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Computer-Assisted Upper Extremity Training Using Interactive Biking Exercise (iBikE) Platform*

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Abstract— **Upper extremity exercise training has been shown to improve clinical outcomes in different chronic health conditions. Arm-operated bicycles are frequently used to facilitate upper extremity training however effective use of these devices at patient homes is hampered by lack of remote connectivity with clinical rehabilitation team, inability to monitor exercise progress in real time using simple graphical representation, and absence of an alert system which would prevent exertion levels exceeding those approved by the clinical rehabilitation team. We developed an interactive biking exercise (iBikE) platform aimed at addressing these limitations. The platform uses a miniature wireless 3-axis accelerometer mounted on a patient wrist that transmits the cycling acceleration data to a laptop. The laptop screen presents an exercise dashboard to the patient in real time allowing easy graphical visualization of exercise progress and presentation of exercise parameters in relation to prescribed targets. The iBikE platform is programmed to alert the patient when exercise intensity exceeds the levels recommended by the patient care provider. The iBikE platform has been tested in 7 healthy volunteers (age range: 26-50 years) and shown to reliably reflect exercise progress and to generate alerts at pre-setup levels. Implementation of remote connectivity with patient rehabilitation team is warranted for future extension and evaluation efforts.**

I. Introduction

Upper extremity exercise training has been shown to improve upper limb function and other clinical outcomes in patients with different chronic health conditions [1] including chronic obstructive pulmonary disease [2], stroke [3], and cerebral palsy [4]. Arm exercise training was also shown beneficial in patients recently weaned from mechanical ventilation [5] and in active elderly [6]. Arm-operated bicycles are frequently used to facilitate upper extremity training and they are widely available in rehabilitaion facilities where patient exercise may be supervised (Fig. 1). Effective use of these low cost exercise devices at patient homes is hampered by lack of remote connectivity with clinical rehabilitation team, inability to monitor exercise progress in real time using simple graphical representation, and absence of an alert system which would prevent exertion levels exceeding those approved by the clinical rehabilitation team.

The goal of this project was to develop a prototype system addressing these barriers and to test it in healthy volunteers.

II. System

Our ultimate objective is to build a distributed system which would allow a rehabilitation system remotely monitor and manage patient use of arm-based exercise equipment at home in an effective and safe way. Previously we reported similar approach for physical telerehabilitation in patients with multiple sclerosis [7]. The distributed web-based telerehabilitation platform is an extension of the Home Automated Telemanagement (HAT) system which is based on Wagner's model of chronic disease care [8]. The HAT system supports the major components of this model including patient self-care, tailored education and counseling, individualized treatment plan, guideline-concordant decision support, comprehensive patient provider communication, and multidisciplinary care coordination [9-11]. Using this model, the HAT system has been successfully implemented and tested in various health conditions [12-16].

The HAT system consists of home unit, HAT server and clinician unit [17]. The previous applications utilized laptops, PDA, IVR, cell phones, Wii, and Xbox for patient home units [9, 18-22]. The HAT system takes advantage of the current technology to provide patients with a convenient treatment plan and exercise regimen as well as enforcing adherence to rehabilitation through more frequent

Figure 1. Arm Bike

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monitoring.

In this project, we developed a prototype of a home-based interactive biking exercise (iBikE) platform which in the future will be integrated into a web-based HAT system. The iBikE platform consists of an upper body cycle machine (Chattanooga Deluxe Exersiser^{TM}, Chattanooga, USA) and a wireless 3-axis accelerometer (Shimmer Research, Dublin, Ireland). The prototype software was developed using LabVIEW 2011 (National Instruments, USA). The conceptual design of the iBikE supports flexible exercise settings by a patient rehabilitation team, automated exercise records, real-time monitoring of patient progress towards recommended patient-specific exercise goals, and generation exercise safety alarm when exercise intensity is about to exceed provider-recommended maximum values. The iBikE platform generated a detailed exercise log which can be communicated to the patient rehabilitation team. This allows the patient providers determine which exercise settings are more challenging to the patient. There are also general exercise safety tips as well as specific tips for each exercise designed to minimize the risk of injury during exercise [7].

A. *Sensor platform and setup*

Shimmer is a small sensor platform (53 x 32 x 15 mm) well suited for wearable applications. The integrated 3-axis accelerometer, large storage, and low-power standards based communication capabilities enable emerging applications in motion capture, long-term data acquisition, and real-time monitoring [23]. In this project, 3 axis 12 bits accelerometer signals with the 1.5g range and the 0.024g sensitivity, the sampling rate 51.2 Hz, and the class 2 Bluetooth radio communications were used. The shimmer unit was attached on lateral wrist of left arm. Adjustable velcro strap was used to hold Shimmer securely for the application.

B. *iBikE Program Algorithm*

For the future combination of the home-based iBikE platform and the remote HAT server, the current iBikE prototype allows manual exercise prescription functionality. Although the default exercise plan and the patient self-choice exercise plan were provided in this project, the eventual goal is to allow exercise prescription by the patient telerehabilitaion team at the HAT provider website so that individualized exercise plan is seamlessly loaded into the home-based patient telerehabilitation unit [7].

In the current implementation, the program requires a user to confirm or to edit target goals of exercise. This manual step if followed by an automated process of establishing Bluetooth radio communication connection. After the pairing communication is successful, all cycling acceleration data are analyzed in real time by the iBikE Parameters Detection Algorithm (iBikE PDA). Four features such as peaks, valleys, and two Zero-crossings are calculated simultaneously in real-time. Current graphical and numerical information such as speed, count, distance, exercise time, and calories burned are represents in the real-time exercise dashboard. Target goals and thresholds for the exercise safety alarm are continuously monitored during the exercise session. When the exercise target goals are reached or exercise parameters exceed the pre-setup alarm thresholds, the patient is notified and the program ends. The exercise can be stopped at anytime by clicking the STOP button. The Fig. 2 provides a detailed iBikE program algorithm.

C. *iBikE PDA*

The iBikE PDA module utilized 3 axis acceleration signals sampled with 51.2 Hz sampling rate. The signals were converted to meters per second squared using the Shimmer 9DOF Calibration program. The raw calibrated acceleration data were first filtered using moving average of 1.75s rectangular window. The resulted signal was then subtracted from the original raw calibrated signal and filtered again using moving average of 175ms rectangular window. These filtering steps removed high frequency movement noise and the static orientation data. The characteristic

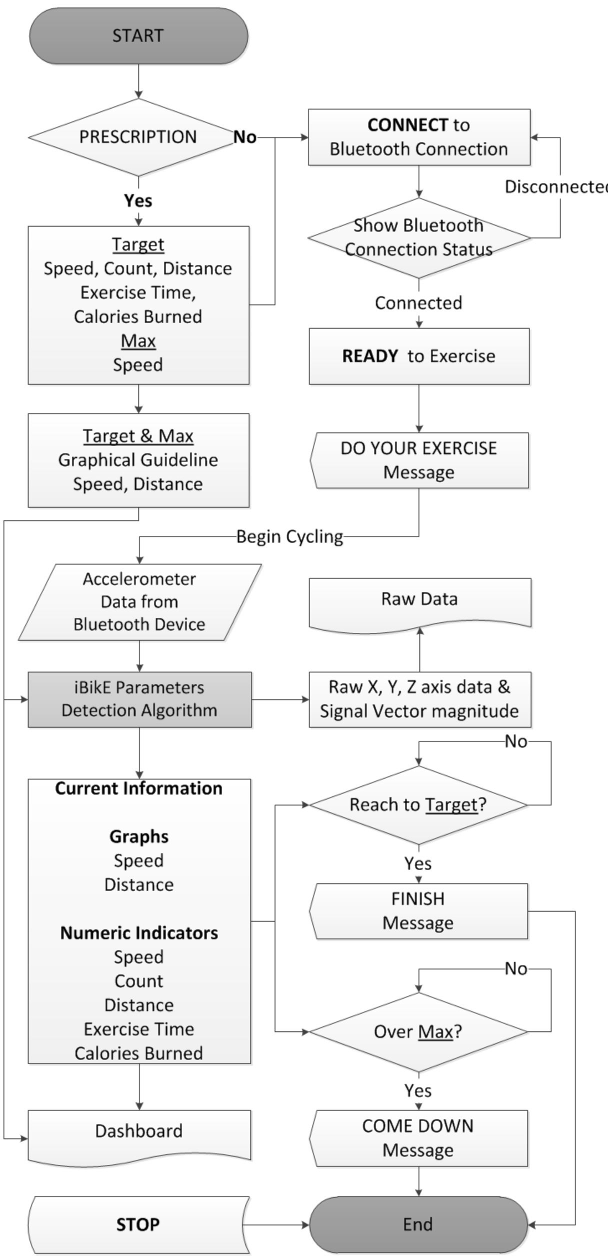

Figure 2. iBikE Program Algorithm

features from the filtered acceleration data are detected by adjustable maximum and minimum threshold and zero-crossing algorithms. To extract peaks and valleys, queue is used. The size of queue is decided by the prescribed target and risk alarm (maximum) speed. The smaller queue is better for the real-time analysis however the queue size is affected by noisy data. Acceleration signals are almost noise free in the high speed cycling, but the influence of noise gets more prominent during low-speed cycling so that the decision of queue size is based on the balance between real feature and false feature detections. Zero-crossing can be defined as the points where a velocity signal is zero. The number of times the signal crosses the orientation data is the number of zero-crossings. In our condition, zero-crossing could mean a direction change of velocity such as forward to backward, upward to downward, and outside to inside. The Fig. 3 shows a detailed iBikE PDA flowchart.

III. Result

A. iBikE Program

The iBikE platform was successfully designed and implemented for Microsoft Windows operating system.

At the start of the program, an exercise prescription page is presented. The user can choose a default exercise or enter new settings. The patient can decide target goals her/himself with the exactly prior knowledge of exercise. The exercise prescription page is shown in Fig. 4.

The next screen presents the wireless connection dialogue which is shown in Fig. 5. This session is based on a modified wireless connectivity module from Shimmer Basic

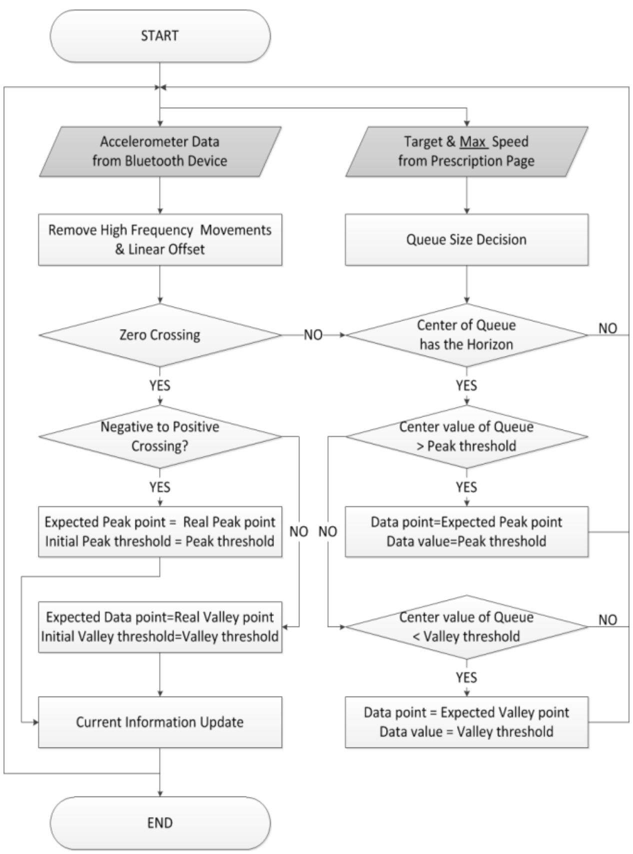

Figure 3. iBikE PDA Flow Chart

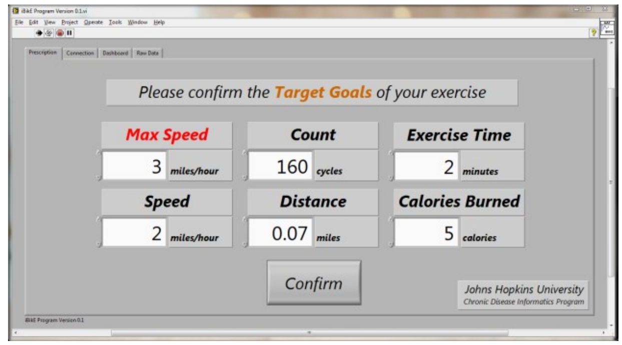

Figure 4. Prescription page

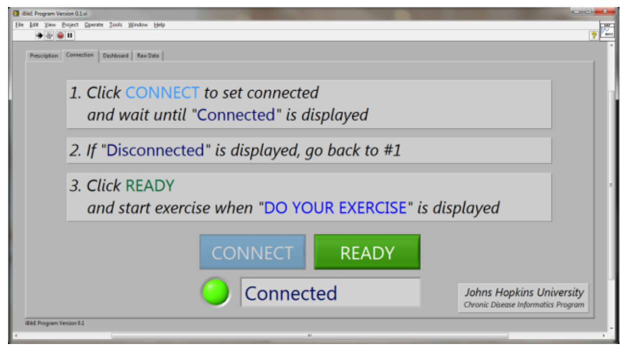

Figure 5. Connection page

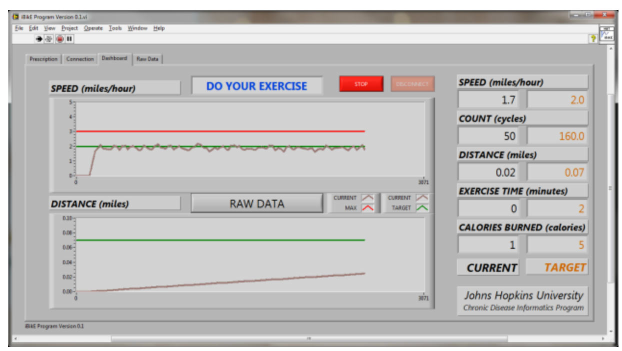

Figure 6. Dashboard page

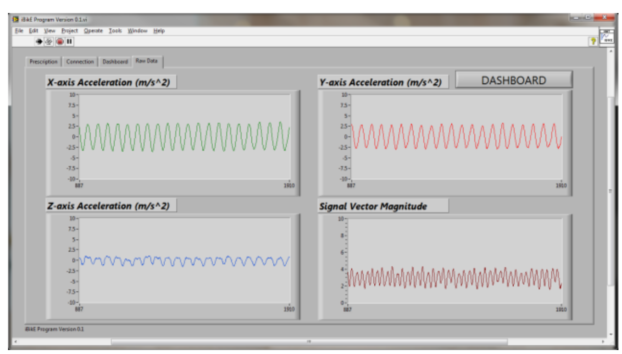

Figure 7. Raw Data page

Control.vi provided by Realtime Technologies, Ireland [23]. Upon successful completion of this step, the the Bluetooth radio communication between accelerometer and patient laptop are established and the platform is ready to monitor patient exercise.

After the Bluetooth pairing is completed, the patient is invited to start exercise. During the patient exercise, current and target numerical information such as speed, count, distance, exercise time, and calories burned are represented in a user-friendly trending format on the exercise dashboard in a real-time mode. Current, target, and maximum readings such as speed and distance also are represented graphically in the exercise dashboard. The Fig. 6 shows the exercise dashboard with these indicators. Each indicator is updated each half cycle during the patient's exercise. When the current parameters reach one of the target goals for the set period, "DO YOUR EXERCISE" message turns into "FINISH" message.

In the dashboard page, a "RAW DATA" tab is built in for the purpose of real-time graphical visualization of 3 axis acceleration data using moving averaging. Fig. 7 shows each axis acceleration data and 3 axis signal vector magnitude. A "DASHBOARD" tab is provided to return the dashboard page.

B. *iBikE Program Tests*

iBikE Program Tests have been conducted in two different ways: the accuracy of cycle count and the error of alarm detection.

The accuracy of count was assessed by comparing the monitor's blind-count and the numeric count indicator. During the test, the subjects and the monitor were not able to see numerical indicators. Tests were conducted at 3 different target speeds: 1, 2, and 3 miles/hour for each subject. The target exercise time was 2 minutes. Overall seven healthy volunteers with age range from 26 to 50 years old participates in the testing.

The reliability of alarm detection was analyzed based on ability to detect cycling speed reaching a pre-setup threshold. Tables I and II present the accuracy of cycle count and the error of alarm detection respectively.

IV. Discussion

We were able to successfully implement an interactive platform which allows monitoring of arm-based cycling in real-time, representation of major exercise parameters in a user-friendly graphical format in exercise dashboard, and detection of exertion levels which preclude further exercise. Based on pilot testing in health volunteers, the iBikE platform provided correct representation of all exercise parameters. The next step of the project will be integration of the iBikE platform into distributed web-based system which would allow health professionals monitor and manage patient exercise at their homes. The proposed platform can be extended to other types of cycling including lower extremity exercise in stationary or free-moving modes. The iBikE program can be potentially implemented on other devices supporting 3-axis accelerometers such as iPads or iPhones [19, 21]. In our previous work, we showed that the HAT system is well accepted by patients and results in improved clinical outcomes [24-29]. Current findings warrant further integration of the iBikE component into a comprehensive telemanagement system for different health conditions such as chronic obstructive lung disease [12, 20], congestive heart failure [9], hypertension [11], multiple sclerosis [7] and other conditions [30-31] which may benefit from remotely supervised exercise [32-33]. For optimal performance, the telemanagement system has to be integrated with electronic medical record and patient personal health record [26].

TABLE I. Accuracy of Count

Speed	Subject	1	2	3	4	5	6	7	Total
1	Program	61	77	72.5	68.5	90.5	80	66.5	73.7±9.78
	Monitor	61	77	72.5	68.5	90.5	80	66.5	73.7±9.78
	Accuracy	100	100	100	100	100	100	100	100
2	Program	102	110	127	133	154	146	130	128.9±18.37
	Monitor	102	110	127	133	154	146	130	128.9±18.37
	Accuracy	100	100	100	100	100	100	100	100
3	Program	165	183	194	196	n/a	208	196	190.3±14.73
	Monitor	165	183	194	196	n/a	208	196	190.3±14.73
	Accuracy	100	100	100	100	n/a	100	100	100

Speed (miles/hour), Program and Self (cycles), Accuracy (%), and n/a means not available to exercise

TABLE II. Error of Alarm Detection

Subject	1	2	3	4	5	6	7	Total
Count	10	10	10	10	10	10	10	10±0
Error	0	0	0	0	0	0	0	0

Count and Error (cycles)

V. Conclusion

The iBikE platform provided accurate estimate of arm-based cycling exercise in real-time. The platform is recommended for further extension and clinical evaluation.

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