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An Integrated Training Aid System using Personalized Exercise Prescription

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Abstract: Continuously motivating people to exercise regularly is more important than finding a way out of barriers such as lack of time, cost of equipment, lack of nearby facilities, and poor weather. Our proposed system presents practicable methods of motivation through a diverse exercise aid system. The Health Improvement and Management System (all-in-one system which saves space and maintenance costs) measures and evaluates a diverse body shape analysis and physical fitness test and directs users to automated personalized exercise prescription which is prescribed by the expert system of three types of exercise templates: aerobics, anaerobics, and leisure sports. Automated personalized exercise prescriptions are built into XML based documents because the data needs to be in the form of flexible, expansible, and convertible structures in order to process various exercise templates. BIOFIT, a digital exercise trainer, monitors and provides feedback on the physiological parameters while users are working out in the gymnasium. If these parameters do not range within the prescribed target zone, the device will alarm users to control the exercise and make the exercise trainer adjust systemically the proper exercise level. Numeric health information such as the report of the physical fitness test and the exercise prescription makes people stay interested in exercising. In addition, this service can be delivered through the Internet.

Keywords: Exercise Prescription, Body Shape Analysis, Physical Fitness Test, Digital Exercise Trainer, Exercise Template

INTRODUCTION

Regular forms of exercise do not only prevent or minimize a cardiovascular, arthritic, and geriatric disease, but they also reduce the risk of mortal diseases such as heart disease, cancer and diabetes [1]. Exercise is a proven, highly beneficial, and strikingly underused health promotion modality [2]. Despite the known benefits of regular exercise, most adults do not participate in levels of physical activity that are sufficient to improve health [3]. In addition, exercise beginners tend to give up exercising because of time constraints, lack of a continuous motivation to pursue exercise, and many factors caused by monotonous, not-planned, and helpless training. Putting a spur to a regular exercise such as helpful counseling is the key to a long-lasting and balanced fit body.

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The help of a personal trainer in a gymnasium can include realistic goals and sufficient knowledge of fitness training, also showing us our body shape and physical fitness state which can act as motivation when we know what our health value is.

Knowledge of the numeric value of the Physical Fitness Test (PFT) and Body Shape Analysis (BSA) is necessary to foster a love of exercise in people who are likely to become bored while exercising. Moreover, exercise prescription based on these parameters can effectively help users increase their health state. In the present research, it is necessary to measure PFT factors such as VO_2 Max, muscular strength, power, agility, and so forth in order to evaluate a physical fitness condition [4][5]. However, only taking the measurements can not provide users with optimal exercise prescription unless a systemically offered expert knowledge analyzes the measurement. This implies that an exercise prescription system must be intelligent enough to guide users through their health maintenance program. Currently, most of the fitness measurement systems can only measure one or two parameters. If all of the measurements are wanted to be integrated, it will take so much time and expert knowledge to integrate the beneficial information among individual equipments. Consequently, integrated fitness measurement systems are well worth the effort as a profitable addition to a maintenance cost or as a smart exercise prescription.

To let people exercise properly as prescribed by exercise trainers, as well as to measure and assess fitness parameters, is important. For instance, the physiological parameters such as ECG and VO_2 Max, which are directly linked to their health state, can be extracted during exercise. These parameters help the exercise trainer to watch or adjust the level of exercise as feedback factors of an exercise monitor. T. Kiryu et. al. suggested a unique fuzzy inference design to provide appropriate cycle ergometer exercise levels for the middle-aged and the elderly [6]. As known by other studies, exercise generation is a complex and time consuming task [7]. Therefore, automated personalized exercise prescription is more required.

Nowadays, as information technology continues to grow, people can receive much information from the internet. Health information such as an exercise prescription makes people stay interested in exercise even if they live in many different environments. The goal of our study is to propose an effective, realistic exercise aid system. The Health Improvement & Management System (HIMS), an all-in-one expert system measuring various BSA and PFT, provides an automated personalized exercise prescription. The Digital Exercise Trainer, BIOFIT, makes people exercise properly while being monitored in order to motivate and encourage people to exercise regularly. In addition, all of this helpful information is offered through the widely spread web-based technology that people easily use at home, fitness centers, and many other places. Therefore, our information suggested by the exercise training aid system will get rid of exercise barriers such as time constraints, insufficient information on fitness, lack of knowledge concerning exercise prescription, and difficultly administered test. Also, it can be possible to remotely guide exercise through the internet.

METHODOLOGY

As shown by Fig. 1, our suggested system consists of three organic parts; HIMS, BIOFIT and the Exercise Trainer. Each part plays an important role in executing separately each function and influencing another part. For instance, the collected BSA and PFT parameters measured by HIMS underlie exercise prescriptions operated in BIOFIT. The exercise trainer's decision of the level of physical training is influenced by the extracted information from ECG data which is acquired in BIOFIT test. In addition, exercise trainers can modify typically automated personalized exercise prescriptions in order to balance one's condition.

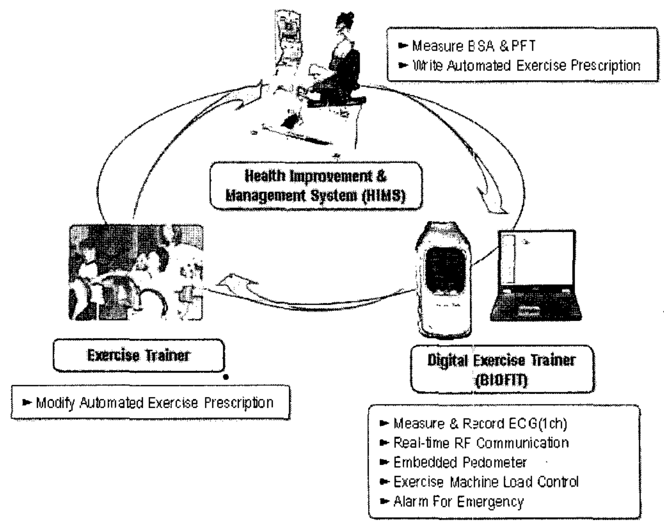

Fig. 1. Exercise Aid System Organic Diagram & Brief Function

HIMS is an integrated system that has diverse bio signal measuring sensors, variable fitness assessments, automated personal-fitted exercise prescription algorithms, and a simple, easily-administered test. HIMS exams two factors such as body weight and body fat in BSA and five ones such as NIBP, muscular strength/endurance, VO_2 Max, power, and agility in PFT. The information extracted from these parameters is used by an assessment basis. As show in Table 1, the parameters of the test are designed to make knowledge available to decision makers and technicians such as fitness trainers and exercise specialists who need answers quickly.

Table 1. Parameters extracted from BSA and PFT

BSA Parameters	PFT Parameters
Weight	Left/Right Hand Grasping Power
Height	VO2 Max variation
Waist	Agility
Body Fat	Muscular Strength
The latest variation of weight/height	Muscular Endurance
The latest variation of body fat	Instant Power
The latest variation of waist	Stable Heart Rate
Body Mass Index (BMI)	Recovery Heart Rate
Body Grade	Max Heart Rate
Health Age	Heart Rate Variation (Before/After Load)

The automated individual prescription of exercise (AIPE) of HIMS is designed to suggest personalized level of exercise which users can perform regularly. By using this system, users will be able to steadily improve their health. AIPE is organized as pre-defined document types which are made from XML technology. AIPE is categorized into three types of exercise templates; aerobics, anaerobics, and leisure sports. Each template has its own specific parameter. These parameters represent the amount of exercise in each session. For example, the system requires users to perform 1-RM (e.g. one repetition maximum weight) in order to ascertain the percentage, frequency, and the number of sets on the anaerobic template. These parameters are derived from the National Official Physical Strength Standards published by the Korean Institute of Sports Science in 1997.

BIOFIT is a small portable device designed to monitor ECG and help people to exercise by schedule of the AIPE. AIPE is applied to HIMS as well as BIOFIT in order to regulate exercise prescription and make or modify predefined exercise prescriptions. Users can utilize exercise prescriptions by means of BIOFIT by connecting with the HIMS using internet web browsers, especially Microsoft Internet Explorer. BIOFIT measure the ECG signal (1 channel) when users are exercising, and sends real-time ECG data to the PC using the RF adaptor by wireless network.

IMPLEMENTATION

BSA & PFT Parameters

The bio-signal measurement module attached in the HIMS can measure several kinds of bio-signal. This measurement module includes an analog part for the ECG (2 channel), body fat, body weight, muscular strength or endurance, SpO_2, NIBP and agility for signal collection. As show in Fig 2, One board contains bio-signal measurement modules (ECG, Body fat, Body weight, Muscular strength), and microcontroller for converting an analog signal to be measured into digital signal through the ADC (Analog to Digital Converter).

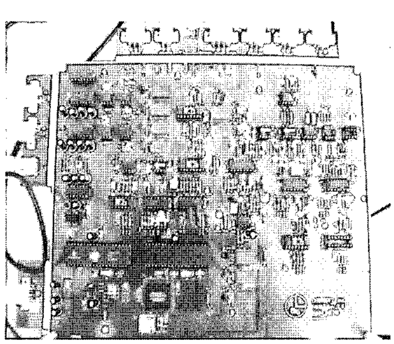

Fig. 2. Bio-signal measurement board

In the NIBP test, we measured indirectly blood pressure with the help of the photoplethysmographic (PPG) signal. We have modified the existing hardware with a microcontroller that collects and handles the data through serial communication. NIBP is measured twice; before exercise and after exercise.

In muscular strength test, we measure grip power and endurance. We used a load cell that could measure 0 ~ 150 kg of grip power range, 0 ~ 100 % range of grip power endurance. In this system, the load cell was adhered at the handle. The maximum value is saved when users seize the handle with all of one's might. As show in Fig. 3, the percentage of the minimum and maximum value is recorded and calculated when users seize the handle during 10 seconds as grip power endurance.

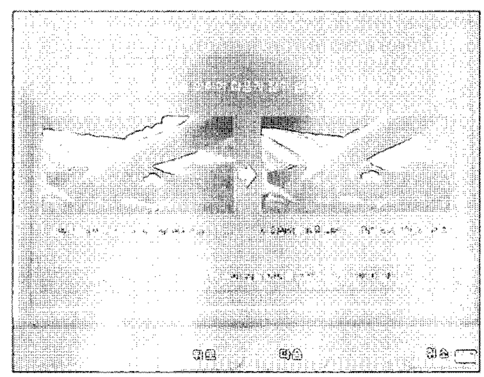

Fig. 3. Muscular strength and endurance test (Grip Power)

In a VO_2 Max test, users perform exercises on ergometer type equipment. This is to consider the safety for the elderly or the user whose articulation is weak. The Åstrand protocol [8], which predicts maximal oxygen consumption from a submaximal heart rate exercise and power output values, is adapted for our test considering the safety sub-maximal protocol. Two channels of ECG signals are monitored during a six minute test period. The channels are evaluated for heart rate while the users are working out, holding a load of 60 rpms. We assumed that the subject's Resting Heart Rate (RHR) and Maximum Heart Rate (MHR) may be estimated according to age, and VO_2 max, and Work Rate having a linear relationship.

In a power test, we measure the average power while pedaling at maximum speed for 10 seconds. Lower limb strength and power are extracted from maximum speed and endurance of this test.

In an agility test, it is designed to estimate agility which is measured by the response time. First, a rectangular image of a red color is displayed on the screen. Then, the user pushes the button of this machine. As show in Fig. 4, the agility is evaluated by the response time between the events. It is repeated three times and the average time is computed as the numerical value of the agility.

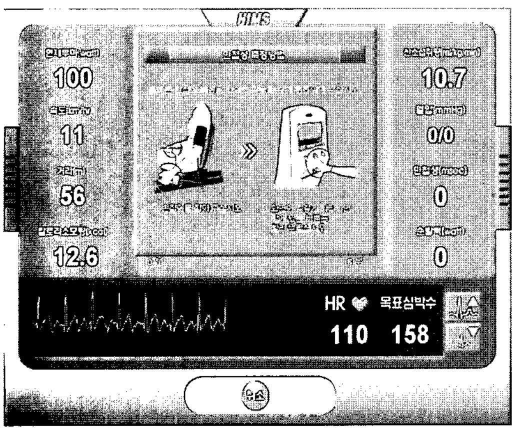

Fig. 4. Agility Test

AIPE Structure and Function

Our proposed system architecture is linked with HIMS and BIOFIT Users through the Internet as illustrated in Fig. 5.

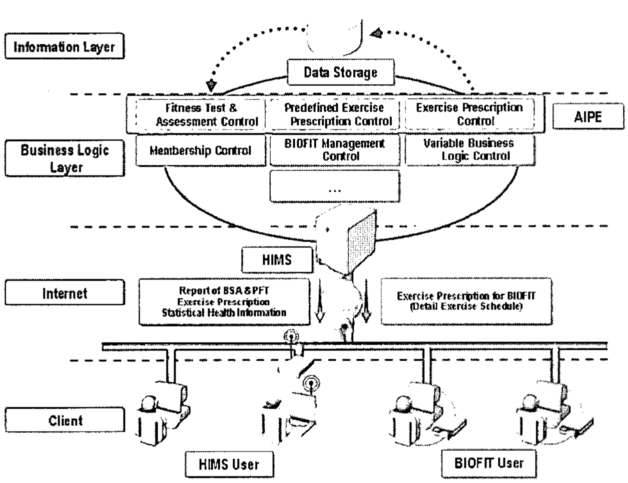

Fig. 5. System architecture of HIMS & AIPE

The HIMS is divided into two layers. The information layer deals with data storage. The business logic layer usually services diverse controls related to AIPE. Membership control rules how much a user's privilege is restricted and the security of each group; Personal Trainer (PT), Exercise Specialist (ES). and users. Fitness Test & Assessment Control, Predefined Exercise Control, and Exercise Prescription Control are a core set of AIPE. The total score of the PFT is resulted from marks of inspected parameters computed by the expert system. This expert system refers to the definitions of exercise prescription as shown in the pre-defined exercise prescription control. As show in Table 1, these parameters are collected from the test of HIMS and evaluated by AIPE. The PT and ES can modify pre-defined prescriptions by means of Exercise Prescription Control to make a user-defined prescription in which their opinion of the users can be reflected. The BIOFIT Management Control allows users to download their own individualized exercise prescription.

XML Based Pre-Defined Exercise Prescription

eb-based HIMS consists of Microsoft .NET Framework, ASP .NET, ADO .NET, and MSXML. We adopted an XML Technology to design our AIPE expert system because flexible and extensible XML Schemas (XSD) offer a powerful set of tools for constraining and formalizing the vocabulary and grammar of XML documents. As XSD becomes large and complex, or when schemas that represent different types of pre-defined exercise prescription template have some sections in common, it can be useful to include smaller schemas as building blocks in the larger ones. As shown in Fig. 6, "Exercise Program" is the root node that has more than one "Session" node. "Session" node refers to the definition of a full exercise procedure which users will do at a time. The "Session" node can be unboundedly attached to the "Exercise Program" node within the period selected by PT or ES. The default period is usually four weeks. The "Session" node must have three "Phase" nodes distinguished from another step of exercise that consists of three steps: warm-up, endurance, and cool-down phase. Each "Phase" node may have zero or unbounded "Exercise/Unit" that refers to the declared exercise template as an atomic pattern of exercise.

"ExerciseUnit" is composed of a common section and exercise template section for lining each other template such as aerobics, anaerobics, and leisure sports. In the case of the aerobic exercise and leisure sports template, repetition counts and sets are unnecessary factors that must be required to formalize the anaerobic exercise template.

Calories consumed by playing leisure sports per weight in time unit (kcal·min-1·kg-1) are used to calculate target calories. There are 34 leisure sport templates standardized and administered by PT or ES. AIPE built in an XML based structure can be freely converted to other types of templates. Exercise prescriptions made by AIPE acts as an exercise guide for users after it is verified, if necessary, modified. Web-based HIMS provide users with a variety of test results concerning physical strength. The data from the latest 10 recorded tests are displayed to give a summary of health at a glance (Fig. 7). Users can confirm this result through the internet at home and download their exercise prescription and save it in the BIOFIT program.

```
<?xml version="1.0" encoding="utf-8"?>
<xs:schema                                    elementFormDefault="qualified"
xmlns:xs="http://www.w3.org/2001/XMLSchema"   xmlns:msdata="urn:schemas-
microsoft-com:xml-msdata">
  <xs:complexType name="ExerciseUnitType">
    <xs:sequence>
      <xs:element name="Mode" type="xs:string" />
      <xs:element name="Intensity" type="xs:decimal" />
      <xs:element name="Unit" type="xs:string" />
      <xs:choice>
        <xs:element name="DurationTime" type="xs:decimal" />
        <xs:sequence>
          <xs:element name="RepeatitionCount" type="xs:unsignedInt" />
          <xs:element name="Sets" type="xs:unsignedInt" />
        </xs:sequence>
      </xs:choice>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="SessionType">
    <xs:sequence>
      <xs:element name="SessionDate" type="xs:date" />
      <xs:element name="Notice" type="xs:string" />
      <xs:element name="SessionNumber" type="xs:unsignedInt" />
      <xs:element     name="Phase"     minOccurs="3"     maxOccurs="3"
type="PhaseType" />
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  </xs:complexType>
  <xs:element name="ExerciseProgram">
    <xs:complexType>
      <xs:sequence>
        <xs:element name="Version" type="xs:decimal" nillable="true" />
        <xs:element name="Organization" type="xs:string" nillable="true" />
        <xs:element name="Author" type="xs:string" nillable="true" />
        <xs:element name="Trainer" type="xs:string" nillable="true" />
        <xs:element name="Eating" type="xs:string" nillable="true" />
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nillable="true" />
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        <xs:element name="Level2" type="xs:string" nillable="true" />
        <xs:element name="Level3" type="xs:string" nillable="true" />
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        <xs:element name="Frequency" type="xs:unsignedByte" />
        <xs:element name="StartDay" type="xs:date" />
        <xs:element name="EndDay" type="xs:date" />
        <xs:element name="ValidPeriod" type="xs:date" />
        <xs:element   name="Session"   type="SessionType"   minOccurs="1"
maxOccurs="unbounded" />
      </xs:sequence>
    </xs:complexType>
  </xs:element>
  <xs:complexType name="PhaseType">
    <xs:sequence>
      <xs:element name="PhaseNumber" type="xs:int" />
      <xs:element name="PhaseTime" type="xs:time" />
      <xs:element         name="ExerCiseUnit"         type="ExerciseUnitRoot"
minOccurs="0" maxOccurs="unbounded" />
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="ExerciseUnitRoot">
    <xs:sequence>
      <xs:choice>
        <xs:element   name="Exercise_WarmUp"    type="ExerciseUnitType"
minOccurs="0" maxOccurs="unbounded" />
        <xs:element   name="Exercise_Endurance"   type="ExerciseUnitType"
minOccurs="0" maxOccurs="unbounded" />
        <xs:element   name="Exercise_CoolDown"   type="ExerciseUnitType"
minOccurs="0" maxOccurs="unbounded" />
      </xs:choice>
    </xs:sequence>
  </xs:complexType>
</xs:schema>
```

Fig. 6. XML Schema description of pre-defined exercise prescription without attributes and constraints using in AIPE

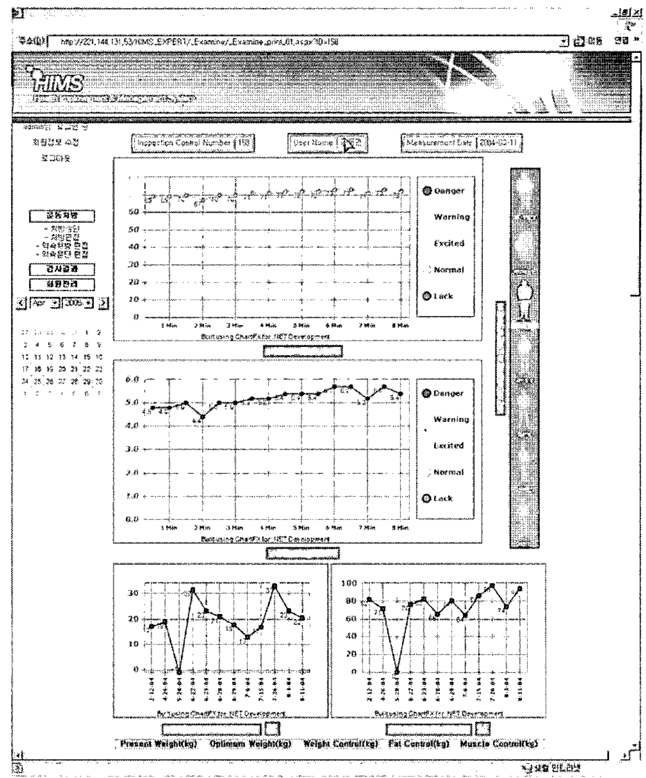

Fig. 7. A part of report page of BSA & PFT

BIOFIT Feedback Data

Fig. 8 shows the overall hardware architecture of BIOFIT. It contains the heart rate monitor, pedometer, clock, RF module, graphic LCD, USB, alarm, and memory. The Microcontroller (MCU) controls the operation of all of these functional blocks.

Every time BIOFIT is put into operation, firmware polls the start date and time for each session. If the polling matches then it will indicate to the user to start the exercise session using the audio alarm. The user attaches our device on its' waist and puts ECG electrodes on his chest and performs the exercise. The Heart rate monitor and pedometer continuously monitor the heart rate and steps respectively and store the information every 10 seconds in memory. This device will guide the user in doing proper exercise according to the preloaded exercise program. If the heart rate falls outside the target heart rate zone then it will alarm the user as feedback to control his exercise process. Exercise parameters such as BPM and ECG are displayed on graphic display. The RF module continuously transmits ECG signals wirelessly which can be displayed on the computer.

Implementation of each functional block is given as follows:

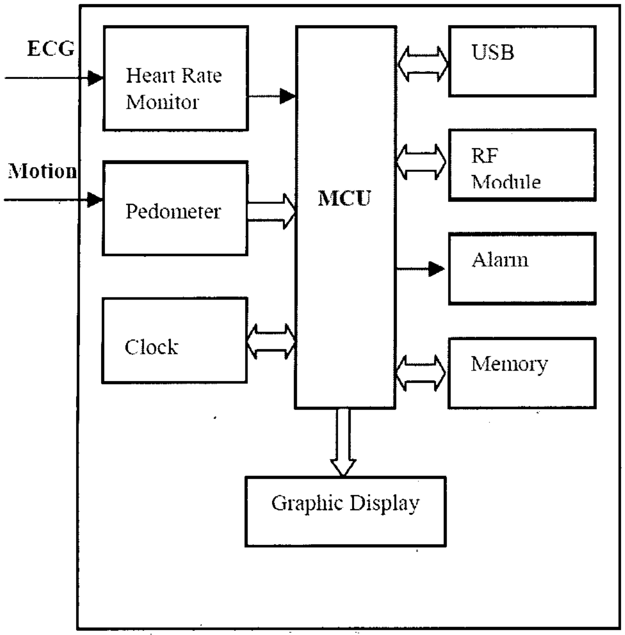

Fig. 8. Block Diagram of the BIOFIT System Architecture

RF Module

Nordic nrf2401 chip [9] used in RF Module enables the device to communicate wirelessly. It is a single chip radio transceiver for the 2.4GHz ISM band and a programmable chip with a 3 wire serial interface to the microcontroller. The microcontroller samples the ECG data every 2.77ms. This sampled data is then added with 4 bytes of receiver address and transferred to nrf2401 for air transmission. Nrf2401 buffers all the data in its FIFO buffer at the rate of 2kbps and then transmits in the air at 250kbps. On the remote PC side the receiver will check the first four bytes of address. If it matches with the correct receiver address then it will accept the ECG data and display it on the computer.

Heart Rate Monitor

This block contains the circuit which gets the ECG signal from the human body through the 3 electrodes and then filters and amplifies that signal compatible to the microcontroller. The circuit contains the pre-amplifier which requires a gain of 1000 because of ECG signals in the millivolt range. Then there is the low pass filter (LPF) with the cutoff frequency at 160 Hz, high pass filter (HPF) with cutoff frequency at 10Hz, notch filter to eliminate the 60Hz noise [10][11].

The amplified ECG signal from the circuit is then sampled by the microcontroller at the rate of 2.77ms (300Hz). The ADC resolution microcontroller is of 8 bit. The heart rate detection algorithm inside the microcontroller calculates the heart rate from this sampled ECG signal

Pedometer

Pedometer is used for calculating running steps, and then checking users whether they well follow in a directed exercise prescription. It uses an accelerometer which senses the motion of the body and then transmits the pulse width modulation (PWM) output proportional to the movement of the body. MXD2125ML used in this part is a low cost, dual axis accelerometer fabricated on a standard, submicron CMOS process. It can measure the two dimensional (x and y) movement of the body. It has two pin outputs. One pin gives the x direction PWM output and the other gives y direction PWM output [12]. Device firmware continuously monitors this acceleration which helps in calculating steps.

USB

The CP2101 chip for the USB communication is used. This chip is USB to UART Bridge with

USB specification 2.0 compliant, full speed (12 Mbps). It converts the serial data from the microcontroller to the USB compatible data. This chip can be interfaced to microcontroller with minimal parts.

Other functional blocks

Other functional blocks are the microcontroller, the graphic display, Memory, and the Clock. The Microcontroller is the PIC16Lf877A. We chose this microcontroller because it is cheap, works in low power mode (3.0 volt), readily available, and contains additional features. The graphic display is 128*64 pixels graphic LCD and is used for displaying date, time, and other useful information. Memory 24lc512 is of 64kb with Inter IC Communication (I2C). NJU63556 is used as a real time clock. A finished product and PCB of BIOFIT is illustrated in Fig. 9.

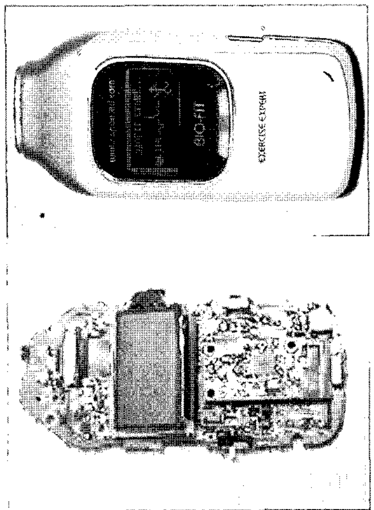

Fig. 9. Full Image and PCB of BIOFIT

DISCUSSION

Many people living in the 21st century's modern society seldom have an opportunity to initiate and motivate themselves to exercise, despite understanding the importance of exercise. Furthermore, there are only few, if any, people who can regularly maintain exercise. This is a problem that is not only related to individual disposition such as patience, sincerity, and tenacity but also intimately associated with an environment that does not lastingly support motivation to attain health.

The proposed solution suggests realistic goals to improve health and continuous concerns to maintain exercise. Providing users with motivation is accomplished by exercise prescription guided by AIPE and BIOFIT utilizing downloaded exercise prescriptions through the Internet. This makes users concentrate their interest on exercise, even if they exist in unmanaged surroundings or time. The XML based expert system is designed to support an elastic, expandable and easily convertible data structure.

In this study, AIPE is built in a partially embedded control of HIMS. However, we will lay out a new architecture of AIPE constructed by Web Services Technology to furnish all of the straggling HIMS with service components in connection with fitness assessment and exercise prescription.

CONCLUSION

In this study, we presented the Integrated Body Shape Analysis and Physical Fitness Test System, HIMS, evaluating or assessing body shape and physical fitness status in an all-in-one system and guiding properly users to exercise. In addition, a portable device to measure the ECG signal in a real-time, BIOFIT, can detect heart rate to check whether users exercise well and send data to the RF adaptor of the PT system to monitor and record the signal. The exercise prescriptions are constructed with XML Documents being flexible, expansible, and convertible. AIPE built in an XML based expert system suggests that users can exercise regularly by means of automated personalized exercise prescription. As a result, our proposed system saves costs, time, space, and an operating labor force than previously used individual instrument cluster systems. HIMS could be used in Health Promotion Centers or in rehabilitation and aging clinics for evaluating body status and providing personalized exercise prescriptions. Additional modules for evaluating balance, coordination, and flexibility should be developed to be used in professional sports areas or in diagnosing some diseases.

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