Method of Monitoring of Young Athletes' Physical State Indicators Based on Wearable Devices Usage

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Abstract. The task of monitoring of human physical state during sports training is considered in this paper. The possibilities of popular on the market wearable devices have been analysed for its solving. It is shown that the main restriction on the usage of the considered devices is the absence of the function of data collecting for the next processing and recommendation formation. Therefore, this work is devoted to the research and development of the method of monitoring the indicators of young athletes' physical state based on the usage of inexpensive fitness bracelet and developed web application.

Keywords: indicators of physical state, wearable devices, fitness bracelet, heart rate, anaerobic threshold, dynamic monitoring, Web Bluetooth API, web application.

1 Introduction

The formation of a professional athlete is a long process that requires constant systematic training related to physical and psychological stress. For this process to be fruitful and not harm the athlete, the coach must be able to properly plan the training program. It is especially important to monitor the health status of young athletes as very intense physical activity can lead to irreversible consequences. Therefore, the implementation of the opportunity for the coach to effectively monitor the indicators of the physical state of juniors during training is an urgent task [1, 2].

In general, an active lifestyle and dynamic monitoring of own physical status are becoming increasingly popular today. Accordingly, every year on the market more and more wearable devices appear that help to monitor indicators of human physical state. Bill Gates cited the usage of wearable devices for monitoring cardiac activity, as one of the most important technologies in 2019 [3]. Different modern heart rate sensors, fitness bracelets, smart watches and even wireless Bluetooth earbuds are presented on the market that can be connected with a smartphone for cardio data transmission [4]. Such companies as Apple, AliveCor, Withings have presented wearable devices with electrocardiogram (ECG) function, which provide accuracy close to the accuracy of medical equipment [5]. Another example is low-cost clinicalgrade AliveCor KardiaMobile ECG Monitor. This is a portable electrocardiograph with two electrodes that can be attached to the back of iOS and Android smartphones [6]. Typically, all these devices are focused on individual usage and the data are usually just displayed locally for self-monitoring. They do not provide centralized data collection and storage for processing and generating recommendations for the following physical activities planning. In some cases, where data collection and visualization in the cloud service is provided, nevertheless, the data is available only to the owners of the devices for self-monitoring.

The goals of the work are research and practical implementation of the method of obtaining and processing information on the indicators of the physical state of the juniors directly in dynamics during sport training.

2 State-of-the-Art

Studies have shown that the main task of a sports coach is to adapt the standard training system to the individual capabilities and characteristics of a particular athlete, as well as setting real training goals and current tasks.

In the management of sports training, we can distinguish such directions as:

- The control of sport activities (accounting and analysis of the work done).
- The level of athlete`s readiness monitoring (biological, mental and technical).
- Generalization and analysis of monitoring data to make changes in the planning of sports activities.

For example, in the framework of the official program of sports training of children and juniors, the Squash Federation of Ukraine uses a mandatory individual card of the athlete, but in paper form [7]. The record is maintained from the very beginning of the child's training and is further performed at each new stage of preparation. The monitoring is performed in two directions: medical examination and control of physical state indicators.

In the study of the functionality of existing software products in this area, the following was revealed. Most of the existing systems provide standard accounting functions based on the schedule, occupancy of halls, coaches and the mark of attendance by the client. Official web sites of sports associations and sports clubs generally have informational character.

An example [8] is the fitness club training accounting system, which is presented as a mobile application for the Android and iOS platforms. Its main functions are customer registration; season ticket purchase; training attendance records; recording for group classes; data about club staff; information about training plans. The application does not monitor the state of health during training, but it is possible to enter anthropological indicators (such as weight, waist size, etc.) and thus to monitor their changes.

Work [9] shows the results of the development of web applications for the Squash Federation of Ukraine. It provides the following functions: user registration; weekly planning of the training schedule for each junior; viewing of schedule; distribution of messages about changes in the schedule; confirmation of participation in the training;

assessment by the coach of the athlete for each type of exercise and the overall assessment for the training and report generation.

The authors of [10] have shown the results of the study on the interdependence of the psychological state and recovery period of athletes depending on several parameters, such as the training load, heart rate, recovery of heart rate and heart rate variability. Data processing was carried out using LISREL (linear structural relations) which is a proprietary statistical software package. However, data collection was carried out by traditional methods, without the usage of specialized software tools.

The paper [11] analyzes the objective and subjective indicators of the athletes' physical state. Objective indicators were taken into account both at rest (for example, blood counts, heart rate), and during exercise (for example, oxygen consumption, heart rate reaction). They were compared with subjective indicators (e.g. mood, perceived stress). All indicators were also evaluated by their response to acute and chronic training load. An electronic search was conducted using the existing data from different databases, so the results are not suitable for a particular group of kids and kind of sport.

The authors [12] suggested monitoring the weekly training load and assessing it based on the health rating scale. The described tools are based on the use of Microsoft Excel also provides for the collection of information and manual data entry for subsequent analysis and providing feedback to the athlete to manage stress or fatigue and prevent possible consequences.

Thus, the investigation has revealed that the existing approaches and software systems are not focused on the control of the health of a person who is engaged in the gym. However, monitoring indicators of the athlete's physical state during a particular training session and subsequent analysis of these indicators are the most informative for assessing the success of the training plan as a whole. Such accounting is useful for both amateurs and professional athletes, especially for beginners, including kids.

3 Analysis of Wearable Devices and Applications for Monitoring a Person's Physical State

In addition to professional medical equipment various wearable devices are actively used today to monitor the indicators of the person`s physical state. They are fitness bracelets and smart watches.

Modern fitness bracelets can be conditionally divided into three groups: trackers, smart bracelets and health bracelets [13]. Trackers are highly specialized gadgets that support the functions of a heart rate monitoring, pedometer, alarm clock and tracking sleep phases. Smart bracelets are advanced tracker models. In addition to fitness functions, they have an indication of calls and messages, reminders about classes, GPS and a compass. They are equipped with a display and look like a "smart" watch. The most popular manufacturers are Jawbone, Polar, Fitbit, Garmin, Samsung, Xiaomi. Health bracelets are designed for professional usage in medicine or sports. The main differences of these devices are the built-in blood pressure monitor, as well as sensors for measuring the level of oxygen in the blood. GSMIN E11 fitness bracelet is designed both for monitoring sports performance and for monitoring the health status of elder people. In addition to common functions such as measuring heart rate, steps and calories, this fitness bracelet provides measuring of blood pressure, oxygen level in the blood and building an ECG. During the work budget fitness bracelet Xiaomi Mi Band 2 was examined. This device performs all the basic functions of a standard fitness bracelet, such as measuring heart rate, calculating steps taken. Additionally, it is equipped with an OLED screen with which the user can view the number of steps taken per day and measure the pulse without using a smartphone.

Smart watches are computerized devices that act as a watch, fitness tracker, switch and control panels. They can perform as:

- Applications for a smartphone (broadcast calls, messages, transmit voice commands, launch applications on the phone, control other types of smart technology, etc.).
- Independent gadgets (make calls, send messages, take pictures, play music, etc.).

Depending on the operating system, a smart watch can be the following types: Android (e.g. Garmin Fenix, SMA S3); Android Wear (e.g. Asus ZenWatch, Huawei Watch, Motorola 360); IOS (Apple Watch); Tizen (Samsung Gear Sport, Samsung Gear S3). Almost all models can be used to monitor the physical state: support the training program, track the route and determine the heart rate and the number of steps based on the usage of a heartbeat sensor and accelerometer. The watch can synchronize with other computers or smartphones with the usage of wireless data transfer technology. This type of equipment includes Samsung's Galaxy Watch Active. Using special motion sensors and built-in GPS, this watch automatically monitors up to seven types of activity, as well as the user's heart rate. It sends instant notifications when anomalies are detected.

The software for fitness bracelets is a specialized utility that allows to send various information from fitness bracelets to smartphones using the wireless connection. After taking measurements, the fitness bracelet is synchronized with the smartphone and transfers the data for processing to the application. In addition, some programs allow communication between people who use these bracelets. Almost all manufacturers of fitness bracelets provide their own unique application that works only with devices from this manufacturer.

For example, Mi Fit is a mobile application for fitness gadgets manufactured by Xiaomi, including fitness bracelets. The user enters his biometric data (gender, age, blood type, weight, height), sets a goal that he seeks to achieve and synchronizes his fitness bracelet with the smartphone. The application tracks the number of steps taken over a certain period of time, calculates the number of calories burned. The application has two modes of usage: daily mode, when only the number of steps is calculated, and a training mode. In training mode, the user determines the type of activity and the application, at certain intervals, measures the pulse and determines the level of anaerobic threshold (AT). After training, a general report is displayed in graphs and statistics. The application is designed for operating systems such as Android and iOS.

Google Fit is the activity monitoring app designed for both smartphones and smart watches, supported by the Android platform. It is a universal application and can sync with Android Wear, Xiaomi Mi, Runkeeper, Sleep as Android, Nike +, Lifesum, MyFitnessPal, Basis, Strava, Withings. In addition, the application is synchronized with other programs that track your health status. All data is stored on the server and the user can see it not only through the application but also through his personal Google account. The advantage of this software is that the data are obtained from many synchronized with smartphone devices and from sensors that are located on the smartphone.

Thus, fitness bracelets can be used as an inexpensive solution for dynamic monitoring of athletes' physical state indicators. However, the urgent task is to develop a web application for centralized data collecting from such devices and processing for further usage by coaches in training planning.

4 Investigation of Variants of Monitoring System Realization on the Basis of Fitness Bracelet

Xiaomi Mi Band 2 fitness bracelet was chosen as a device for data collection, due to its low price and at the same time the availability of basic functionality for monitoring athletes' health indicators.

The manufacturer does not provide an open Application Programming Interface (API) either for the bracelet or for its proprietary application. The fitness bracelet is a Bluetooth Low Energy (BLE) client-device and it transmits data via Bluetooth. To obtain data, we needed a device that would act as a server. This role can be performed either by a personal computer (PC) or a smartphone.

The implementation of the technology for obtaining data transmitted by the device was an important task of the project. Several variants have been considered:

- To write own mobile application that would synchronize with the device and exchange data.
- To receive data from another application through the API.
- To receive data without the usage of a smartphone but with a PC.

The first option was to synchronize the bracelet with a smartphone. For this purpose, an Android application was developed on the basis of the library for working with BLE devices. This application transfers data to the web application server. The first step in the interaction of the application with the BLE device is to connect to the Generic Attribute Profile (GATT) server on the device. For this aim, the connectGatt() method is used. The application connects to the GATT server located on the BLE device and returns an instance of BluetoothGatt, which can be used to perform GATT client operations later. The Android application is a GATT client. BluetoothGattCallback is used to obtain the results by the client, such as the status of the connection and any additional GATT client operations. As soon as the application connects to the GATT server and discovers the services, it can read and write attributes, where it is supported. In practice, the application hasn`t connected to the bracelet all the time. Sometimes the device hasn`t appeared at all during the search. When the connection could be established, other imperfections of the used library were revealed, in particular, the characteristics and descriptors could not be recognized automatically.

Another option was to receive data through the universal Google Fit application. Data from the application is automatically synchronized with the user's Google account and stored on the server. The documentation points out the API with which it is possible to receive and to add data to this server. This was the easiest variant since data can be obtained directly to a previously developed web-based application for training squash players and there is no need to create additional software. During the experiment, it was revealed that it was possible to get from the Google server only the data that has been sent there from our application. The data obtained by it from a fitness bracelet was inaccessible. Thus, we can conclude that this API is necessary only for the developers of applications for fitness bracelets who want to synchronize data from their devices with Google accounts of their users.

The next phase of research was to consider a new Web Bluetooth technology. The first version of this specification allows client-side websites with a central role to connect to GATT servers through BR/EDR (Basic Rate/ Enhanced Data Rate) or BLE (Bluetooth Low Energy) connection. This means that Web Bluetooth allows to control any BLE device, including a smart bracelet, directly from a PC or a smartphone without the installation of a special application. In addition, such a solution will be cross-platform. Web Bluetooth technology is now supported by all popular browsers of the latest versions: Chrome, Samsung Internet v6.4, Opera, Servo, Firefox, Microsoft Edge, Safari. Although the solution is cross-platform, restrictions on operating systems exist. The technology is supported on the following operating systems: Android 6.0 Marshmallow+, iOS X Yosemite+, Linux Kernel 3.19+ and BlueZ 5.41+, Windows 10. It is necessary to know the list of characteristics and descriptors for working with a BLE device. We got these parameters using the free configuration software nRF Connect for BLE devices. This app connects to any BLE device, detects and analyses services and features. Table 1 contains UUID (Universally Unique Identifier) characteristics of Mi Band bracelet and Fig. 1 shows results of its scanning.

Table 1. UUID characteristics of the device

Name	UUID
Hardware service (HRDW)	0000fee0–0000–1000–8000–00805f9b34fb
Heart Monitor Service (HMS)	0000180d-0000–1000–8000–00805f9b34fb
Heart Rate Measure Characteristic (HRM)	00002a37–0000–1000–8000–00805f9b34fb
Heart Monitor Control Characteristic (HMC)	00002a39–0000–1000–8000–00805f9b34fb
Sensor Characteristic (SENS)	00000001–0000–3512–2118–0009af100700

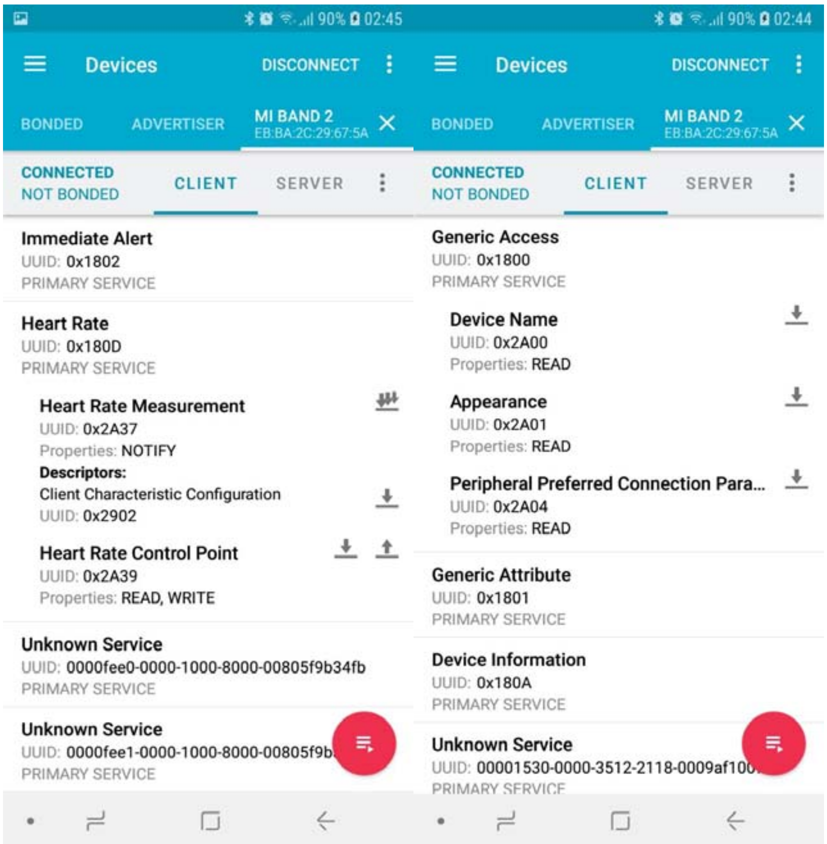

Fig. 1. The results of fitness bracelet Mi Band 2 scanning with nRF Connect

Web Bluetooth provides an API for development in the JavaScript language. The Internet also has an example of a working application for searching and connecting to a fitness bracelet. This application stably connected to the device and took heart rate measurements. Therefore, as a result of the study, Web Bluetooth technology was chosen for the development.

5 Model and Algorithm of Athletes` Physical State Indicators Identification

Existing models of training effects development use three groups of key variables. They are quantified training load, quantified athletic performance and variables that describe the state and dynamic characteristics of fatigue and fitness [14]. Training load is a combination of intensity, duration and frequency of training. In this work, the TRIMP (TRaining IMPulse) method is used for assessing training intensity, since it takes into account the combination of the external load and the physiological response of the athletes' body [15]. The TRIMP based model can be presented in the form (1):

$$M = <t, x, y, z> \tag{1}$$

where t is a training volume, measured in minutes, x is a set of indicators related to heart rate (HR) or lactate response, y is a set of indicators related to maximum HR or oxygen consumption; z is a set of indicators related to ventilation or anaerobic threshold (AT).

In accordance with the proposed algorithm (Fig. 2), such indicators as the maximum HR during training, the pulse zones and their duration, the level of metabolism or AT and the pulse zone in accordance with the AT are calculated.

Stage 1. Assessment of the intensity of physical activity. Determining the basic values of the maximum HR depending on the age (Table 2) and comparing them with current ones during training. Typical data for juniors are shown in Table 2.

Stage 2. Calculation of training intensity zones, which is based on a percentage of the maximum HR (Table 3).

Stage 3. Calculation of the AT level based on special tests to obtain the most accurate data on training zones. If there is no test data, it is possible to use the theoretical data from Table 4.

Stage 4. Evaluation of levels of training zones according to Table 5.

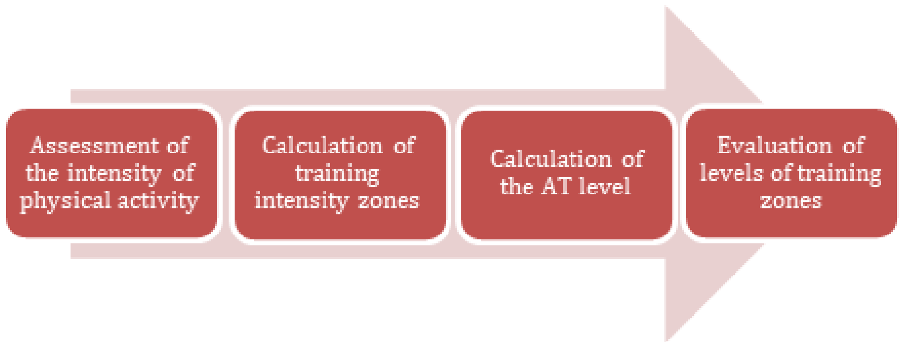

Fig. 2. Algorithm of athletes` physical state indicators identification

Table 2. Typical value of maximum HR for juniors

Age	Boys	Girls
11	200	199
12	199	198
13	198	197
14	197	196
15	197	195
16	195	195
17	194	194

Table 3. Calculation of heart rate zones for HR = 197

Zone	% from MHR	Heart rate	Feeling of exercise
1	<66%	<110,2	Very easy
2	66%-73%	110,2 – 121,9	Easy
3	73%-84%	121,9 – 140,2	Normal
4	84%-91%	140,2 – 151,9	Hard
5	>91%	>151,9	Very hard

Table 4. Theoretical calculation of the AT level

Age	HR
9-11	179±3
11-14	161±5
14-17	145±7

Table 5. Calculation of heart rate zones for AT = 161

Zone	Description	% from AT	HR	Feeling of exercise
1	Restoration	<69%	<111	Very easy
2	Endurance	69%-84%	111-135	Easy
3	Tempo	84%-95%	135-152	Normal
4	AT	95%-106%	152-170	Hard
5	Maximum oxygen consumption	>106%	>170	Very hard

6 Development of the Web Application for Dynamic Monitoring Indicators of the Athletes' Physical State

Functional requirements for the application are pulse reading; synchronization with the web application; determination of indicators of athlete's physical state during training; report generation. Potential users of the system are coaches, juniors and parents. The program is a part of a previously developed web application that has a three-tier architecture (Fig. 3). It includes the server level, as well as the database with which the application server level works. A client program connects to the application server. Fitness bracelet connects to the client program using the Web Bluetooth API. HTML, CSS, JavaScript, PHP languages were used for the application development. A cross-platform integrated development environment PhpStorm from JetBrains has been also used.

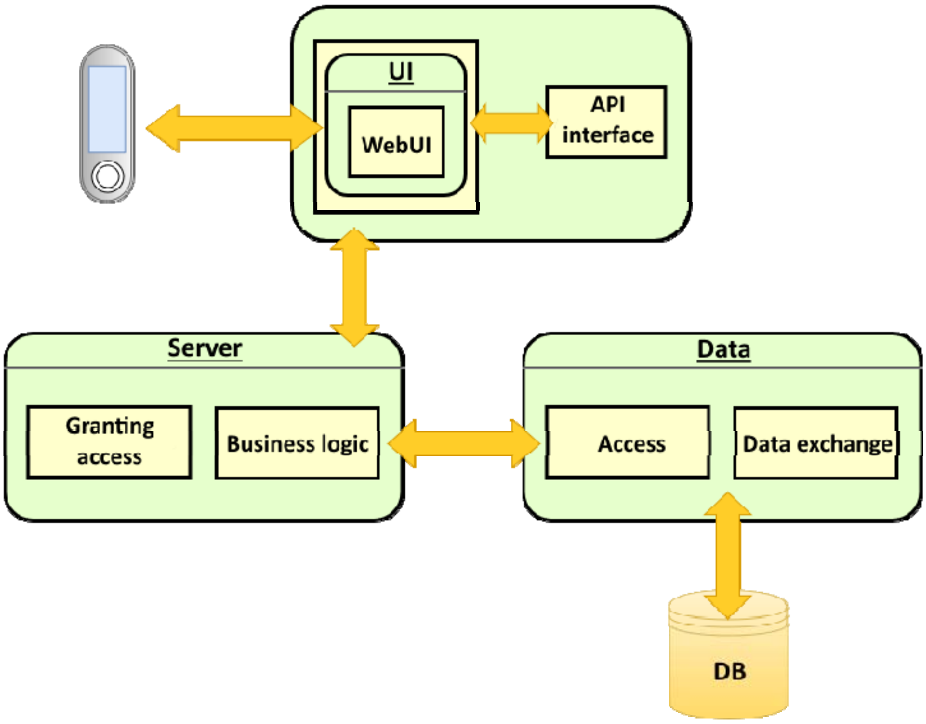

Fig. 3. Web application architecture

Conventionally, the process of functioning of the system is divided into two stages: connecting to the device and processing the received data. User interaction with the application is necessary only at the beginning and at the end of the process.

At the beginning, the user selects the necessary device and connects to it. After that, the application via Bluetooth receives data from the fitness bracelet. Heart rate and time data are stored in an array. Further, the program calculates the pulse zones, finds the maximum heart rate for the entire training period. All received data is displayed in the form of a graph and a table. After that, the received data is transmitted to the server, where it is entered into the database.

Fitness tracker connection is implemented in JavaScript and it is located in the miband.js file.

In order to connect the device to the web application, the navigator.bluetooth.requestDevice method is used. This method accepts an array of filters that return only devices that match the specified Bluetooth GATT functions or device names. As noted above, the Mi Band 2 device has a Heart Rate feature with UUID = 0x180d. After executing this code, the browser will display a window with the devices found near it. The functions used for working with the fitness tracker are shown in Table 6.

Table 6. Description of miband.js functions

Function name	Description
device.gatt.connect()	Connecting to a device
getPrimaryService(0x180d)	Getting main service with UUID = 0x180d - heart rate reading
getCharacteristic('00001531-0000-3512-2118-0009af100700')	Getting pulse measurement characteristics
characteristic.startNotifications	Tracking data changes
device.gatt.disconnect()	Disconnect from device

During training, an array is formed with the pulse and measurement time data. Data processing occurs after the device is turned off. Processing of the received data occurs in the miband.js file using the function and CharacteristicValue (data []). An array with the received data is passed to the function, there, using the standard switch () operator, the data is divided into 5 pulse zones and the time of athlete's stay in this or that zone is calculated. The maximum heart rate is found. The array is not transferred to the server using AJAX technology.

This technology enables the "background" exchange of browser data with a web server. As a result, when updating data, the website does not restart completely, and web applications are faster and more convenient. Below there is a function for transmitting the data to the server.

```
$.ajax({url: "test.blade.php",type: "POST", data: ({source: data, len: data.lenght()}) dataType: "int", beforeSend: function(){ console.log("Please wait..."); }, success: function(d){ console.log (“Success!”); });
test.blade.php – the file to which the data is sent;
POST – type of data transmission;
source: data, len: data.lenght() – the transmitted array and its length;
dataType: "int" – data type;
beforeSend:function(){ console.log("Please wait...");},- when sending data to the console, a message is displayed "Please wait..."
function(d){console.log (“Success!”); }) – if the sending was successful, a message is displayed in the console “Success!”.
```

Views contain HTML code that the application passes to the user. Views are in the resources/views directory.

The Blade Templating Engine template structure was used for this work. It uses special tags and functions to separate view logic and application code. In order to separate the main part of the layout from the content, the content is highlighted with @ section marks (section name). Layout of page templates is done with the usage of layers. A layer is implemented with the <div> tag. Layers are independent of each other. One layer may contain another.

Fig. 4 shows a web page with basic information about indicators of an athlete`s physical state during training. The data collected by system can be effectively used by coach for improving the effectiveness of training for optimal development of athletes.

For individual planning of athletes’ training loads a special environment can be realized based on the fuzzy reasoning model for decision support system [15-16].

For the recommendations formation about the individual combination of intensity, duration and frequency of training for different juniors, knowledge-based recommendation method can be realized that were presented in [17-18].

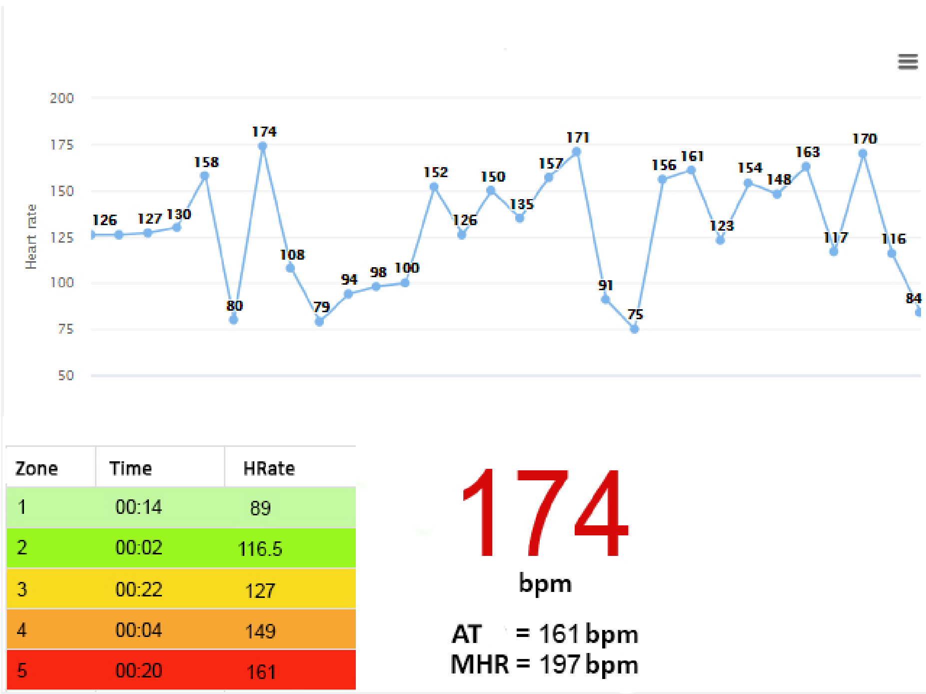

Fig. 4. Form with indicators based on heart rate data

7 Conclusion

Information regarding the health, level of physical development, biological maturation of athletes is evaluated in the framework of an in-depth medical examination by the medical specialists. Nevertheless, dynamic monitoring of the main indicators of athletes' physical state is very important for trainers, as it allows assessing the real state and the level of athlete's functional capabilities.

This work proposes a method for monitoring athletes' state during training based on fuzzy sets of variables. Basic indicators have been identified, which can be judged by the physical loads in training and relative to the athlete's physical development.

Various methods of obtaining data from a fitness bracelet to a web application have been analyzed and the best way to solve the task was found. A web application has been developed that became a part of the management system for training squash athletes.

The scientific novelty of the work lies in the fact that the method of monitoring indicators of athletes` physical state has been further developed through the implementation of the method of reading data from a fitness bracelet with the usage of Web Bluetooth technology.

The practical value of the work is that the implemented method makes it easy to obtain data for monitoring the physical state of athletes directly during training.

In the future, the application requires the implementation of the ability to receive data from multiple devices simultaneously.

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