PAPER

An Internet-Based Cycle Ergometer Health Promotion System for Providing Personally Fitted Exercise

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SUMMARY General exercise approaches are not convenient for some people in undertaking appropriate exercise due to the limited variety of present programs at existing exercise machines. Moreover, continuous support by one sports doctor is only available for a limited number of users. In this paper, therefore, we propose an Internet-based technical framework, which is designed on multi-tiered client/server architecture, for integrating and easily upgrading exercise programs. By applying the technical framework, a cycle ergometer health promotion system was developed for providing personally fitted. We also presented some facilities to assist sports doctors in quickly designing and remotely improving individual exercise protocols against cycle ergometer exercise based on a history database. Then we evaluated the Internet-based cycle ergometer system during two months of feasibility experiments for six elderly persons in terms of usability. As a result, the Internet-based cycle ergometer system was effective for continuously supporting the personal fitting procedure.

key words: *cycle ergometer, health promotion, multi-tiered client/server architecture, personally fitted exercise*

1. Introduction

With an increasing elderly population in recent years, maintenance and promotion of health is becoming a serious concern. Moreover, the importance of exercise for health promotion is widely accepted among people of a variety of different ages [1]–[3]. Reflecting such social changes various types of exercise machines have appeared on the market. However, it is difficult for people to perform sufficient and appropriate exercises by directly using these exercise machines because users find it difficult to perceive the correct exercise levels; there is a risk of overtraining syndrome due to excessive and inappropriate exercise levels [4], [5]. Therefore, exercise must be performed under some controls, especially for elderly people due to their slow reaction to sensations during exercise.

At present, a general exercise approach is to go to a gymnasium or a sports center to undertake exercise under the guidance of sports doctors. However, since a sports doctor generally supervises several individuals at once, it is difficult and inconvenient to give continuous exercise advice for each individual. Moreover, it is necessary to offer an optimal exercise environment for performing appropriate exercises especially for the elderly, and also to provide facilities for sports doctors to manage individuals' exercise programs.

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Some commercial machines provide pre-installed exercise control programs to let individuals perform customized exercise without the need for a sports doctor at their side to give advice [6], [7]. However, these pre-installed exercise control programs are very simple in terms of variation and quantity, which cannot represent changes in physical activity during exercise. Moreover, it is very complicated and sometimes impossible to upgrade the machines by revising conventional control programs and appending new ones.

Among current popular exercise machines, a cycle ergometer is commonly used in several fields such as sports training, health promotion, and rehabilitation [8]. Most commercial cycle ergometers only provide predetermined and limited variation of workload patterns. Some latest cycle ergometers can monitor electrocardiogram (ECG) and blood pressure, and accordingly adjust the workload to achieve a desired exercise level. However, by using these limited control parameters, an appropriate exercise program cannot be implemented properly. For example, some other physiological indices and subjective index should also be considered to determine exercise levels [8], [9].

As a standalone process of creating appropriate exercise levels for the elderly while exercising by cycle ergometer, Kiryu et al. have proposed a fuzzy system design, and classified subjects into four exercise types [8], [10]. The process uses fuzzy inference and an artificial neural network to evaluate the designed workload control [11]. However, the previous studies did not implement a convenient way to redesign and update the exercise protocols (Exercise protocols including a set of fuzzy rules and workload patterns, are computer files for defining the scenario of a whole time-course of exercise). Renewed protocols had to be manually installed to a computer. When sports doctors were in a different place, acquisition of the exercise protocols was very inconvenient. Moreover, exercise protocols become insufficient due to gradual change of physical activity even in the same subject. Therefore, it is necessary to change exercise protocols constantly to try to fit each subject's actual physical conditions. That is, the personally fitted workload control for a cycle ergometer should involve 1) continuous support of users' exercise activities regardless of time and place, and 2) providing appropriate workload control at the time of exercise. An open transmitting structure, such as the Internet, can be used as the backbone for exercise systems.

In this paper, we firstly introduce a technical framework as a fundamental structure to address the purpose of achieving the essentials of a personal fitting concept via the Internet. The framework comprises three roles: a central server, a history database, and two types of user applications. Then, we provide a practical system, a personally fitted Internet-based cycle ergometer exercise system, in which control program and cycle ergometer are physically separated and dynamically coupled via the Internet. In addition, a utility for sports doctor in designing cycle ergometer exercise protocols is provided. Feasibility experiments for six elderly persons proved the benefits of the system over two months.

2. Methods

2.1 Technical Framework

We propose a technical framework for a universal model of exercise systems for health promotion. An exercise system is an integrated exercise solution that contains hardware (exercise machine) and software (exercise control program). Figure 1 presents the main configuration of our proposed technical framework, including brief process flows. The technical framework adopts multi-tiered client/server architecture [12] to meet the demands of easy upgrades. The design of the technical framework is not itself very exciting. However, for an exercise system, the multi-tiered structure is further useful for implementing: physically separating exercise control programs and exercise machines; dynamically integrating these two via the Internet.

We suppose that exercise control programs are not preinstalled in exercise machines, but are separated from the machines and collected in the central server. In Fig. 1, the central server serves to integrate all kinds of exercise services, such as downloading of exercise control programs. Each service, which is responsible for a specific type of exercise approach, manages a number of exercise control programs. For instance, if an exercise service is regarding cycle ergometer exercise, the service can hold many different exercise control programs for cycle ergometer-based exercise. Exercise control programs are possible to be dynamically downloaded from the central server at the time of exercise. In addition, all measured results are uploaded to the central server after exercise finishes. Thereafter, measured results are deleted from the exercise field at the client end to protect users' personal information.

The client end includes two types of users: general user and sports doctor. General users don't participate in any analysis; they just utilize their favorite exercise control programs. To sports doctors, since they may not be skilled in computer use, it is important to integrate complicated techniques into a user-friendly facility to assist them. That is, health promotion systems should provide a utility that is embedded with complex analysis functions, and user interfaces that allow simple operation for sports doctors. We defined such a utility as the Sports doctor Analysis Tools (SDAT). SDAT should contain adequate high-end analysis features to facilitate the design of exercise protocols.

SDAT is optimal to be developed on a platform-independent language, such as Java. From the viewpoint of simplifying development, Java is helpful for writing once and running on different operating systems, and facilitates Internet-based programming with features native to the Internet. However, applications residing at a general user's end cannot be developed for platform independence because the applications will always connect with exercise machines to control exercise and to acquire the biosignal data. Consequently, the use of other languages, such as C, C++ and Fortran, should be used for developing actual control functions, and use Java technologies for developing other parts of a general user application such as user interfaces and data

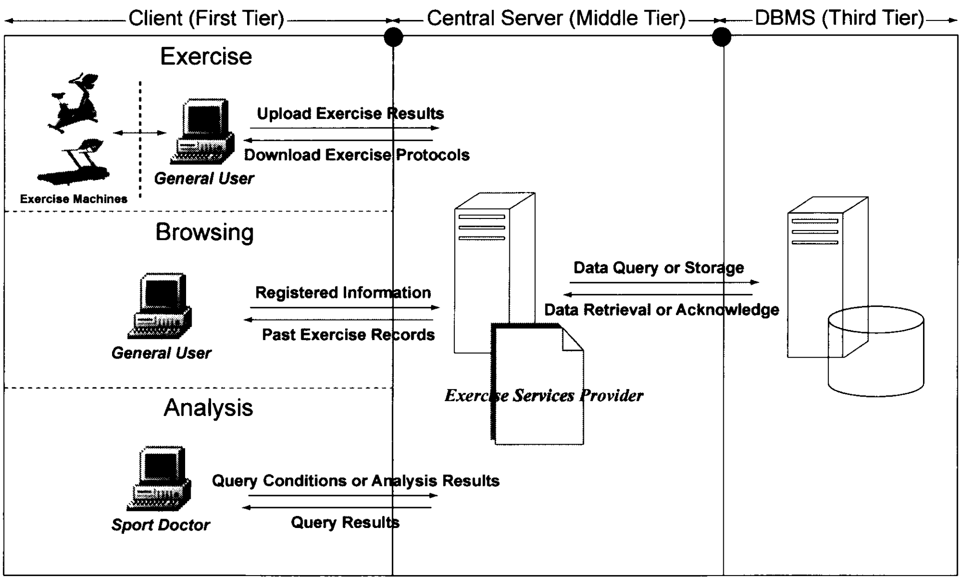

Fig. 1 Main configuration of the technical framework with brief process flows.

transferring functions with the central server.

A two-tier client/server type design has been selected as the database management solution: the central server as a client, and the database system as a server. We only record some relevant information that can be used as reference data for target biosignal data. Since querying the database must always be performed through the central server for a security consideration, the actual biosignal data are directly stored in the central server. Thus, when querying the history database to acquire actual biosignal data, only small quantities of data (information of some pointers to actual biosignal data) are sent in response to the requests from the central server. Data transfer time can be shortened by about 50% in theory if the history database is deployed on the Internet separately from the central server.

Although the actual control processes of different exercise approaches are not always identical, the technical framework can be applied to various health promotion systems. The central server attempts to manage a group of exercise services, and adheres to the requirement for discovering each exercise service. The client users must communicate with the central server to discover their expected exercise services and obtain corresponding exercise control programs.

2.2 Three Layers of the Central Server

The central server is designed as a three-layer application to accommodate various types of client applications, including web clients and conventional Java applications. The three layers include presentation layer (JSP/Servlets) for dealing with web clients, control layer for controlling the interactions between the conventional client application and database system, and object process layer (Java Beans) for real data processing with the database system. The control layer is the most important component, and supports transaction management to ensure the reliability of actions. An action will be withdrawn if some errors occur during data processing, and all updates will be rolled back. In our proposed design, a transaction is the execution of a unit of work that consists of a set of correlated history database accessing operations. The operations must be completed together. For instance, to accomplish the storage action of renewing exercise protocols by a sports doctor, operations include authenticating the sports doctor's identity, storing exercise protocol's pointer data to database, and storing actual data of exercise protocol to the central server. Such the operations must succeed without any fails. Otherwise, if a new record containing the exercise protocol's pointer data has been inserted into the database, a rollback command will be committed to undo the database updates.

2.3 Specific Implementation of the Internet-Based Cycle Ergometer System

It should be kept in mind that the abilities of individuals differ in terms of exercise levels because of their different physical work capacities. To realize the concept of personal fitting, appropriate workload control protocols must be designed in time for each individual. The protocols should also be available on the Internet to guarantee that individuals can use the latest exercise protocols at any place. We mainly used Java language to develop our practical system.

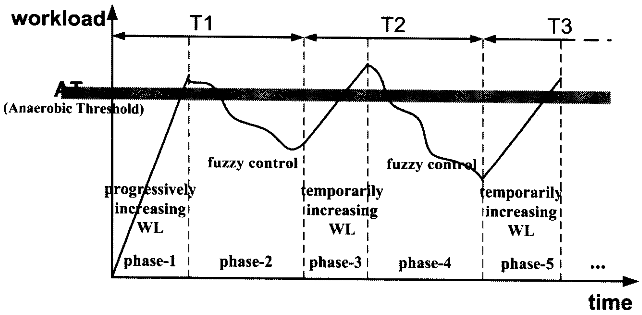

Fig. 2 A dynamic workload variation for cycle ergometer exercise.

2.3.1 Appropriate Workload Control

The prerequisite for establishing a personally fitted exercise is an appropriate workload control method. We have studied a dynamic workload variation for cycle ergometer exercise, that is, the basic workload variation with a few temporal workload changes (Fig. 2). The temporal workload change consists of a short-term, progressively increasing workload and a dynamic workload control. The anaerobic threshold is an important evaluation index to design workload pattern, and the dynamic workload control is continuously determined by fuzzy rules [10]. The personally fitted workload pattern is determined by adjusting A) intervals at each phase and B) exercise levels [8]. For instance, if sports doctors find that a workload pattern is hard for a user, they can 1) shorten intervals of the phases of the increasing workload and lengthen intervals of the phases of dynamic fuzzy control, and 2) decrease the value of maximal exercise level. These adjustments are based on subjective evaluations and objective indices.

2.3.2 Data Retrieval and Query

Personal information about users, all measured biosignals, and evaluation results are stored in the database server. In case of the cycle ergometer system, personal information, which is submitted at registration, includes name, date of birth, and gender etc. Biosignals include heart rate and several muscular activity indices. Note that critical information, which is transmitted via the Internet, is encrypted by Secure Socket Layer (SSL) standard connections to secure Internet communications at the transport protocol level.

According to the two different end-user types, the system has defined two different sets of rules for data retrieval and query respectively. For general users, this is enough to only offer restricted rights, such as changing personal profile and examining past exercise data. For sports doctors, on the other hand, this system provides complete access for data analysis and update.

2.3.3 Client Application

Since we explicitly expect two types of users, implementations of the general user application and the sports doctor application are extraordinarily different. The general user application, which resides on the exercise side, uses platform specific drivers of analog-to-digital converters to measure necessary biosignals. Since there are no Java-compatible drivers, Java Native Interface (JNI) [13] was used to solve this problem. The JNI is a standard programming interface for writing Java native methods to embed the Java virtual machine into native applications. We implemented a control library, which includes a real control process written by C language, and interoperated it within JNI classes. The other parts of the general user application, including user interface and communication functions, are developed using the Java language.

We implemented a SDAT for Cycle Ergometer, and expressly named it "SDATCE". SDATCE is programmed entirely in Java language. The user interface is developed using the Java Swing [13] graphical toolkit. The SDATCE is deployed over the web using Java Web Start technology [13], and accordingly sports doctors can easily launch it by clicking on a web page link with any popular web browser. The web page is placed in the central server. Moreover, we use Java Secure Socket Extension (JSSE) technology [13] to enable secure communications with the central server. In practical developments, the applied specific implementation technologies can be alternated depending on different purposes and different programming skills. We concentrically present the functions of the SDATCE that we have implemented.

Figure 3 shows an example of SDATCE's main control interface. At startup, the SDATCE connects to the central server to obtain all information on valid users. To assist analysis, newly registered users and new exercise records are highlighted on the control interface. Furthermore, some specialized explanation graphs can be displayed according to each exercise record. We have developed two types of explanation graphs: time-series and scattered graphs to cater to different demands. Such graphs are adequate to assess personally appropriate workload levels [8], [10]. A spotlight function can be selected to highlight expected section of exercise data. In addition, to better assist a sports doctor in designing exercise protocols, a search function has been developed to obtain and separately represent workload and heart rate information within an arbitrary period of time in one place to better observe the sequential change of exercise states.

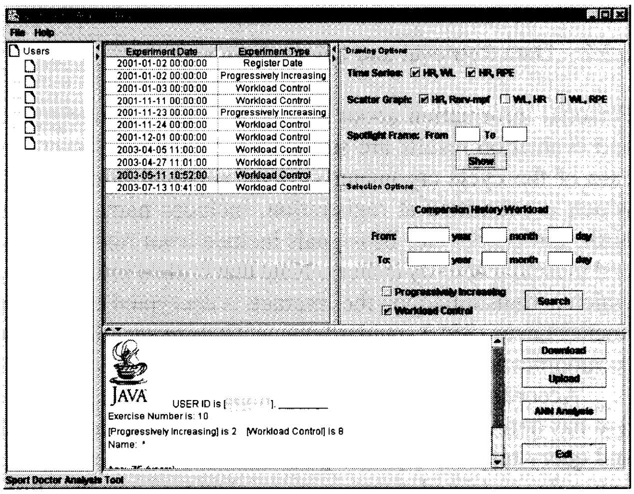

Fig. 3 Main control interface of SDATCE.

By using the SDATCE, sports doctors can make three choices: "download", "upload", and "analysis" for each user. This means sports doctors can obtain past exercise information of any selected user, update user exercise protocols, and execute further analysis by artificial neural network computing if necessary. The artificial neural network was used to further interpret the gap between the subjective data and the objective data, and to design the personal fitting procedure [11].

3. Results

3.1 Overview of Feasibility Experiments

We conducted a set of field experiments for a period of two months. Six able-bodied senior subjects (73.7 ± 2.3 years old), who had participated in our previous experiments, assisted us in carrying out our feasibility experiments. We selected these subjects because they clearly represented different exercise types. The feasibility experiments were conducted on a hypothetical Internet-based environment with 100 Base-T Ethernet connections. The central server (Pentium-II 500 MHZ, 256 MB RAM) and the database server were all set up with static IP addresses. The experiments were centered on the Microsoft Windows system (Windows 2000). Java Runtime Environment (JRE) 1.3 was installed on the computers of each tier (see Fig. 1). In addition, we selected MySQL as history database for its stability and open source.

The exercise protocols were decided based on remotely browsing of the history database with a sports doctor by using the SDATCE. Previous exercise data of 60 data sets from the six subjects were imported into the history database beforehand to ensure the integrality of experiments this time. Such the history exercise data presented a personally fitted exercise process in our fundamental studies performed in a local place. A subsequent exercise protocol was designed on considering former exercise results. Note that there were at least two progressively increasing workload exercise records for each subject in the history database.

3.2 Practical Procedures of Using the SDATCE

The following is an example of a practical procedure for providing appropriate exercise. Before beginning the personally fitted exercise, the history database was accessed by the SDATCE at the sports doctor's end. By employing the search function, the sports doctor acquired a subject's recent exercise data, such as workload and heart rate. Based on observations of the history exercise records and other functions of SDATCE, the sports doctor redesigned exercise protocols for workload control, and then uploaded the modified information to the central server through SDATCE. Actually, the process was carried out at a different location to the actual exercise field. At the exercise field, the subject downloaded the latest exercise protocols from the central server before exercise. The actual workload control exercise took about 30 minutes. It should be pointed out that during the whole course of the exercise, Borg's 15-point the ratings of perceived exertion (RPE) scale [14], a subjective data, was obtained every minute, and the data was recorded to the client application at the same time. After the exercise finished, measured data were transferred to the central server and then stored in the history database. At the doctor's end, the sports doctor inquired about and obtained new exercise information, then made decisions for the next exercise with the help of SDATCE.

Figure 4 shows an example of screenshots at the sports doctor's end for evaluation of results. At the left sub-graph, it shows the scatter graph between heart rate and muscular fatigue index ($\gamma_{ARV\text{-}MPF}$) [10]. Note that minus region of $\gamma_{ARV\text{-}MPF}$ indicated muscular fatigue. At the right-bottom subgraph, it shows the heart rate and RPE as a function of time. It is obvious that the heart rate doesn't correspond closely to the RPE, especially in the latter half of the exercise period (from 240 to 360 [frame], one frame equals 5 seconds). That is, the workload pattern was not compatible for the subject. Consequently, the exercise program needed significant modification prior to the next trial. In fact, the exercise workload increased by a larger extent (about 20 watts) than past two times. Even though the redesigned exercise program was safe, the subject didn't suitably accommodate with the workload change. Since the subject became too tired midway through the exercise, the subject was inactive in the latter of the course. Such determinations could be simply determined with SDATCE. Moreover, in our self-impression survey about exercise, the subject reported as "The exercise level this time is tight for me". Such the survey results were corresponded to the observations by with the SDATCE.

Figure 5 shows two HR-$\gamma_{ARV\text{-}MPF}$ scatter graphs representing the change in a personally fitted process for the 76-year-old man. Denoted by a square, there were more samples around anaerobic threshold in (b) (about 33.2%) than those in (a) (about 20.1%). Therefore, the subject performed more appropriate exercise at the latter one (exercise of (b)). Figure 6 shows the time-series of the personally fitted workload pattern of Fig. 5 (b). Refers to Fig. 2, the timing for progressively increasing workload and fuzzy controlled dynamic workload were as follows (the time unit is frame): T1 = 158; phase1 = 91; phase2 = 67; T2 = 100;

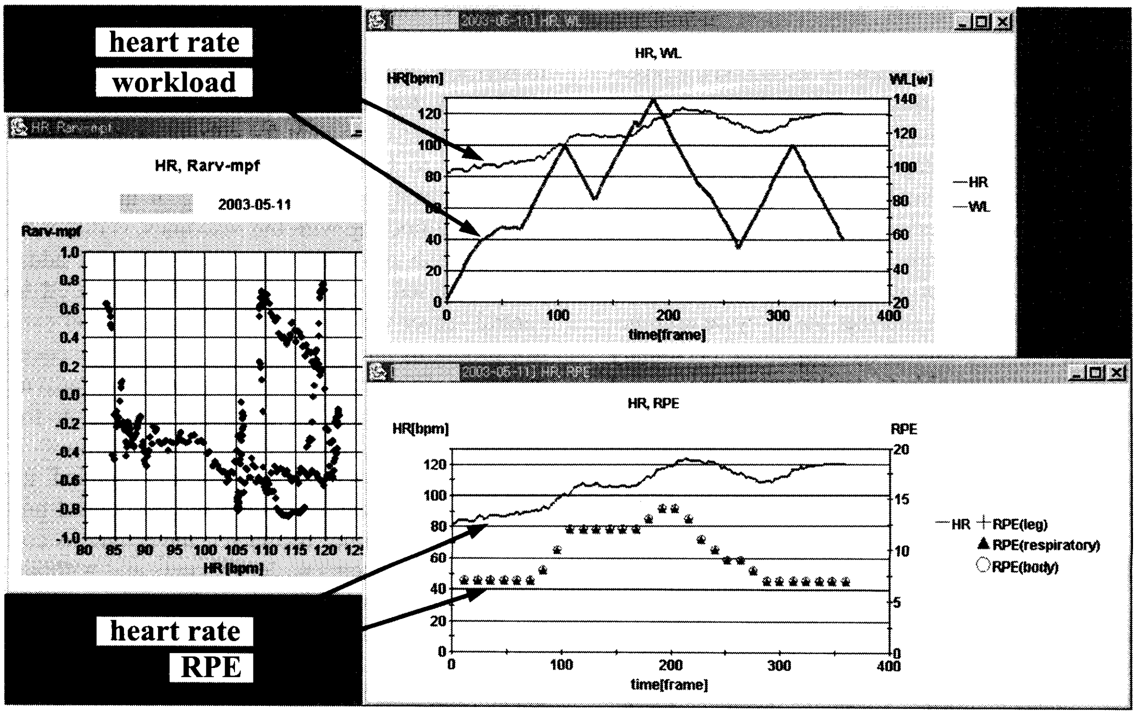

Fig. 4 The figure shows a screen dump during analysis, and the different windows are, top to bottom and left to right: HR-$\gamma_{ARV\text{-}MPF}$ scatter graph, time-series of HR and WL, time-series of HR and RPE. The data were obtained from the history exercise database via the Internet.

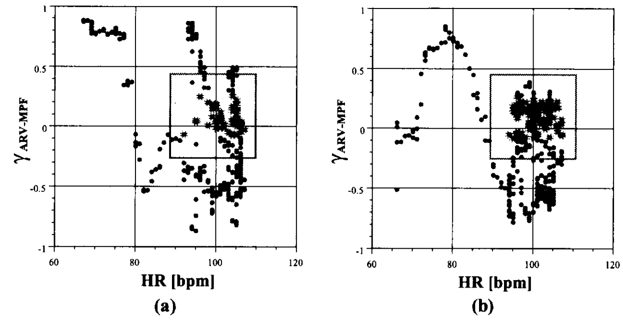

Fig. 5 Change in scatter graph between HR and $\gamma_{ARV\text{-}MPF}$ during the personally fitted process. Exercise of (b) is a latter one than (a).

phase3 = 36; phase4 = 64; T3 = 87; phase5 = 36; phase6 = 51. The last two peaks of workload were temporally increasing workload changes. The time-series of heart rate and $\gamma_{ARV\text{-}MPF}$, were related to the changes in the workload for all of the three peaks. Further, at the third peak, $\gamma_{ARV\text{-}MPF}$ did not show a negative value. That is, muscle did not show exhausted stage, and the subject subjectively recognized the workload changes.

Approximately 1 KB of exercise protocols were downloaded from the central server, and the measured results, including data of original signals and estimated indices (heart rate, muscular fatigue index, workload, and RPE), totaled about 8.45 MB. Actually, SDATCE only required estimated indices, workloads, and RPE information, and the transfer time for downloading those files of all authorized users was about two minutes.

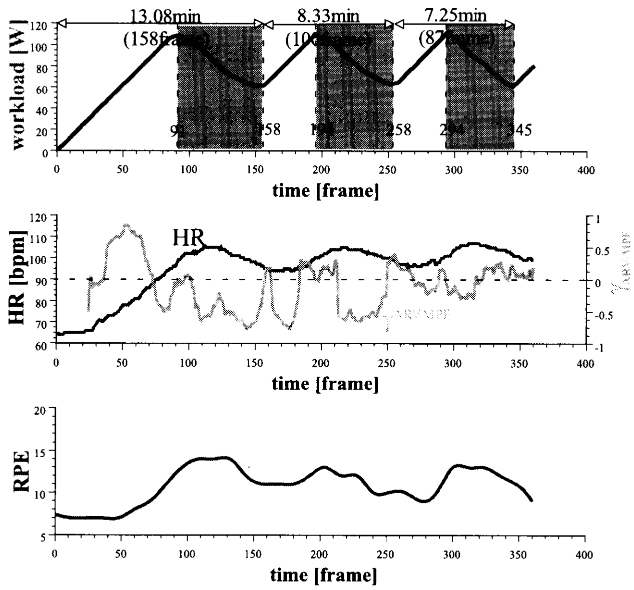

Fig. 6 Example of a personally fitted workload pattern. From top to bottom, workload, heart rate and $\gamma_{ARV\text{-}MPF}$, and RPE. RPE is a subjective index, and it was interpolated by a cubic spline function.

4. Discussion

Recent health promotion studies have investigated the possibility for continuously supporting exercise activities without using exercise machines [15]–[17]. These studies concentrated on how to take advantage of telephone or Internet-based communication tools, such as e-mail, to allow users to get advice from their supervising sports doctors. However, for machine-based exercise, it is difficult for users to judge and control the appropriate exercise levels by themselves [10]. We developed an Internet-based cycle ergometer exercise system for continuously supporting personally fitted exercise. Users were able to easily access the newest exercise protocols designed with the help of a sports doctor via the Internet. We checked the feasibility of our system and confirmed that the personal fitting process was ensured by our system.

Results of our experiments showed that the SDATCE provided powerful ways to simplify the design of exercise protocols. The SDATCE developed with Java integrated several analysis techniques to one application, presented simple operation interface for sports doctors, and was validated to facilitate them on rapid and evidence-based design of exercise protocols. On the basis of observing the history database remotely, the sports doctor was able to update corresponding exercise protocols that would best fit the gradual change in users' physical work capacity (refers to Fig. 6). The experimental procedure indicated that the subjects could take appropriate exercises and employ renewed exercise protocols. However, some of the subjects who were not skilled in using computer needed help to execute the programs for starting exercises. We have not yet implemented a good user interface of exercise programs for general users, but concentrated on building facilities for sports doctors. Therefore, to enable users, especially the elderly persons, to perform exercise by themselves, a user-friendly interface needs to be further developed.

It is cost-inefficient for current exercise machine manufacturers to fix their exercise control programs in exercise machines because upgrading of the programs, which requires tampering with the machines, is difficult. Our proposed health promotion system framework addressed this problem based on an Internet-based multi-tiered design. The central server was used to converge different exercise control programs and provide the service of discovering these programs. In practical use, a variety of programs are dynamically obtained from the central server via the Internet and dynamically integrated with exercise machines. If exercise machines and programs were loosely coupled, it would be able to easily install different exercise control programs on an exercise machine. Moreover, the programs could be developed by independent departments and without against a specific exercise machine. Actually, various types of loosely coupling design have been employed in many fields, especially in the fields of computer-related industry, to reduce development and management cost [18]–[20]. Regarding health promotion, studies on loosely coupling design have not been introduced. Thus, our approach will be helpful for improving the quantity and quality of exercise control programs, which are currently limited due to pre-installing programs in commercial machines.

Our system can be used for a lot of situations, such as for a single user under home-based exercise [21], or a group of users who share the machines at a gymnasium [22], or a combined approach. Some fitness and health care companies have provided Internet-based on-line support services for home-based exercise users [23]. However, these users can only get verbal advice from sports doctors via the on-line services, and there are no services for controlling exercise machines to appropriate levels. Thus, we proposed the loosely coupling design for providing personally fitted exercise by distributing exercise control programs as well as protocols on the Internet and dynamically integrating these resources with machines at the time of exercise.

5. Conclusions

We proposed a multi-tiered client/server technical framework for health promotion exercise via the Internet. Through our technical framework, exercise control programs have been separated from exercise machines. An exercise machine and exercise control program will be dynamically combined at the time of exercise. Such design leads to a cost-efficient solution.

By applying the framework, we presented an Internet-based cycle ergometer exercise system mainly developed by Java technology. The system provides a practical solution of implementing a personal fitting process that includes continuous support and appropriate workload control for cycle ergometer exercise at any time from any suitable place. Moreover, a Sports doctor Analysis Tools for Cycle Ergometer was developed to assist sports doctors in the easy and quick design of exercise protocols. In a future revision, the system will be constructed on a proven application infrastructure, such as .NET and J2EE, to improve the reliability and easily address the security considerations. Moreover, we want to integrate other health promotion studies to realize a wide ranged comprehensive exercise solution. Consequently, more specific analysis tools regarding various types of exercises need to be developed for sports doctors.

Acknowledgments

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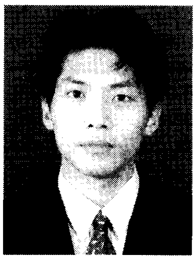

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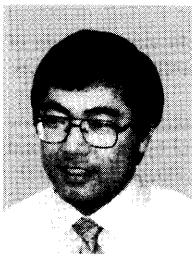

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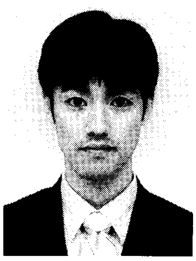

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