustical features. In parallel to the tRMS, we are developing a Motion Monitoring System (MMS) that measures motor actions associated with arm and chest motion. We will integrate the two systems and demonstrate open-loop and closed-loop schemes for maintaining arm movements and for breathing patterns to be used during radiotherapy.

4 FUTURE WORK

We have developed a tactile respiratory management system that will monitor and manage breathing patterns of lung cancer patients during radiotherapy. The system will work either in an open-loop scheme where normal breathing motion will be directed by the tactile cues or in a closed-loop scheme where the cues will provide error commands corresponding to the difference between the patient's breathing and a desired respiratory motion waveform. We will conduct a psychophysical study to determine the subjective measure of location of the vibrating motor stimulating the skin of the forearm and thigh. From this study, we will determine relationships between the actual spacing and subjective length between the motors. Knowledge of such relationships will allow us to determine the optimal spacing of the motors that can effectively control the human motor commands for breathing. We will also investigate the temporal sequence of spatial cues as described in [4].

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