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"Smart clothing" wearable for vital signs monitoring

Streszczenie. *Autorzy niniejszego artykułu skupili się na monitorowaniu temperatury ciała , tętna oraz poziomu napięcia mięśniowego. Do wytworzenia urządzenia monitorującego wyżej wymienione parametry życiowe wykorzystano mikrokontroler ESP8266, pulsometr SparkFUN MAX30105, czujnik napięcia mięśniowego MyoWearMuscle sensor, czujnik temperatury DS18B20. Autorzy wykonali również testy wytworzonego przez siebie rozwiązania. Testy zbudowanego systemu wykazały poprawność działania systemu. Należy mieć na uwadze, że przedstawiony w niniejszym artykule system do monitorowania parametrów życiowych jest jedynie wersją prototypową, ukazującą możliwości i potencjał projektu.*

Abstract*. The authors of this article focused on monitoring body temperature, heart rate, and muscle tone. The ESP8266 microcontroller, SparkFUN MAX30105 heart rate monitor, MyoWearMuscle sensor, DS18B20 temperature sensor were used to produce the monitoring device for the abovementioned vital signs. The authors also performed tests of the developed solution. Tests of the constructed system showed the correct operation of the system. It should be borne in mind that the vital signs monitoring system presented in this article is only a prototype version, showing the possibilities and potential of the project. (****Odzież „Smart" do monitorowania parametrów życiowych****)*

Słowa kluczowe: inteligentna odzież, mikrokontroler ESP8266, urządzenie monitorujące parametry życiowe, tętno, napięcie mięśniowe.
Keywords: smart clothing, ESP8266 microcontroller, vital signs monitoring device, heart rate, muscle tension, temperature

1. The need for human vital signs monitoring

Modern medicine has established specific standards and procedures, which depend on patients' recorded vital signs. These procedures are very important in situations of deteriorating patient health in hospital emergency rooms or during recovery (e.g. after surgery) [2]. However, current technology enables continuous monitoring of various vital signs, such as:

- pulse;
- body temperature;
- muscle tension;
- respiration;
- blood pressure.

The data collected from these measurements can facilitate an early response to a patient's deteriorating condition, reducing the risk of death [9,10].

2. Primary vital signs

The authors of this paper focused on monitoring the three primary human vital signs mentioned in the previous section of the paper. A brief description of basic human vital signs is provided below.

2.1. Body temperature

Body temperature is a measure of human body heat. A nominal value of body temperature is 36.6°C, and temperature can change depending on various factors, such as:

- performed work;
- physical effort;
- weather;
- consumed meal;
- illness.

Human body temperature changes from its nominal value depending on the time of day. Typically, it is lower between 11 PM and 3 AM than between 10 AM and 6 PM [2].

Temperature is measured using thermometers. Body temperature measurements are important in medicine, since changes in body temperature are a symptom of many illnesses. Furthermore, constant temperature measurement can be used to monitor the course of many illnesses, and consequently to react with appropriate treatment as required. Fever is the body's response to specific stimuli of the illness, and the increase in body temperature depends on the body's needs while it tries to defend itself against an illness. In fact, a fever is the most common immune response of a human body [2].

2.2. Pulse

Heart rate, otherwise referred to as pulse, is the movement of blood vessels caused by contractions of the heart muscle. A person's heart rate depends primarily on their age and physiological state. We distinguish between a resting heart rate and a maximum heart rate.

The maximum heart rate is the highest number of heart beats per minute allowed. It is calculated by subtracting a person's age from the number 220.

The normal human resting heart rate is:

- for a fetus, 110-150 heartbeats per minute (bpm);
- for an infant, 130 bpm;
- for a child, 100 bpm;
- for teens, 85 bpm;
- for an adult, 70 bpm;
- for elderly persons, 60 bpm.

Pulse is measured at the circumference of the brachial artery (at the wrist) or the carotid artery (at the side of the neck) [2,8].

2.3. Arterial blood pressure

Arterial blood pressure describes the force of blood flow against the walls of an artery. Each heartbeat pumps a portion of blood into the arterial vessels, supplying the body's internal organs with needed nutrients and oxygen. At the same time, deoxygenated blood, which contains carbon dioxide taken from the cells after converting sugars into energy, returns to the heart through the venous vessels.

The maximum blood pressure is called systolic pressure, and the minimum blood pressure is called diastolic pressure. Normal blood pressure is 120/80 mmHg (millimeters of the mercury column). In a healthy body, this value increases during exercise or stress, and decreases during sleep. This value also depends on a person's age and their state of health [2].

2.4 Respiration

Breathing is a reflex action, in which a human body rhythmically draws in oxygen from the air into the lungs, and expels carbon dioxide into the environment. An adult typically breathes about 10-12 times per minute. Normal breathing is calm, deep and slow. Air should be inhaled through the nose and exhaled through the mouth. The respiratory rate of a person depends on their age, physical exertion, as well as health [1].

3. Data acquisition

Vital signs data acquisition can be divided into four stages:

- phenomenon isolation;
- sensor data registration;
- transmission of recorded signal;
- signal processing.

According to the requirements of the PN-EN 60601-1-4:2006 standard [3], data recording and its transmission must be performed in a manner that is safe for humans. This means that these processes must not cause adverse effects or endanger the life of the person being monitored.

All stages of the vital signs acquisition process are handled by the device, the design of which presented in the next part of the article, in the form of a block diagram, a schematic diagram and the description of the software algorithm responsible for controlling the device. Due to the small size of the device, it can be integrated into the clothing worn by the person being monitored.

4. Design of the human vital signs monitoring device

A block diagram of the human vital signs monitoring device is presented in Figure 1. This device is capable of monitoring the values of:

- body temperature;
- pulse;
- muscle tension.

A thermometer is used to measure body temperature. This device must be accurate and small enough so as to be easily attached to clothing, while not hindering the user's movements.

Heart rate is measured using a pulse oximeter that works on the principle of photoplethysmography. This is a non-invasive method, so the person being monitored does not feel any discomfort during the heart rate measurement process. This method requires illumination of the part of the body being tested, such as the tip of the ear or finger. In the developed device, the heart rate monitor is mounted on the tip of the ear, so as to not impair the wearer’s motor functions – in contrast to situations. in which the heart rate monitor is placed on a finger.

An EMG (electromyograph) sensor is used to measure muscle tension, which is designed to collect information about the tension of the monitored muscle. For technological reasons, in order to ensure that the system is as small as possible, and an off-the-shelf sensor made by SparkFUN was used for this purpose.

Sensor control and information control is handled by the Amica NodeMCU ESP8266 microcontroller.

The collected sensor data is sent to an external server through a built-in WiFi module. The use of wireless communication significantly increases the comfort of the wearer, and reduces the total price of the vital signs monitoring system.

The monitoring system was designed to be powered by a powerbank. The design forgoes a standard lithium-polymer battery in the interest of wearer’s safety, and to increase the convenience of operating the system.

The software responsible for controlling the operation of the monitoring system is designed to publish and update the measurement data on a webpage, which can be accessed by an authorized user. Data from the website can be read with the help of e.g. an Android-based phone with a dedicated app. The purpose of this application is to retrieve information the aforementioned webpage and display it in a clear way.

The sensors, microcontroller, and the Wi-Fi module are attached to the wearer's clothing (in this case, a T-shirt).

The EMG sensor is analog, and therefore should be connected to the analog pins of the microcontroller. The heart rate monitor and thermometer should be connected the digital pins of the ESP board. Signals from the EMG sensor, heart rate monitor and thermometer are transmitted to the microcontroller via shielded cables. The microcontroller processes the received information using an algorithm described in the next section of the article.

The processed information is sent via the WI-FI module and placed on a HTTP server, which in turn can be accessed with a dedicated app capable of visualizing the data collected on that server.

Table 1 lists the components required to build the monitoring system. The schematic diagram of the monitoring system is presented on Fig. 2

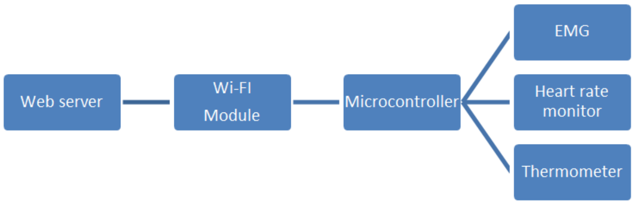

Fig. 1. Block diagram of the human vital signs monitoring system

Table 1. List of structural elements of the life functions monitoring system

No.	Component name
1.	ESP8266 microcontroller
2.	Heart rate monitor SparkFUN MAX30105 pulse oximeter
3.	MyoWearMuscle Sensor
4.	DS18B20 temperature sensor
5.	Vakoss TP-2574B powerbank

The ESP 8266 microcontroller is tasked with processing the received information read from connected sensors, and uploading it to the website via the Wi-Fi module.

The microcontroller chip and the Wi-Fi module are powered by a powerbank, which is connected to the USB connector of the microcontroller.

The heart rate monitor is based on the MAX30105 circuit (U1), connected to adjacent electrical circuits as follows. The ground plane of the components must be connected to the ground of the ESP controller board. The circuit is powered from the microcontroller 5 V power supply pin. The SDA signal should be connected to pin D2 on the board, and the SCL signal should be connected to pin D1.

The ground of the temperature sensor (U2) should be connected to the microcontroller’s ground as well, while the power input VDD should be connected to a 5 V supply pin on the microcontroller. DQ pin should be connected to pin D4; pins DQ and VDD must connected to each other using a resistor R1= 4.7 kΩ.

The SIG output of the EMG muscle tension measurement sensor (U3) should be connected to the A0 pin of the microcontroller. This circuit is powered from the microcontroller 3.3 V power supply pin. The ground pin of the sensor is connected to the ground of the microcontroller board.

The monitoring system is integrated with a single piece of clothing made out of two separate t-shirts. The first t-shirt functions as a mounting surface, to which the sensors are attached, while the second shirt provides both weather protection and aesthetic covering (Fig. 3). Both t-shirt layers are fastened together using velcro strips.

The main electronics are located in a pocket sewn to the back of the shirt (Fig. 4). The left pocket holds the powerbank, while the right pocket holds the ESP microcontroller and the WiFi module.

The thermometer is located under the left sleeve. The pulse oximeter wiring is run through the collar hole, and to the left or right ear of the monitored person. The EMG sensor was brought out to the right side.

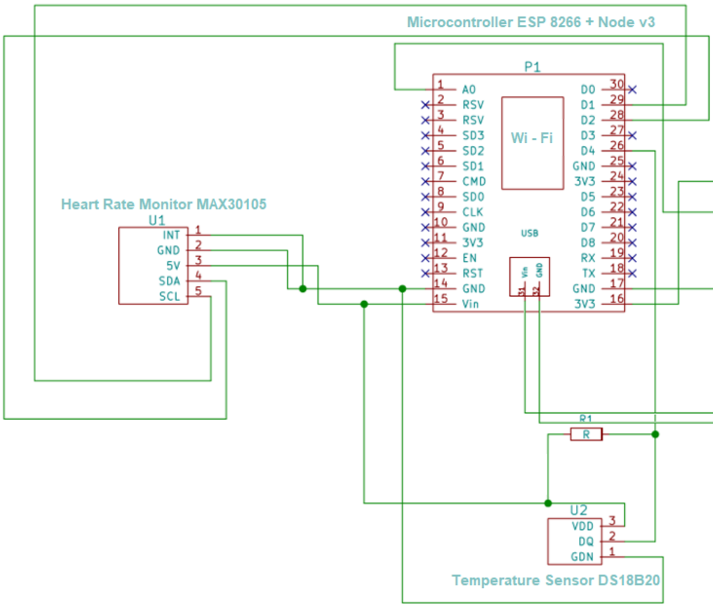

Fig.2. Schematic diagram of the human vital signs monitoring system

Fig. 3. The designed system

Fig. 4. Final system

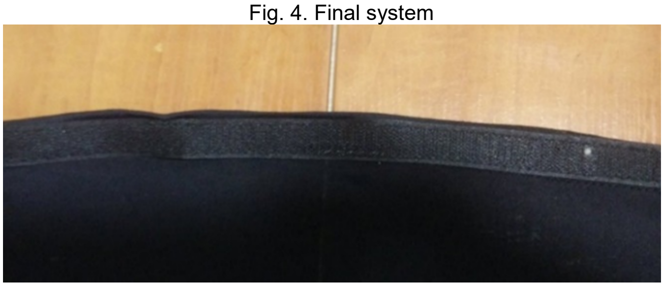

Fig. 5. Velcro strips used to fasten the two t-shirts together.

5. Software algorithm controlling the operation of the monitoring system

The software algorithm controlling the monitoring system should operate as fast as possible, and must minimize erroneous data collected from the measurement sensors.

The algorithm begins by creating a server to store the data read from the sensors. Next, the algorithm checks whether the Wi-Fi module is functioning correctly, and whether the sensors are properly connected to the body and the microcontroller. Once this is done, the algorithm initiates data acquisition from the sensors and processes the received information.

In the case of the heart rate monitor, the value of the voltage read from the pulse oximeter is variable and depends on the number of heartbeats per minute. In this case, to ensure correct visualization, pulse oximeter measurements are averaged to avoid recording extreme values due to the inaccuracy of the sensor.

The microcontroller takes data from the EMG sensor and converts it to degrees Celsius.

When the module hangs, and when the application is not able to retrieve data, the algorithm is tasked with restarting the Wi-Fi chip.

The received and processed data are visualized using an application for Android phones.

6. Software displaying measurement results

An application for Android phone has been developed to display the collected measurement information. Fig. 7 shows the startup screen with the application name – "Fenek". The application’s menu was presented on Fig. 8 The options in the upper right corner of the screen allow the user to connect to a vital signs monitoring device built into the garment, and allow them to read the values collected from the sensors.

Fig. 9 shows an example presentation of the measurement results for a period of 250 seconds. During the measurements, the monitored person tensed their muscles of the right hand (held a book tightly) for approximately 170 seconds, and loosened them at the 200th second of the measurement. The pulse rate of the monitored person was 65.09 BPM. Body temperature was recorded as 36.7℃.

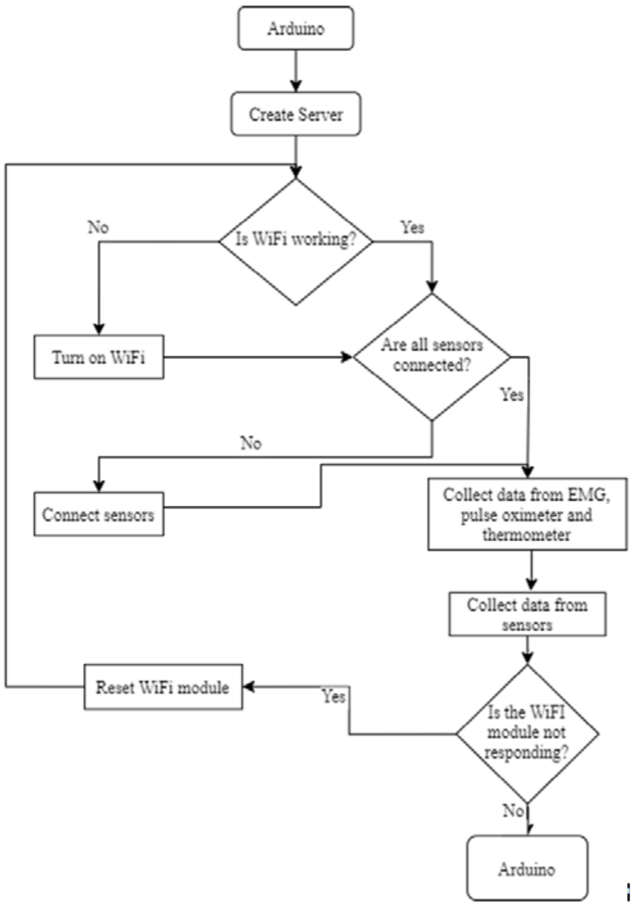

Fig. 6. Software algorithm controlling the operation of the monitoring system

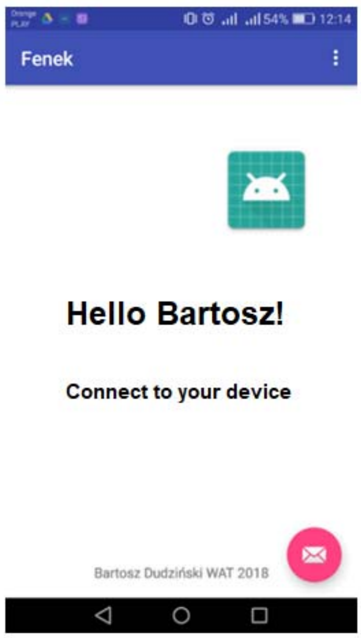

Fig. 7. Application start screen

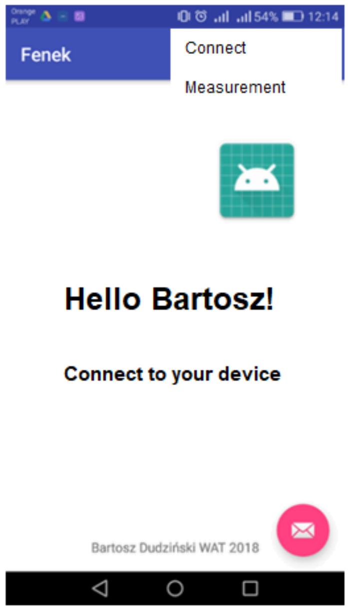

Fig. 8. Application menu

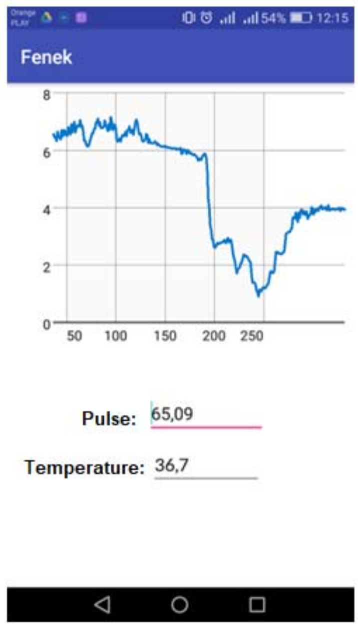

Fig. 9. Presentation of measurement results over a period of 250 seconds

7. Conclusions

The tests of the constructed vital signs monitoring system have demonstrated that the assembly operates correctly. It should be kept in mind that the presented version of the vital signs monitoring system is only a prototype built to demonstrate the capabilities and potential of the project.

In order to improve the functionality of the system, the number of EMG sensors should be increased, a more accurate temperature sensor and pulse oximeter should be used, and a dedicated microcontroller should be designed to optimize connectivity and handling of the required medical sensors.

The designed system can also be expanded with additional medical functions such as sugar level measurement or ECG measurement.

The device may also be fitted with a gyroscope and an accelerometer to the device, to provide feedback in case of the monitored person falls down. This information would be useful especially in elderly care, where a fall can cause serious health problems and even lead to death.

Ideally, electrical pathways would need to be embedded in the material of the smart clothing, appropriately protected from external factors, such as water and temperature.

The program code can be supplemented with an algorithm responsible for alerting appropriate emergency service if a life threatening event is detected, so an ambulance can be summoned as quickly as possible in order to minimize the damage to health and increase the response time of medical assistance.

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