Development of the Electronic Circuit and Printed Circuit Board for the Breathing Simulator

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Abstract

Due to the COVID-19 pandemic, the field of Internet of Medical Things (IoMT), which combines Internet of Things (IoT) technologies and medical devices, has recently received significant development. The paper provides an overview of some successful IoMT projects implemented in recent years, including solutions related to the functioning of the human respiratory system. One of the difficult issues facing medicine now is the rehabilitation of patients who have suffered from COVID-19, and in particular, those who have problems with the respiratory system. The project "Development of a software and hardware complex for monitoring and correcting respiratory functions based on multimodule technologies" is aimed at developing a modern breathing simulator with the ability to monitor the patient's body parameters and use the obtained data to further improve the rehabilitation process. This work discusses in detail the development of an electronic circuit for the breathing simulator of this project.

Keywords

IoMT, Raspberry PI Zero, electronic circuit, printed circuit board, breathing simulator

1. Introduction

IoT is currently one of the most relevant and rapidly developing areas. IoT occupies a special position in medicine, and the special term "IoMT" (Internet of Medical Things) is even used to refer to IoT in healthcare, meaning the combination of IoT technologies and medical devices [1]. The difficult challenges facing medicine during the COVID-19 pandemic have given impetus to even greater development of IoMT. According to the following article [2], the global market of IoMT was valued at 159.51 billion USD in 2022 and, moreover, it is expected to reach over 800 billion USD in 2030. This work [3] presents a detailed study of the use of IoMT systems during the pandemic. According to this study, IoMT projects during the pandemic solved problems such as detection, tracking, monitoring, prediction, record and others.

Moreover, the combination of such areas as IoT and artificial intelligence provides the most effective solutions. The authors of the study [4] consider the combination of these two technologies under the name AI-IoT and provide a classification of AI-IoT technologies in the context of the COVID-19 pandemic. The following works [5, 6] present examples of systems that monitor the patient's condition according to the main indicators of the body and use the obtained data for further analysis. The authors of the projects [7, 8] proposed the use of IoT technologies in protective masks to solve problems that are relevant during the pandemic. The examples of successful projects above confirm the effectiveness of introducing new technologies to solve medical problems.

One of the most important medical tasks at the moment is the rehabilitation of patients who have suffered from COVID-19, in particular people with problems with the respiratory system. The use of IoT technologies to solve such a problem can improve the rehabilitation process of such patients and achieve more effective results. As part of the project "Development of a

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software and hardware complex for monitoring and correcting respiratory functions based on multimodule technologies", which is presented in this work, the breathing simulator with real-time monitoring of the patient's body parameters and wireless transmission of the received information to the doctor's device to control the training process is being developed. This paper reveals the process of developing an electronic circuit for the breathing simulator of this project.

2. Development of the electronic circuit and printed circuit board

This section presents the first version of the electronic circuit and printed circuit board for the project "Development of a software and hardware complex for monitoring and correcting respiratory functions based on multimodule technologies" and describes its constituent elements in detail. The main element of the developed circuit is Raspberry PI Zero. According to studies [9, 10], Raspberry Pi is considered one of the most suitable hardware for implementing IoMT applications. The authors of the studies [11, 12] provide an overview of existing solutions using Raspberry Pi, including in the field of medicine and healthcare.

2.1. Raspberry PI Zero

The printed circuit board (PCB) of the " Development of a software and hardware complex for monitoring and correcting respiratory functions based on multimodule technologies" project utilizes a single-board computer Raspberry Pi Zero, as its main component. This Raspberry Pi Zero serves as the central element and controls the entire circuit. Therefore, this board performs the following functions:

- Reading data from sensors;
- Controlling servo drives;
- Executing algorithms for smooth servo control based on sensor data.

The Raspberry Pi Zero was selected for this project for the following reasons [13]:

1. Compact Size: Among the entire Raspberry Pi lineup, this computer is the most compact and affordable, with dimensions of 65 x 30 mm.
2. Performance: Raspberry Pi Zero features a 1 GHz single-core ARM1176JZF-S processor, 512 MB of RAM, and 8 GB of flash memory.
3. Ports: It offers one HDMI input, two USB 2.0 inputs, an SD card slot for OS boot, and an audio/video output.
4. Wireless Connectivity: Raspberry Pi Zero includes a built-in Bluetooth module and supports 802.11n wireless communication.
5. GPIO (General-Purpose Input/Output): This interface is used for communication between components in the circuit. Raspberry Pi Zero has 40 GPIO pins, including pins for SPI, RXD/TXD, and I2C.
6. Cost: Due to its small size, limited memory, and lack of built-in Wi-Fi, the Raspberry Pi Zero is cost-effective.

In Figure 1, the complete specifications of the Raspberry Pi Zero are presented [13].

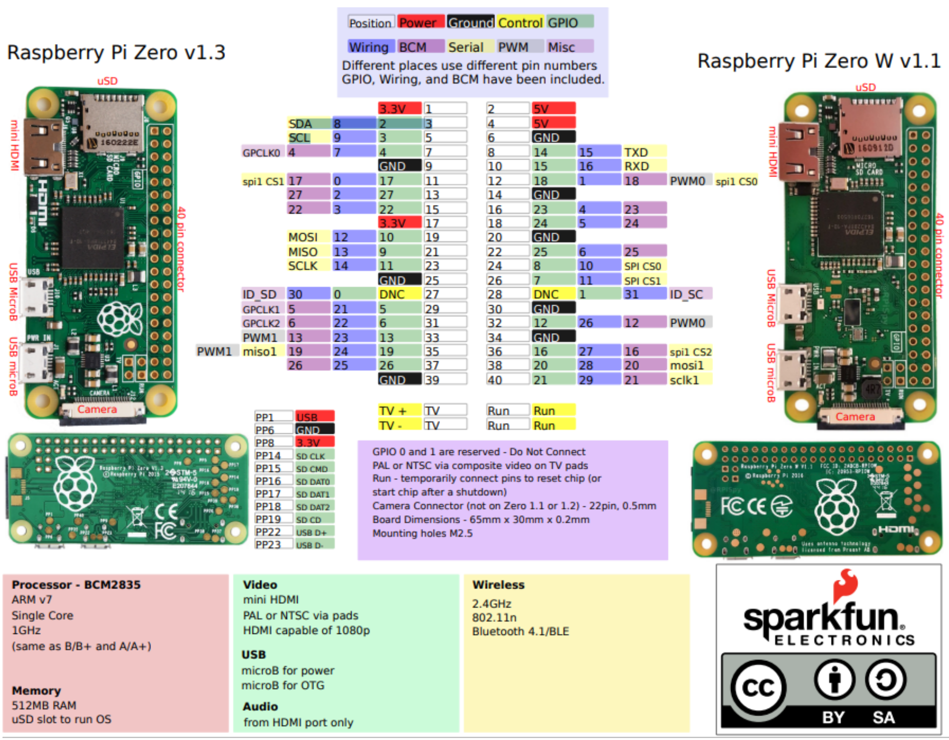


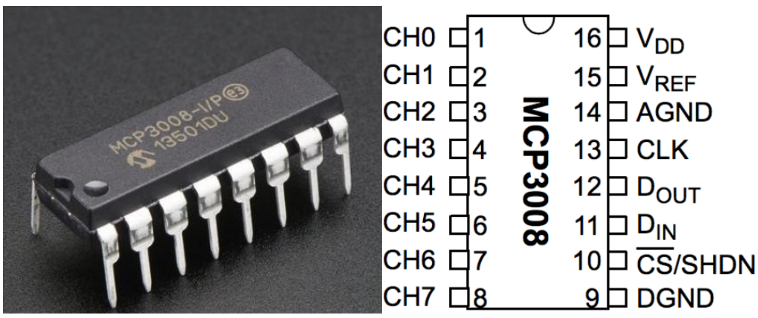
Figure 1: Datasheet Raspberry PI Zero

However, despite the advantages, one drawback of the Raspberry Pi Zero is the absence of analog input ports. This limitation restricts its usability. In this situation, an analog-to-digital converter (ADC) can be used. In this project, the MCP3008 will serve as the ADC converter, described in more detail in section 2.2.

Additionally, the output voltage of the Raspberry Pi Zero ports is insufficient to control servo drives effectively. To address this voltage issue, transistors 2n7000 will be used in this project to facilitate control over linear servo drives. These transistors are described in more detail in section 2.4.

2.2. MCP3008

The MCP3008 is a 10-bit Analog-to-Digital Converter (ADC) with 8 input channels. It features low power consumption and a sampling speed of 200,000 samples per second. The MCP3008 is available in 16-pin PDIP and SOIC packages. A representation of the MCP3008 is in Figure 2(a) [14].



a) b)

Figure 2: MCP3008 (a) and MCP3008 pin diagram (b)

For proper operation with the Raspberry Pi Zero, the SPI (Serial Peripheral Interface) interface will be used to interface with the MCP3008 ADC, which will be discussed in the next section. Figure 2(b) illustrates the ports of the MCP3008 [14].

As mentioned earlier, the MCP3008 has 8 channels (CH0-CH7). Additionally, in Figure 2(b), AGND and DGND represent the analog and digital ground, respectively. Vdd is the power supply, Vref is the reference voltage, and CLK, Dout, Din, SC/SHDN will be used for SPI connectivity.

2.3. SPI

SPI (Serial Peripheral Interface) is an interface that follows a standard for serial and synchronous data transmission. Its primary characteristic is communication between one master device and one or more slave devices. In this project, the master device is the Raspberry Pi Zero, and the slave device is the MCP3008. This data transmission involves the use of 4 pins, and their information is provided in Table 1.

Table 1
Pins used in SPI

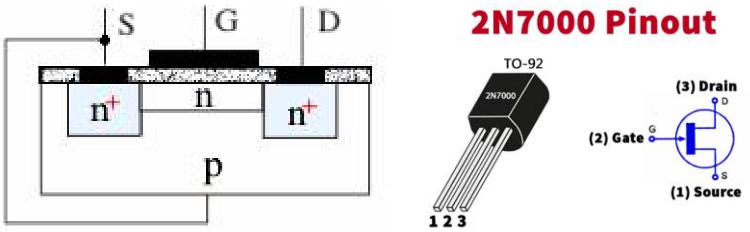
Name	Explanation	Characteristics
MOSI	master output slave input	The master transmits, and the slave receives.
MISO	master input slave output	The master receives, and the slave transmits.
CS	chip select	Each slave has a dedicated pin with its own identifier. This is to ensure that the master knows to whom it is sending data and from whom it is receiving.
SCLK	serial clock	The clock signal is used for reliable synchronization.

For the implementation of this project, high reliability and high-speed data transmission are required. For these reasons, the decision was made to use the SPI interface. The connection scheme is presented in section 2.6.

2.4. Transistors 2n7000

An important aspect of the electronic circuit is the correct control of the servo drives. Linear servo drives will be used in the project to achieve the set objectives. However, they operate at a voltage of 3.7V, which the Raspberry Pi Zero cannot provide. In such cases, it is necessary to use transistors. Field-effect transistors will be used in this project, as they offer the following advantages:

- High DC input resistance at high frequency;
- High speed of operation;
- High-temperature stability;
- Low noise level;
- Low power consumption.



a) b)

Figure 3: Field-effect transistor design (a) and transistor 2n7000 (b)

Field-effect (unipolar) transistors have three terminals: source, drain, and gate. The gate serves as the control pin. Figure 3(a) illustrates the structure of a transistor.

To control the voltage sufficient for operating a linear servo drive, a transistor with a control voltage of 3.3V is required. The 2n7000 transistor, as depicted in Figure 3(b), is suitable for this purpose.

2.5. Block scheme of PCB

As shown in Figure 4, the block diagram will operate as follows:

1. Power is supplied to the DC-DC converter to ensure that the output voltage remains constant over time.
2. The voltage from the DC-DC converter powers the Raspberry Pi Zero.
3. Raspberry Pi Zero initiates communication with the MCP3008 through the SPI interface.
4. Data from the sensors will be acquired by Raspberry Pi Zero, and based on this data, the field-effect transistors will be controlled.

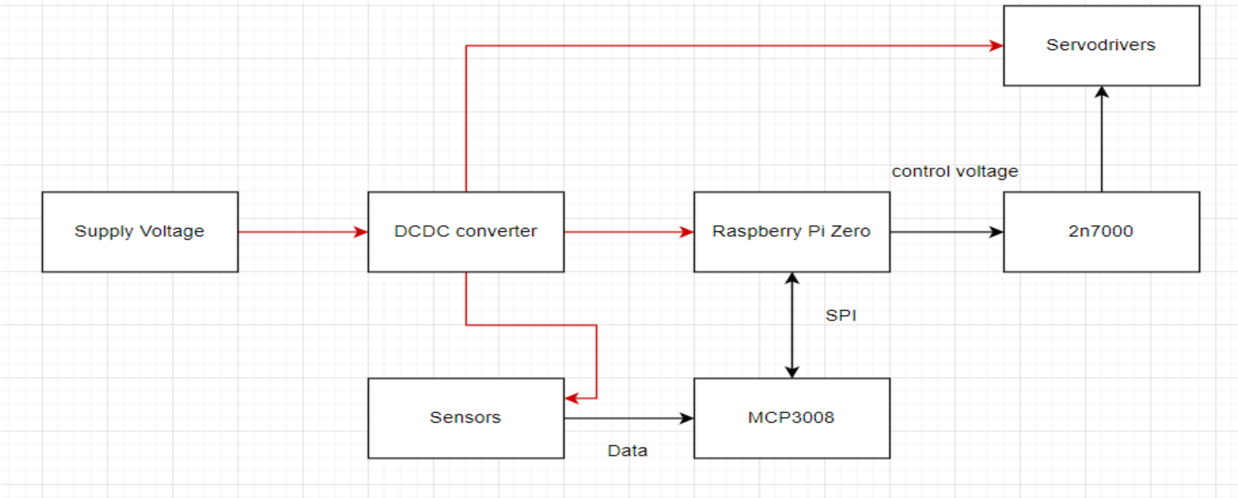


Figure 4: Block scheme

The entire system will be highly dependent on the algorithms used for controlling the servo drives, as well as the sensors themselves. Ultimately, a feedback system has been developed, which passes through the sensors, creating a closed-loop control system.

2.6. Schematic diagram of PCB

In this section, a schematic diagram is presented, divided into blocks for ease of understanding.

2.6.1. Block of the schematic diagram with Raspberry Pi Zero

In Figure 5, which was created with Altium Designer software, a block of the schematic diagram with Raspberry Pi Zero is presented, where:

- CON is the connector, a component that connects external wires to the circuit (double (CON2X1) and triple (CON3X1) connectors are used in the project);
- Raspberry Pi Zero is a graphical representation of the Raspberry Pi Zero;
- DCDC is the DC-DC converter;
- GND is the common ground for the entire circuit;
- +3.3V is the power supply for the circuit.

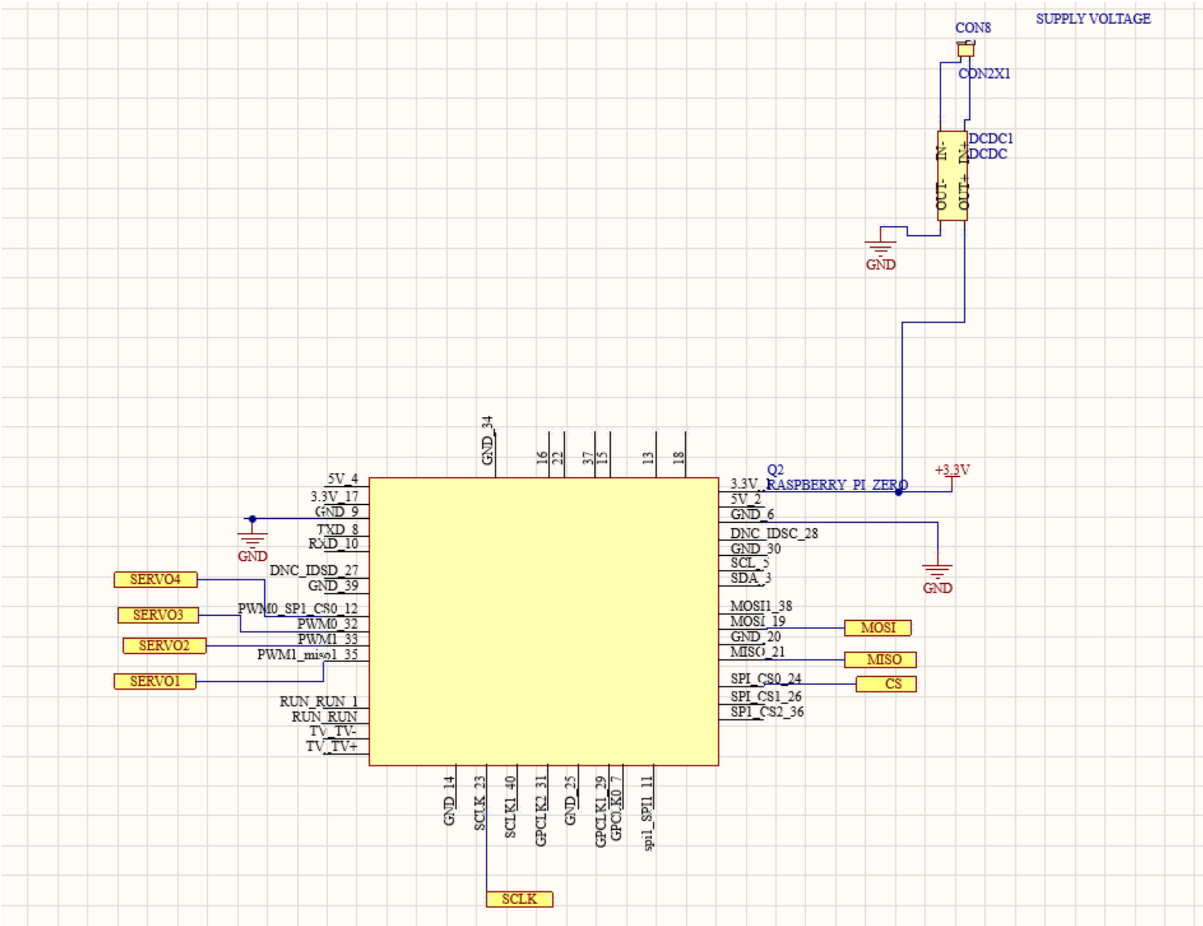


Figure 5: Block of the schematic diagram with Raspberry Pi Zero

As mentioned earlier, the SPI interface is used to communicate with MCP3008, so the following Raspberry Pi Zero pins are used in the circuit, as presented in Table 2.

Table 2
Ports SPI

Port	Purpose
19	MOSI
21	MISO
24	CS
23	SCLK

To control the servo drives, the ports described in Table 3 are used.

Table 3
Ports to control the servo drives

Port	Purpose
12	SERVO4
32	SERVO3
33	SERVO2
35	SERVO1

2.6.2. Block of the schematic diagram with MCP3008

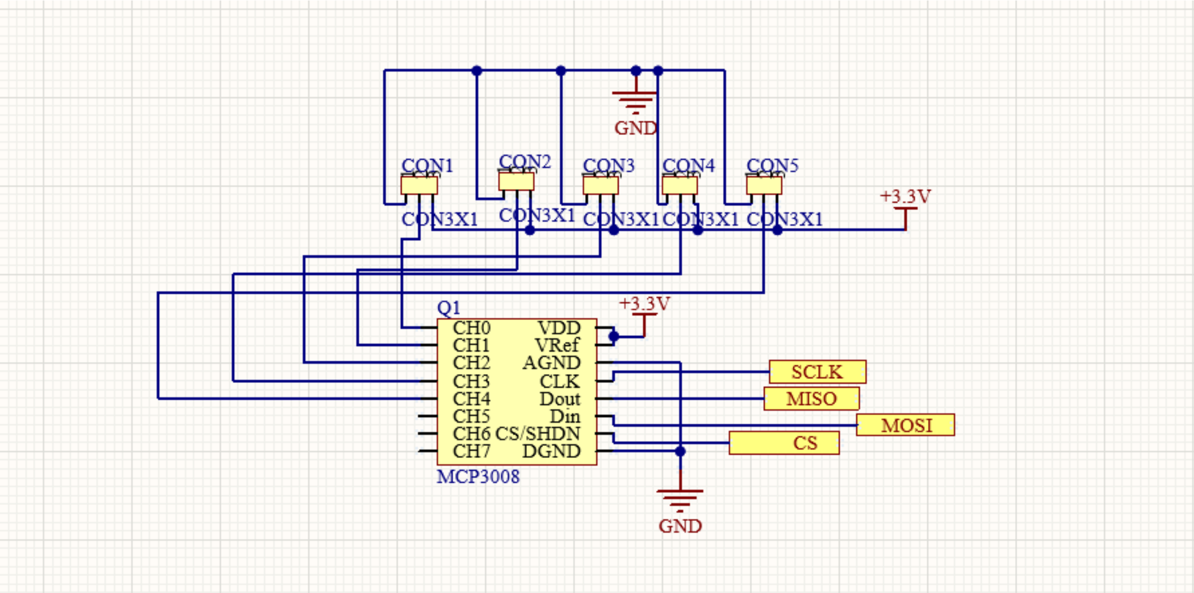


Figure 6: Block of the schematic diagram with MCP3008

In the block presented in Figure 6, connectors CON3X1 and MCP3008 are used. The use of triple connectors is necessary to supply power to the sensors while also providing a common ground for them and a contact for transmitting sensor values.

2.6.3. Block of the schematic diagram with the control of the servo drivers

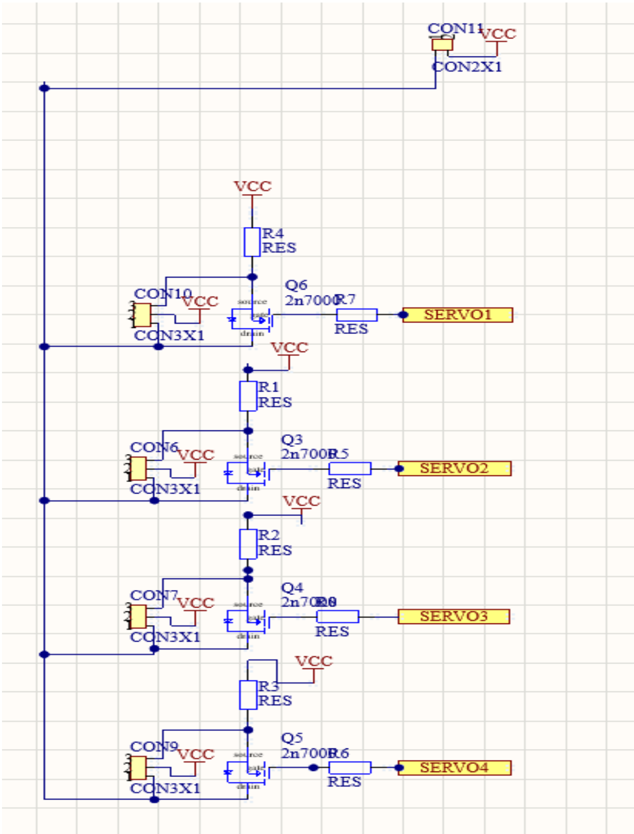


Figure 7: Block of the schematic diagram with the control of the servo drivers

In the schematic presented in Figure 7, the following components are used:

- RES – resistor;
- 2n7000 - field-effect transistor;
- VCC - power supply.

Resistors R3, R2, R1, R4 are used as a load. Resistors R5, R6, R7, R8 are used to limit the charge current of the gate capacitance to prevent the transistor from burning out.

2.7. Preparing of PCB

After preparing the schematic diagram, the circuit was assembled on a board. Here, the first version of the circuit is presented, and changes are planned for the future. Therefore, this version of the circuit is designed on a DIP package and a single-sided PCB. The printed circuit board after layout is shown in Figure 8.

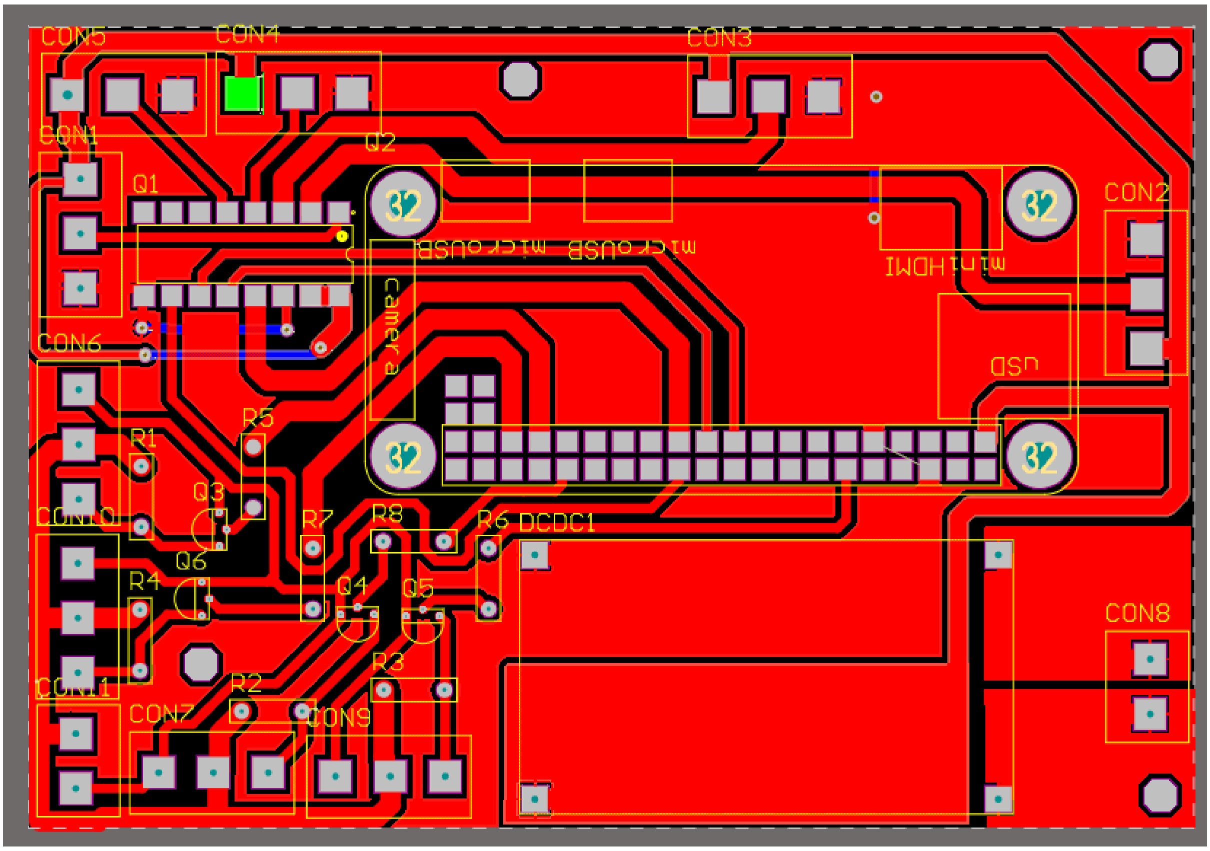
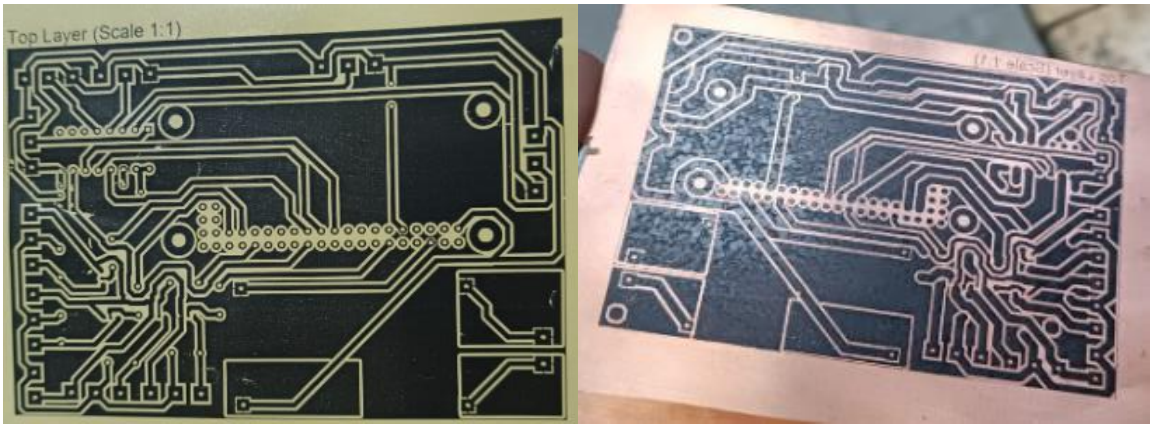


Figure 8: Printed circuit board

The next step involved transferring the image onto the PCB. To do this, the first step was to print the image on special PCB etching paper, as shown in Figure 9(a).



a) b)

Figure 9: Transferring the image of the circuit board to glossy paper (a) and LIT (b)

The second step involved using heating elements to transfer the image onto the PCB. This technology is known as laser ironing (LIT). As a result of the heat transfer, the PCB was obtained, as shown in Figure 9(b).

The next step is to obtain the printed circuit board through the etching process. Etching is one of the methods used to remove unwanted copper areas from the PCB as they do not match the PCB's design.

2.8. Result

As a result of the steps described above, the printed circuit board was obtained, as shown in Figure 10.

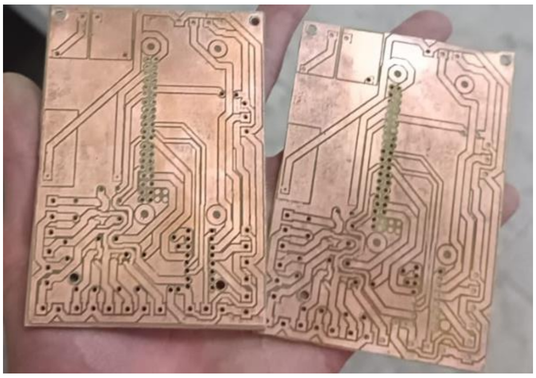


Figure 10: The printed circuit board

Thus, this paper describes the process of creating the electronic circuit and printed circuit board for the breathing simulator and characterizes its components. During the development of this printed circuit board LIT technology, etching of the printed circuit board and drilling were used. During the development of the electronic circuit, the Altium Designer program was used. The tools of this program allowed to draw a schematic, as well as to develop a circuit for the circuit board. As a result, the first version of the printed circuit board, where the main goal was to work out the program algorithms, was received. Further plans for the project include improving the presented circuit and adding sensors that will be used to measure the patient's body parameters in the process of training.

3. Acknowledgements

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