Cardiovascular Fitness Strengthening Using Portable Device

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***Abstract*— The paper describes a reliable and valid Portable Exercise Monitoring sysetm developed using TI eZ430-Chronos watch, which can control the exercise intensity through audio stimulation in order to increase the Cardiovascular fitness strengthening.**

I. Introduction

Exercising plays a vital role in improving and protecting the human being health; many diseases can be avoided by just exercising regularly, those diseases such as cancer, blood pressure, heart problems and diabetes. Heart Rate (HR) and Oxygen Uptake (VO_2) are key indicators of functional health status; their measurements can aid early detection of cardiac diseases [1], [2]. The cardiovascular fitness is defined as the ability of the heart and lungs to supply oxygen-rich blood to the working muscle tissues and the ability to use oxygen to produce energy for movement [3]. Cardiovascular fitness is measured as the amount of oxygen transported in the blood and pumped by the heart to the working muscles and as the efficiency of the muscles to use the oxygen. Regular exercise can increase the cardiovascular fitness as the heart becomes more efficient at pumping oxygen-rich blood to working muscles and body tissues [4]. Increasing the cardiovascular fitness means increasing the capability of the heart and the rest of the cardiovascular system in supplying oxygen and energy to the body.

The training protocol consists of three major phases; that is a warm up, exercise and cools down. Warm up prepares the body for more intense exercise by improving blood flow to the heart, increasing the muscle temperature and protecting against injury through improved flexibility of muscles [5] . The second phase in training protocol is the exercising; the main characteristics of this phase include the intensity, duration, frequency and mode of exercise [6]. Cooling down is the last phase of the training protocol and is defined as the phase that bring the body back to its normal physiological level after fast, vigorous exercise or activity by gradually slowing the pace of activity or by doing gentle exercises or stretches [7]. Any training or workout such as running, swimming or cycling that involves high intensity training session with resting periods is called interval training protocol. The interval training protocol has proven to build up and strengthen the athletes cardiovascular system [8]. It can usually be noticed that long distance runners are performing the interval training protocol as well as footballers. This newly developed wearable exercise monitoring system has been customized to suit Interval Training.

The Portable Exercise Monitoring System was implemented by using the eZ430-Chronos watch [9] from Texas Instruments, BM-CS5 wireless chest strap [10] from BM Innovations and $K4b^2$ [11] from COSMED. The eZ430-Chronos watch is a flexible and powerful development tool, which can integrate heart rate monitor as one of physiological sensors by using low power consumption wireless communications. The BM-CS5 is using BlueRobin^{TM} data transmission technology to measure and transmit the heart rate values wirelessly.

$K4b^2$ is the first portable system for pulmonary gas exchange measurement with true breath-by-breath analysis, $K4b^2$ has previously been reported to be valid, accurate and reliable [12], [13]. $K4b^2$ has been used in this study to compare the measured HR values with that one from eZ430-Chronos watch and it has been found that they are nearly identical under proper pre-signal processing, which means using the proposed portable exercise monitoring system is valid, reliable and cost effective in building cardiovascular fitness. Figure 1 show various devices used in this study.

Fig. 1. Wearable Exercise Training System

The UTS Human Research Ethics Committee (UTS HREC 2009000227) approved the study.

II. The wearable exercise training system

The Portable and Wearable Exercise Monitoring System consists of two parts, the eZ430-Chronos watch and the

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BM-CS5 chest strap. However, K4b^2 has been used in this study to verify and compare the HR values. The interval training protocol has been adopted in this study to strengthening the cardiovascular fitness, in this protocol, the exerciser is required to shift between high intensity and low intensity exercise.

The Inbar [14] formula has been used to find out the HR_{max} for each participant as following:

$$\begin{aligned} HR_{max} &= 205.8 - 0.685 \times age \\ &= 205.8 - 0.685 \times 26 \\ &= 187.99 \\ &\approx 188 \end{aligned} \tag{1}$$

So, as we can see that for participant whose age is 26 years old, his HR_{max} is approx. 188 bpm. The subject must reach 80% of his HR_{max} to guarantee an improvement in the cardiovascular fitness [15].

The proposed system monitors and guides the exerciser through audio stimulation to alter between High Intensity (the subject reaches 80% of HR_{max}) and Low Intensity (subject reaches 60% of HR_{max}) exercises in order to build and strengthening his/her cardiovascular system fitness.

A. Subjects

Five volunteers with different ages and physical characteristics were participated in the experiments; all volunteers were free from any health issues. The subjects physical characters are shown in the table I:

TABLE I
PHYSICAL CHARACTERSTICS OF THE PARTICIPANTS.

Subjects	Age (Yrs)	Height (cm)	Weight (Kg)
1	25	168	73
2	27	174	75
3	30	177	72
4	33	168	74
5	26	172	65

As mentioned earlier, the subject must reach 80% of his HR_{max} to guarantee an improvement in the cardiovascular fitness, and based on Formula (1), the HR_{max} have been calculated for all participants along with their High Intensity and Low Intensity HR values as shown in table II:

TABLE II
PARTICIPANTS HR_{MAX} VALUES

Subjects	Age (Yrs)	HR_{max}	60% of HR_{max}	80% of HR_{max}
1	25	189	113	151
2	27	187	112	150
3	30	185	111	148
4	33	183	110	147
5	26	188	113	150

B. Flowchart

The flowchart of the proposed health monitoring system running on eZ430-Chronos watch is represented in Figure 2

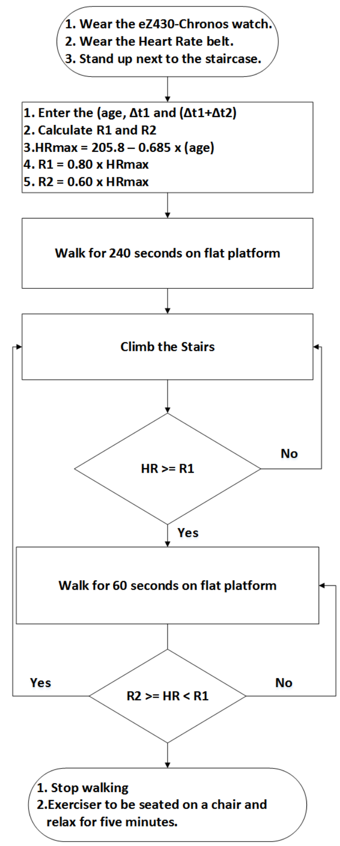


Fig. 2. Wearable Exercise Training System Flowchart

In this instance, after a successful connection between the wearable eZ430-Chronos watch and the BM-CS5 chest strap, the system prompts the exerciser to enter his age and the recommended training zones are computed based on the HR values.

C. Experiments

The proposed system guides the exerciser during any exercise whether indoor or outdoor through audio stimulation to switch between high and low intensity exercise to guarantee cardiovascular fitness increase and development.

The proposed system tested on stairs climbing exercise. The experiment starts by asking the subject to wear the ez430-chronos watch on their hand, the BM-CS5 chest strap on their chest, and the K4b^2 system and mask. The devices will continually measure the HR and the subject is required to act accordingly.

In this experiment, the exercise starts by warming up phase which is walking on a flat platform for 240 seconds; the exercising phase starts by climbing the stairs for a specific time, i.e., 60 seconds, or until the subject reaches 80% of his HR_{max}. The system will produce an audio tone to notify the subject to alter the exercise intensity from High Intensity to Low Intensity exercise, which is in this case is walking aside on the step for either 60 seconds or until he reaches 60% of his HR_{max}, Once this condition becomes true, the system will produce a different audio tone to notify the subject to switch back to High Intensity exercise. High Intensity exercise is climbing the stairs, while walking on the same stair is considered Low Intensity exercise as shown in Figure 3.

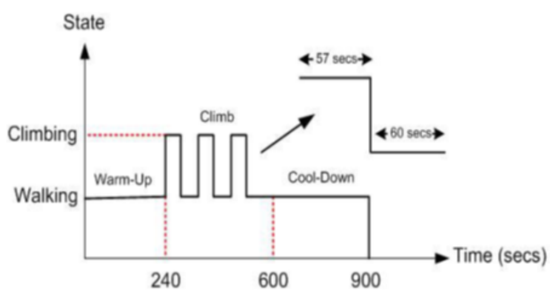


Fig. 3. Walk-Climb-Walk Interval Training Protocol

The subjects has been seated and rested for five minutes after completing the final walk.

Figure 4 shows the HR and VO_2 experimental results for subject 5 under the proposed interval training protocol.

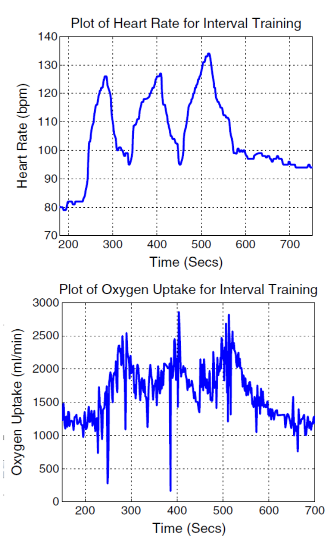


Fig. 4. HR andVO_2 experimental results for subject 5 under the proposed ITP

D. Results

The interval training protocol aim in the study is to develop the cardiovascular fitness system, having this in mind; the exerciser is required to train in a range of 70% to 80% of his HR_{max}, as mentioned earlier, climbing the stairs represent onset stage in the training protocol and walking on the same step is considered as offset period.

A controller with self-adaption feature that can tune the duty cycle Δt_1 and the period ($\Delta t_1 + \Delta t_2$) gives the exerciser the opportunity to reach the desired setpoints after a certain number of training sessions as shown in Figure 5

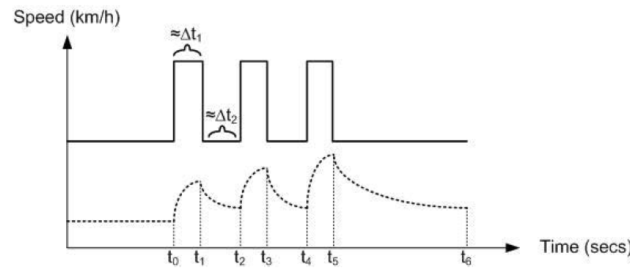


Fig. 5. HR Response During ITP

Figure 6 shows the controller structure that has been implemented in the watch, where the exerciser needs to enter age,Δt_1 and (Δt_1+Δt_2), and based on these values the R_1 and R_2 are calculated, where R_1 is the onset value and R_2 is the offset value.

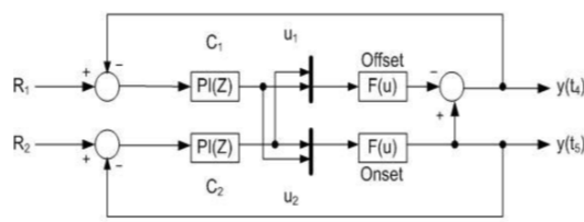


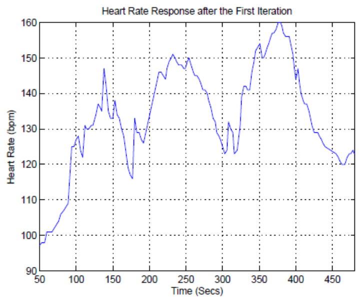
Fig. 6. Controller structure

The watch and its controller will guide the exerciser of how many iteration does he need to reach his setpoints, and the controller will tune up the outputs values until it reaches the desired setpoints. The watch and controller parameters are as shown in table III:

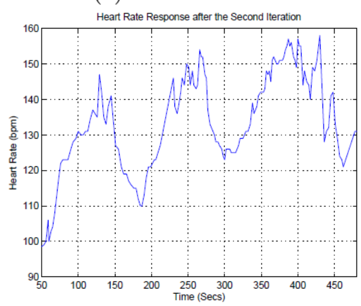
TABLE III
WATCH AND CONTROLLER PARRAMETERS

Iteration	Onset Time	Offset time	Period	Duty Cycle	$y_{(t4)}$	$y_{(t5)}$
Ref.	60	60	120	50	113	150

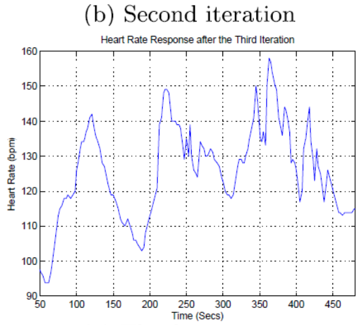
In the first iteration, 60 seconds is set to be the onset and offset times. At the end of the first training session, the reading of HR at t_4 and t_5 were observed and feed backed to the multi-loop control system to update the controller outputs inputs (the duty cycle and the period). Accordingly, the controller adjusts the time of onset and offset periods for the next training session. Figure 7 shows the heart rate response after the first, second and the third iterations.



(a) First iteration



(b) Second iteration



(c) Third iteration

Fig. 7. Subject 5s HR responses under stairs climbing exercise

Table IV shows the watch and the controller parameters after the third iteration:

TABLE IV
WATCH AND CONTROLLER PARRAMETERS AFTER THE THIRD ITERATION

Iteration	Onset Time	Offset time	Period	Duty Cycle	$y_{(t4)}$	$y_{(t5)}$
Ref.	60	60	120	50	113	150
1	54.48	56.18	110.66	49.23	123	160
2	55.52	56.59	112.11	49.52	122	156
3	56.25	56.78	113.03	49.77	118	157

We can conclude from the previous table that the exerciser has almost reached to the desired setpoints after only 3 iterations. We kept in mind that after certain number of training sessions, the training capacity of the exerciser will improve, and this might affect the result of his/her HR response.

III. Conclusion

A prototype of portable health monitoring system has been developed, implemented and tested.

The proposed system allows continuous monitoring of heart rate during any exercise and guides exerciser using audio stimulation to increase or decrease exercise intensity in order to build and strengthening the cardiovascular system based on interval training protocol.

The developed Portable and Wearable Monitoring device and its associated algorithms are technically feasible in various exercise monitoring and regulation related projects. Based on this portable system, recently, a new effective interval training protocol has been proposed and implemented in the Centre of Health Technologies, University of Technology Sydney (UTS). Furthermore, the developed system can be utilized in the control of other automated exercise machines, such as treadmill or bicycle for rehabilitation program and exercise training.

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