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The Wearable Electronic Customizable Device for Monitoring Activity Indicators

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Abstract— *Nowadays electronic devices market is constantly changing at a very fast rate. Particularly, the number of devices designed to monitor the parameters of the human body and, especially, activity indicators during sports, is growing dramatically. There are currently too few activity tracking devices on the market that provide extensive customization options. In the present work we propose an innovative wearableelectronic device for monitoring human activity parameters. Novel features of the product that are expected to make it stand out in the market are wide adjustment options and a broad range of attachment possibilities to various accessories. An additional distinctive feature of the product is the activity prediction function. The results of the work contain a working prototype of the basic version of the designed device and a mobile application that is developed to display and control the data collected by the device.*

Keywords— *Activity monitoring, customization, electronic device, fitness tracker, innovation, internet of things, prototype, wearable devices.*

I. Introduction

Smart wearable devices are becoming more and more popular these days, since people start to reconsider their lifestyle, monitor their health and activity parameters. This growth is supported by the general increase in the popularity of smart IoT devices [1]. Covid-19 had an additional positive impact on the wearable electronics market [2]. Furthermore, inrecent years it has become fashionable to adhere to a healthy lifestyle [3], and the presence of a wearable device seems to be one of the main ways to demonstrate this.

The most popular wearable device for monitoring health and activity is a smartwatch [4]. Its popularity is not accidental, as it has many advantages, such as a quick access to notifications and convenient activity tracking [5]. However, smartwatches have plenty of shortcomings. For instance, they have limited battery life [8]. In addition, smartwatches are rather expensive and quickly become obsolete [5]. Consequently, these issues may force customers to look for alternatives. For example, devices such as a fitness tracker and a heart rate belt may be selected by the consumers if they strive to acquire a cheap and high-precision product, respectively [6], [7]. Nevertheless, customers have to spend a large amount of time reviewing a variety of factors before making a purchase decision [9]. In addition, clients do not seem to be able to find a gadget that perfectly meets all their needs. Therefore, they are forced to compromise. As a result, forty-seven percent of smart wearable devices consumers are dissatisfied with their use [10].

The mission of this paper is to create the foundation for a customizable wearable device for activity and health monitoring, which will be user-oriented and will provide customers with a wide freedom of choice. To achieve this, in particular, a novel method of attaching the device will be proposed.

In the present work we implement a prototype of a wearable device for monitoring human body parameters, which is adjustable and modifiable, can be easily attached to different objects, such as sportswear, belts, bracelets, and which has an activity prediction function. Additional factors that make the device highly competitive are compact size, light weight, high reliability level and low power consumption rate.

The rest of the paper is organized as follows. In Section II, similar developments are examined. Section III shows the device structure, explains the device operation. Section IV presents detailed information on the product development process and methods used in it. In Section V, the results of the work are presented, and the ways of device usage are shown. In Section VI further development opportunities are presented. Section VII concludes the paper.

II. Related Work

Along with the exponential growth of the Internet of Things technologies in recent years, the number of articles about smart wearable devices is increasing. In this section, several articles on the latest developments in the field of electronic devices for monitoring human organism parameters are reviewed. The publications considered below were selected based on their level of importance for this work.

The first article is called “Smart Wearable Device for Health Monitoring in the Internet of Things (IoT) Domain” [11]. It contains a detailed description of the device designed by the authors. The proposed product is developed to monitor user activity and detect extraordinary signals that may constitute a warning. The main advantages of the device created by the authors, low cost, and low power consumption, are taken into account when developing the device in the present paper. Moreover, the publication clearly describes the entire architecture of the designed system, and it served as an example of the structure of the device being engineered in the current work.

The next work is related to the main concept of the device being developed in the present paper. It is labelled “Customizable Wearables: Exploring the Design Space of Wearable Technology” [12]. The paper includes detailed information on the classification of techniques for customizing wearable devices. The authors highlight four customization

Volume 6, Issue 5, pp. 32-39, 2022.

methods: functional customization, customization of interaction with the device, location on the body customization, and appearance customization. Customization methods, described by the authors of this article, are used for developing the device in the present paper.

The third work, which is labelled "The Wearable Smart Device for Early Detection of Vital Signs Related to Heart" [13], describes the device proposed by the authors. As stated, the main purpose of the developed prototype is the early detection of vital signs related to the heart. Nevertheless, it is mentioned that it can be used as a fitness tracker as well. The sensors used in the prototype are taken into considerationwhen choosing components for the product in the present work. However, the choice of the microcontroller by theauthors could be considered a disadvantage due to its large dimensions and high-power consumption.

The positive sides of the products reviewed are taken into account in the development of the device in the present project. The drawbacks of the analyzed works are noted, and the goal is set to convert them into advantages when designing a device in current work.

III. Structure of the Proposed System

The basis of the device is a small microcontroller board Tinypico which uses such a widespread chip as ESP32. It provides communication with the monitor via a Bluetooth connection, power to the indicators, as well as communication and power to all connected sensors. In addition to its small dimensions, the board has numerous other advantages such as a low energy usage, LiPo battery management support, a built-in 0.7A 3.3V LDO regulator, which enables the direct plug-in of LiPo batteries; an optimized power path and a Bluetooth Low Energy (BLE) module.

The microcontroller is powered by a 0.5 A h LiPo battery, which provides up to 40 hours of autonomous operation of the device. The choice of battery capacity was made to guarantee the most optimal size and weight of the unit, and, at the same time, the maximum time of autonomous operation of the device. The selected unit has the dimensions of 0.035*0.018 m and weight of 0.012 kg.

To monitor the activity parameters, which are, in the basic version of the device, human body temperature, pulse, oxygen saturation level and the number of steps taken, the following sensors are selected: MPU-6050, MAX30205MTA+ and MAX30100 (from left to the right at the top of the figure 1).

The MAX30205MTA+ body temperature sensor has a measurement accuracy of 0.1 degrees Celsius when measuring temperatures in the range of 36 to 39 degrees Celsius and has overheating protection. The element also supports the I2C protocol, which is used in this project to transfer the collected data to the microcontroller. The sensor has a low supply current – 0.0006 A, as well as a supply voltage in the range from 2.7 V to 3.3 V, which ensures low power consumption. Moreover, the component is small (0.015*0.007 m) and has a light weight (0.008 kg).

The MAX30100 pulse and oxygen saturation sensor has small dimensions and light weight (0.015*0.01 m and 0.0115 kg respectively), an optimized and programmable power supply circuit, which makes it possible to save the maximum amount of energy. The operating voltage range for the component is 1.8 - 3.3 V. The operating current of the element is 0.0006 A. The high ratio of signal power to noise power provides reliable resistance of the sensor to motion artifacts. To ensure the accuracy of measurements, the component has an embedded suppression of scattered light.

The MPU6050 accelerometer, as well as the other devices used, supports the I2C protocol. Thanks to the built-in FIFO buffer, the processor consumes less electrical power. For signal processing, the sensor has a built-in low-pass filter. The operating voltage of the sensor is in the range of 3 to 5 V, the operating current of the power supply is 0.0005 A. The size of the module is relatively compact: 0.015*0.025 m, the weight is also small – 0.015 kg.

The I2C protocol is organized according to the following scheme: 1-Master, 3-Slaves, which means that three slave sensors obey the commands of the master device – microcontroller. Each sensor is connected to Serial Data (SDA) and Serial Clock (SCL) bidirectional communication lines, as well as to the power source and to the ground.

To transfer the data collected by the device to the mobile application, the Bluetooth Low Energy module is used. It provides energy-efficient and cost-effective wireless communication between the devices. The small dimensions of the BLE module contribute to its use in compact electronic devices.

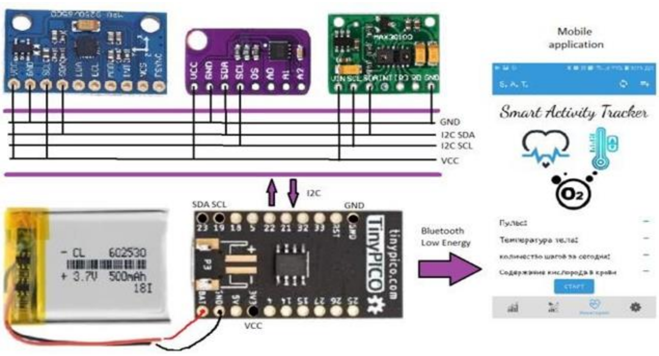

Fig. 1. The structure of the device

IV. Methods & Development Process

This section of the article explains the stages of product development and the methods used.

The implementation of the product consists of the following eight phases.

A. *Overview of existing alternatives*

At the first stage, wearable electronic devices for monitoring human body parameters that exist on a market are considered and their characteristics are reviewed. The analysis made is based on the collected information from the world's biggest online marketplaces: AliExpress, Amazon, and eBay.

In addition, information gathered from several articles on resources such as ResearchGate and Google Scholar is used for the review. The conducted research highlights the features of

Volume 6, Issue 5, pp. 32-39, 2022.

various devices, the advantages, and disadvantages of each type, and determines the level of satisfaction of consumers based on reviews left on marketplaces. At the end of this stage, conclusions about the needs of customers are drawn, and the relevance of the present project is confirmed.

B. Choosing components and development tools

In the second part of the work, the components, materials, communication protocols, and development tools are selected. When choosing components, the following factors are considered: cost, quality, reliability, parameters (size, weight, etc.), accessibility, and the possibility of integration with other parts. The selected components are shown in the previous section. The development tools are selected based on the usability and functionality of each application. In this project the following software products were used: EasyEDA, SolidWorks, Arduino IDE, Android Studio.

C. Electrical schematic diagram and printed circuit assembly development

At this stage, the device designing process starts. As the first step, the Electrical Schematic Diagram (figure 2, Appendix A) and Printed Circuit Assembly (PCA, figure 3) are created.

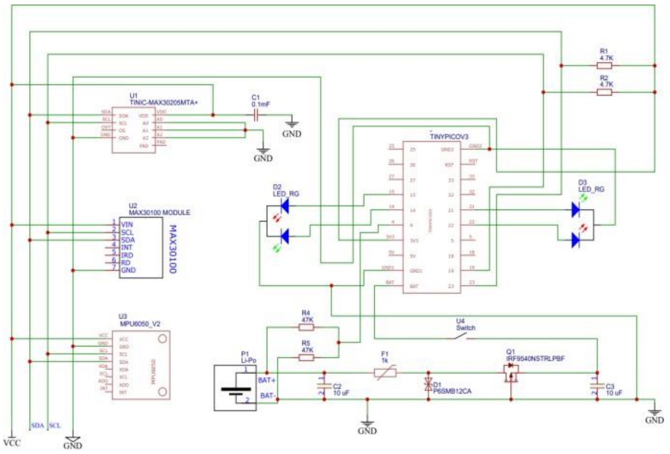

Fig. 2. Electrical Schematic Diagram

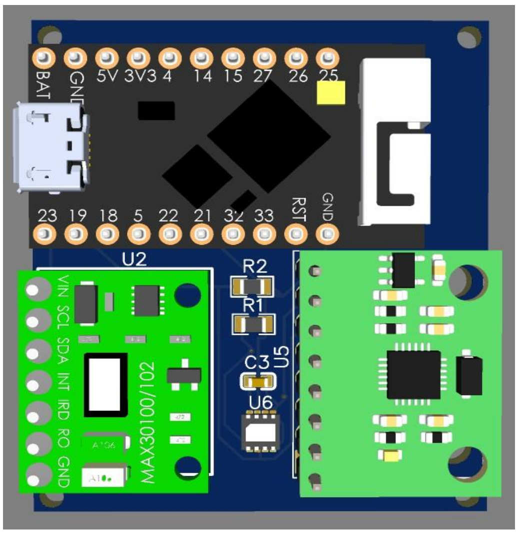

Fig. 3. 3D view of Printed Circuit Assembly

At this step, the printed circuit board (PCB) is traced in two layers as well (the result can be viewed in Appendix B). The dimensions of the PCB printed circuit board are 0.038 * 0.045 m, the thickness of the board is 0.0015 m, the height of the highest component is 0.009 m. PCA material is a foiled fiberglass FR4. The weight of the printed circuit board is 0.0055 kg. The total weight of printed circuit assembly is 0.0213 kg.

The created electrical circuit contains reverse polarity and overvoltage protection.

In this part of the project, the hardware logic of the device is formed. Moreover, at this stage, the compatibility of the components is checked and, if necessary, some parts are replaced. This step is carried out in the EasyEDA cloud-based software tool.

D. 3D modeling

This part of the work represents the development of the case of the device. Taking into consideration the work accomplished in the previous steps, a 3D model of the product is designed. It is implemented using the SolidWorks computer-aided design computer program.

As a result, a 3D model of the case (figure 4, figure 5) and a 3D model of the case with PCA inside (figure 6) were obtained. ABS plastic was chosen as the material of the case of the device because it has high impact resistance and is also the most optimal material for 3D printing. The model contains many special parts that make it possible to attach the device to various accessories, which are taken into consideration in details in section V. To turn the device on or off, there is a button on the side of the case with the corresponding indicator to the right of it (which lights up and saves this state when the device is turned on and goes out when the device turns off).

Fig. 4. The case of the device. Bottom view

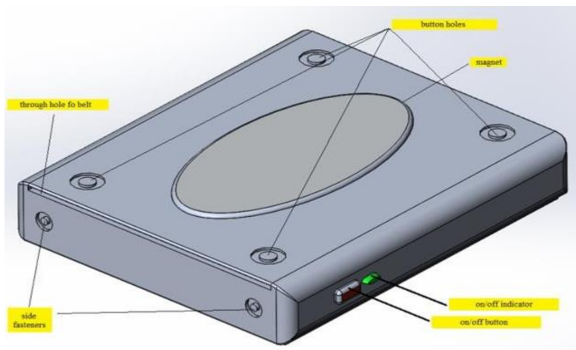

Fig. 5. The case of the device. Top view

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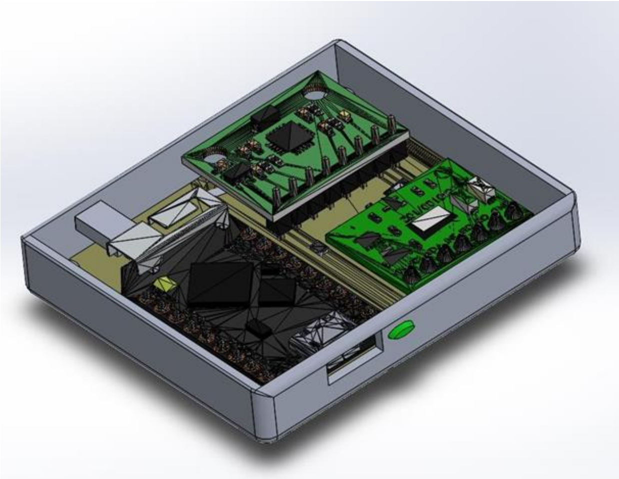


Fig. 6. The case of the device with PCA inside

To charge the battery of the device, a Micro USB-B connector is provided with a corresponding indicator next to it.

The dimensions of the construction are as follows: 0.048*0.041*0.014 m. It makes the device competitive in terms of size and usability.

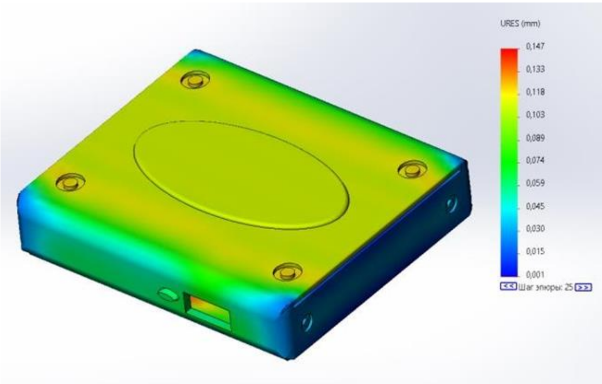


Fig. 7. The resulting displacement. Direct impact.

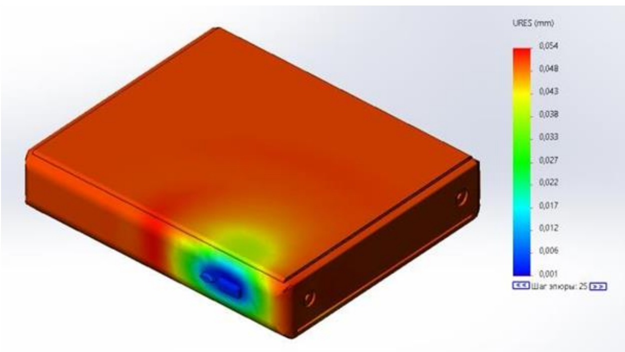


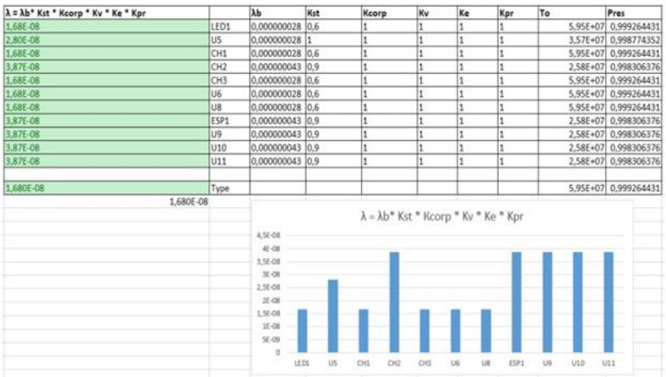
Fig. 8. The resulting displacement. Lateral impact.

The case has been tested for durability. As a result of the analyses carried out by the simulation of direct and lateral impacts when falling from a height of 1 meter, it was found that the case is sufficiently strong. According to the resulting displacement graph obtained in the Solidworks program, the deformation distribution of the body is uniform, the maximum displacement is no more than 150 microns with a direct impact (figure 7), and no more than 55 microns with a lateral one (figure 8); which are insignificant values. The average safety margin coefficient is 7, which means that the construction can withstand a load 7 times greater than the calculated one.

E. Device reliability calculation

This step is performed to calculate the service life of the device and the probability of any failure. The calculations are performed according to the formulas specified in GOST PB 20.304 standard.

When calculating the reliability indicators of the device, the features of each component are taken into account, as well as the currents in the circuit, the voltages in its nodes and the power allocated to its elements. For each element, the probability of the uptime of the operation is calculated, which depends on its class, parameters, and position in the electrical circuit.



λ = λb* Kst * Kcorp * Kv * Ke * Kpr		λb	Kst	Kcorp	Kv	Ke	Kpr	To	Pres
1,68E-08	LED1	0,000000028	0,6	1	1	1	1	5,95E+07	0,999264431
2,80E-08	U5	0,000000028	1	1	1	1	1	3,57E+07	0,998774352
1,68E-08	CH1	0,000000028	0,6	1	1	1	1	5,95E+07	0,999264431
3,87E-08	CH2	0,000000043	0,9	1	1	1	1	2,58E+07	0,998306376
1,68E-08	CH3	0,000000028	0,6	1	1	1	1	5,95E+07	0,999264431
1,68E-08	U6	0,000000028	0,6	1	1	1	1	5,95E+07	0,999264431
1,68E-08	U8	0,000000028	0,6	1	1	1	1	5,95E+07	0,999264431
3,87E-08	ESP1	0,000000043	0,9	1	1	1	1	2,58E+07	0,998306376
3,87E-08	U9	0,000000043	0,9	1	1	1	1	2,58E+07	0,998306376
3,87E-08	U10	0,000000043	0,9	1	1	1	1	2,58E+07	0,998306376
3,87E-08	U11	0,000000043	0,9	1	1	1	1	2,58E+07	0,998306376
1,680E-08	Type							5,95E+07	0,999264431
1,680E-08									

Fig. 9. Uptime probability calculation for integrated circuits class

In the figure 9 the example of uptime probability calculation for elements of integrated circuits class is provided. The result is presented in the first (failure rate) and the last (uptime probability) column of the table shown in the figure. The graph shows the distribution of calculated indicators by components. Computations are carried out for each class of elements, and then the obtained values are summarized, and the overall reliability indicators for the entire device are calculated.

The calculations have shown that the service life of the device is at least 5 years, and the probability of its trouble-free operation during this time is 99.8%.

F. Creating a device operation algorithm

At this stage, the software logic of the device is formed. This is implemented using the software tool called Arduino Integrated Development Environment. The algorithm is written using the C programming language. The operability of the created program is validated by loading it into a microcontroller. Sensors that determine the main functionality of the device are connected to the microcontroller, and their readings help determine the correctness of the functioning of the algorithm. The check is carried out manually under conditions close to the actual operating conditions of the product. After several tests in the real environment, the algorithm is improved and adjusted.

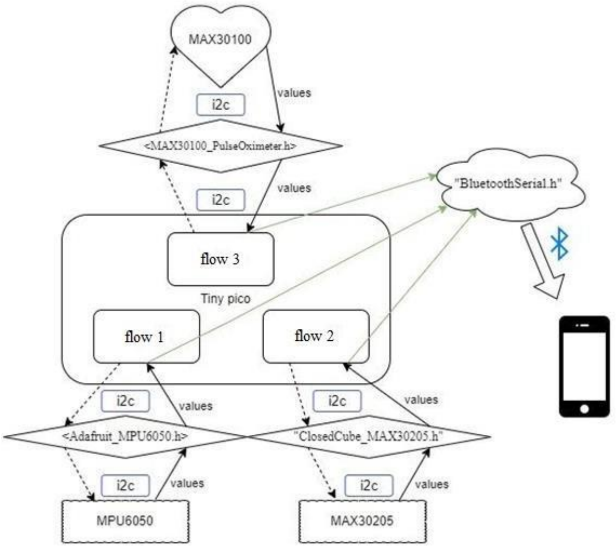


Fig. 10. The block diagram of an algorithm

The block diagram of the developed algorithm, which demonstrates the organization of data communication between the device elements, used libraries and protocols, is shown in figure 10.

G. Mobile application development

This part of the work is performed in the Android Studio Integrated Development Environment.

The code is written using the Kotlin programming language. Data from the microcontroller is transmitted to the application via Bluetooth wireless technology standards. The mobile application provides complete data on the parameters of the human body in real-time and saves it every second to the database, where the statistics can be viewed at any time. The predicted parameters are provided as well. Linear regression is used as the main forecasting method. To eliminate noise, the method of minimizing the square of errors is used.

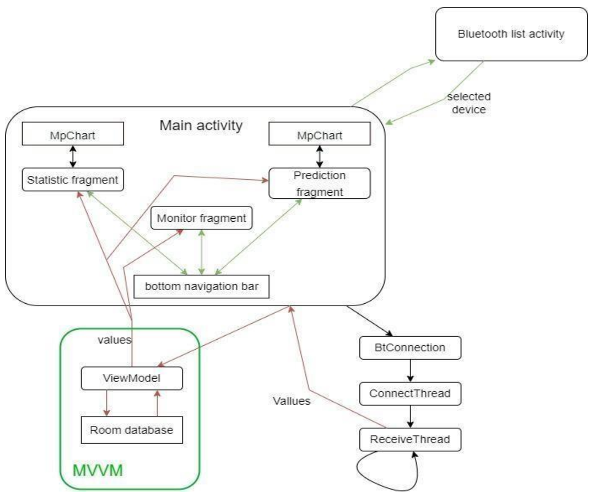


Fig. 11. Mobile application structure

The mobile application structure is shown in figure 11. This flowchart reflects all the technologies, libraries, patterns, and entities used in the development process.

H. Creating a prototype and testing

At the final stage, the prototype of the device is assembled. This is implemented by combining the results of the work carried out in the previous stages.

The Printed Circuit Assembly, which was obtained on step 3, is made by soldering the components onto the Printed Circuit Board. After it, the PCB is traced on its reverse side with the use of wire solder to form tracks. The battery is also attached to the manufactured prototype from the bottom side. The on/off switch is soldered to the corner of the PCB. The position of the components is optimized to ensure the small size of the module, as well as for the convenience of its testing.

The created prototype is depicted in figure 12.

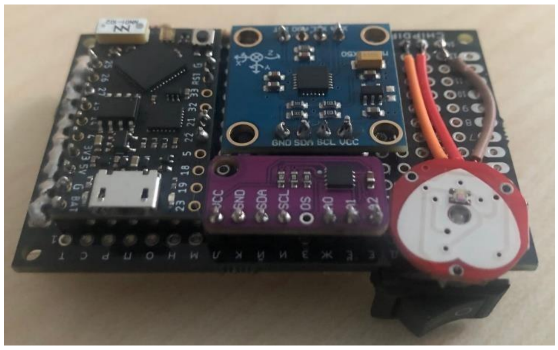


Fig. 12. The prototype of the device

The software is loaded into the prototype via a Micro- USB-B cable that connects the microcontroller to an Arduino IDE installed on a PC or a laptop. As soon as the algorithm is loaded into the microcontroller, the prototype is ready for use. There is no need to re-load the software to the board before the next period of use unless the user wants to update the firmware.

The testing process revealed minor drawbacks in the device operation algorithm and in the tracing of PCB, which were subsequently eliminated. After it the prototype demonstrated the correct operation. More information on the results of testing can be found in section V.

V. RESULTS

As a result of this work, a working prototype of a basic version of an electronic wearable device for monitoring human activity parameters, a ready-to-print 3D model of the case of the device, a mobile application that will be used to control and display the data collected from it, were obtained. The main features of the device are extensive customization options and convenient attachment to various elements of clothes. The distinctive characteristics of the product are the simplicity of construction, high reliability level, and low power consumption.

The version of the device developed in this work can monitor such activity indicators as a heart rate, body temperature and is able to count the number of steps taken.

As can be seen from the figure 4 and figure 5, the case of the device has a lot of fastening capabilities to different accessories. It has 2 through holes for attaching belts of various thickness, 4 buttonholes and 4 side fasteners for attaching any piece of clothing that have buttons, and a light (11 g) neodymium magnet for fixing the device on the inside of sportswear.

Figure 13 shows the possible places on the human body to place the device, however, the actual placement options are not limited to those depicted below. Nevertheless, it is recommended to wear the device on any part of the arm or chest to maintain the high measurement accuracy.

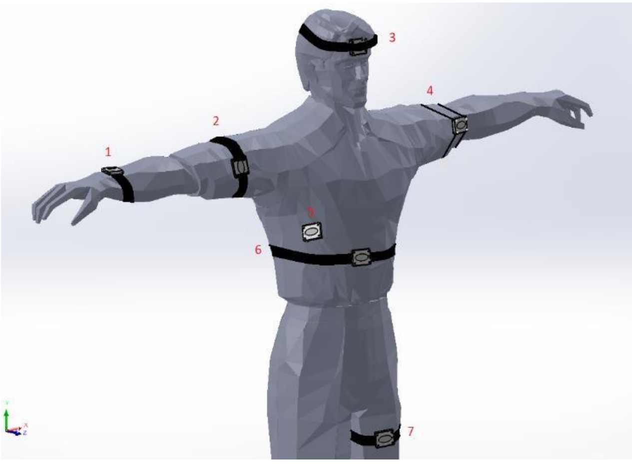


Fig. 13. Recommended attachment places on the body

To use the created prototype, first, it must be turned on by pressing the switch button. When it is enabled, the corresponding LEDs on a microcontroller and a pulse sensor light up, as shown in figure 14.

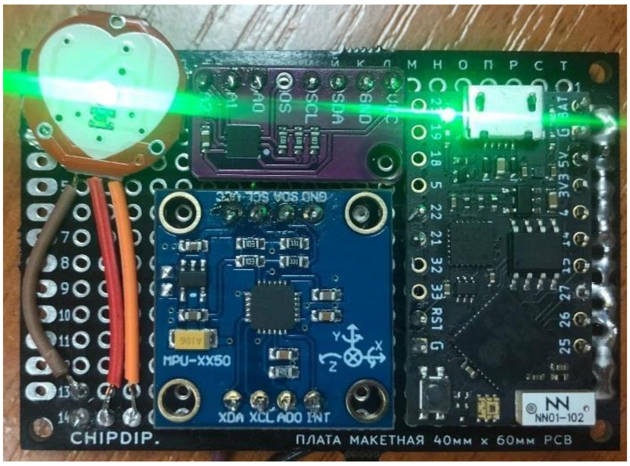


Fig. 14. The prototype in the enabled state

After that, it is necessary to place the device on the body using any desired accessory and install the connection with a mobile application.

To do this, a mobile app should be opened, and the icon marked “1” in figure 15 should be clicked. Then, from the list of Bluetooth devices that appears, SmartActivityTracker should be selected. Finally, the icon marked “2” in the figure 15 should be pushed to install the connection.

Once the connection is set, the measurements can be started via clicking the “Start” button.

To stop the use of the device, the “Stop” button should be pressed. To view the statistics or activity forecast, it is needed to be switched to the corresponding tab using the lower navigation menu (the icons marked “5” and “6” in figure 15). The interface of both tabs can be found in Appendix C.

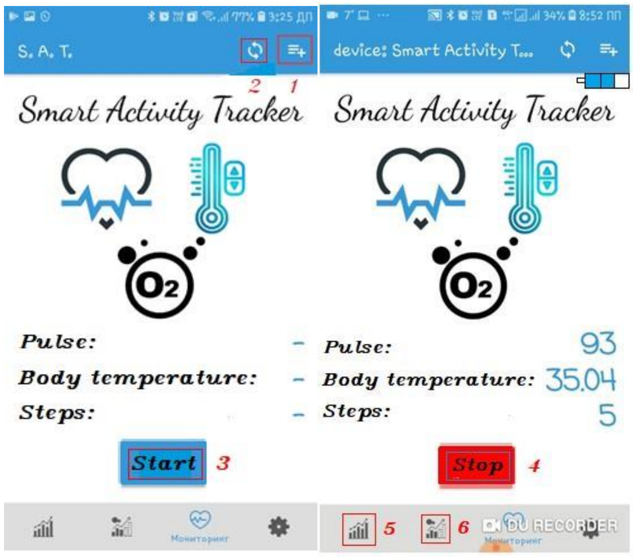


Fig. 15. Interaction with mobile application

To check the performance of the developed prototype, 10 tests were conducted under various conditions, when running and when at rest. The results were compared with the reference device, as which Garmin Instinct was taken. The goal of testing was to show the effectiveness of the developed device in comparison with the reference one, and any other professional product could have been taken for this occasion.

According to the test results, the average measurementerror of the parameters does not exceed 2%. Moreover, measurement errors are minimized with an increase in the timeof use of the device. When using the device for 1 minute, the measurement error of pulse sensor was 1.9%, body temperature sensor - 0.27%, accelerometer - 1.79%. When the testing period was 5 minutes, the measurement error was, for pulse - 0.75%, for body temperature - 0.09%, for the number of steps completed - 0.41%. Therefore, the correct operability of the device and the competitiveness in measurements were confirmed.

Customization Options

The design of the device was developed taking into account the possibilities of its adjustment. The 3D model of the case was created in Solidworks software tool as a solid body; hence, it is scalable, i.e. its dimensions can be uniformly reduced or increased if necessary. It makes it possible to add more or, on the contrary, minimize the number of sensors and other electronic components inside the device. This opportunity broadens the functionality and applicability options of the developed product. For example, by replacing the heart rate sensor and body temperature sensor with more accurate ones, the device can be used for medical purposes.

Customization applies to the developed mobile application as well. Upon the final completion of the product development, a wide range of its variations will be created. As a paid service

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in the developed mobile application, the client will be able to indicate their preferences regarding the use of the product. The customer will be able to specify both the desired design and the characteristics and functionality of the device.

Furthermore, the flat front panel of the device makes it possible to install a screen on it, thereby turning the device into a smartwatch or a fitness tracker.

VI. Further Work

The product proposed in this article is still incomplete and is only a prototype of the basic version of the device. Therefore, first of all, it is planned to complete work on the product to make it valuable enough to bring to the market. A significant work needs to be done to add various design options and features. As for the basic version of the product, the design of it should be optimized and improved, as well as the data forecasting methods should be ameliorated. The first copy of the device can be put up for sale after completion of the mentioned improvement processes.

It is also planned to update the created device by adding new functions to the mobile application, increasing its usability, improving its reliability, accuracy of measuring activity indicators and other characteristics, as well as adding the ability to monitor more activity parameters. It is also vital to improve the product on a permanent basis. For instance, the number of customization options should be constantly growing.

To make the device more user-centered, it is planned to create a special website that will describe the product and the possibilities of its customization, as well as contain a description of the entire wide range of device features provided to customers.

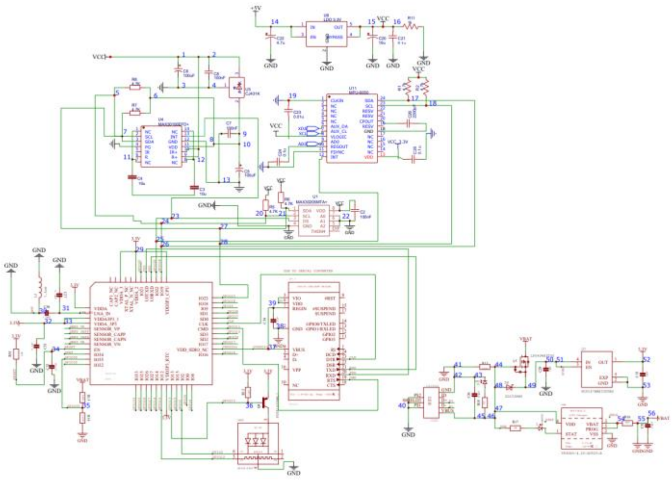
In addition, it is essential to conduct more tests of the device in a real environment to ensure its reliability, the correct functioning, and to get the feedback from the first users. Based on customer reviews, the product will be improved, and possible flaws will be eliminated.

VII. Conclusion

The rapidly developing technologies of the Internet of Things, as well as the growing market for smart things and electronics, bring a lot of opportunities for creating innovations. The present project attempted to create an innovative device that will be in great demand among fans of tracking the parameters of their body. The developed product allows consumers to choose numerous functions and parameters of the device according to their desires. We expect that this feature will help the product stand out significantly in the market.

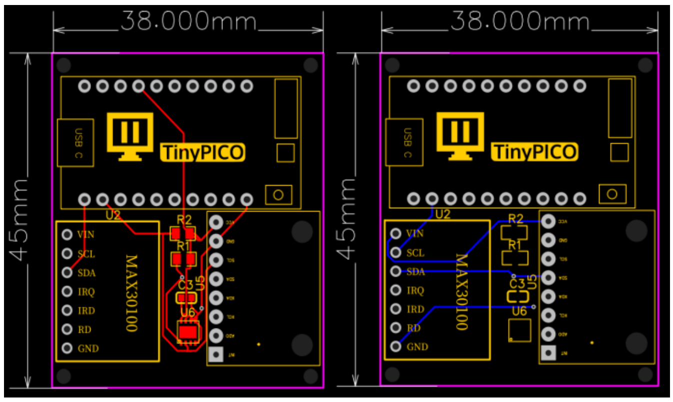
Moreover, the ability to attach to different elements of clothes will make the device more attractive to clients. High reliability level and low energy consumption will contribute to user satisfaction with the device. We expect that due to the increasing degree of production mobility and the development of 3D printing technologies, the future belongs to extensively customized products and, consequently, the device developed in this work, will not become obsolete.

Appendix A



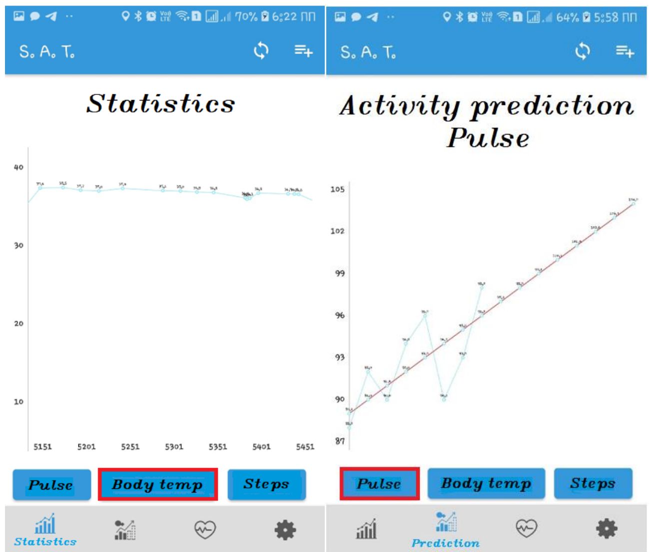
Full Electrical Schematic Diagram

Appendix B



Tracing of the PCB on the upper (on the left) and lower (on the right) layers

Appendix C



Statistics and Activity Prediction menus in a mobile application

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