Application of the IoT Concept in the Field of Medical Devices: Development of a Prototype of a Mechanotherapeutic Simulator and Software for Its Control

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Summary
The article discusses the application of the IoT concept in the sensitive field of medical devices on the example of a developed prototype of a mechanotherapeutic simulator. Mechanotherapy is a complex of therapeutic, preventive, and restorative exercises conducted using simulators, specially designed for developing movements in individual joints. Mechanotherapy is used for the early and painless restoration of joint mobility, to prevent complications associated with prolonged immobilization of the injured area of extremities. Using the mechanotherapy simulator allows developing the joint painlessly, which accelerates the metabolism in the injured area, and soft tissues are restored to normal. The article provides information about the electronic components that ensure the wireless operation of the device and describes in detail the applied software as well as the client application for a mobile device.
Keywords:
Mechanotherapy; Wireless Control System; Client application.

1. Introduction

Currently, the concept of the Internet of Things (IoT) is widely used to automate household operations [1, 2]. This concept involves the organization of a data transmission network between physical objects (things) equipped with built-in tools, using technologies for interacting with each other or with the external environment. It is assumed that creating such networks can restructure economic and social processes, and eliminate the need for human participation from part of actions and operations.

This field is developing due to the integration of many technologies, including the application of powerful embedded systems, machine learning algorithms, and a variety of industrial and household sensors. In the consumer market, IoT technology is most synonymic with products related to the smart home concept, including devices and appliances (such as lamps, thermostats, home security systems and cameras, and other household appliances) that support one or more common ecosystems and can be controlled by devices associated with this ecosystem, such as smartphones and personal computers. IoT can also be used in healthcare systems [3, 4].

The second motivational reason for the present study is that currently there are problems of a shortage of medical personnel involved in the rehabilitation of patients, as well as a shortage of post-traumatic rehabilitation devices in the Komi Republic and other remote regions of the Russian Federation.

Thus, to solve the specific task of developing an import-substituting device and the general task of researching the prospects of using the IoT concept for medical equipment, the Pitirim Sorokin Syktyvkar State University is implementing a project to create a mechanotherapeutic simulator with a modern control interface.

2. Mechanotherapeutic Simulator

The technique of mechanotherapy provides for a local impact on the musculoskeletal system and contributes to an enhancement in the functional adaptation by increasing the amplitude of movements in the joints and eliminating spasms and contractures in the muscles. This treatment method has a targeted nature of the impact, which is quite effective, however, it does not allow achieving a comprehensive impact on the disease, and therefore can be used in combination with other rehabilitation methods, for example, physical therapy [5].

Figure 1 shows the visual appearance of the developed mechanotherapeutic simulator.

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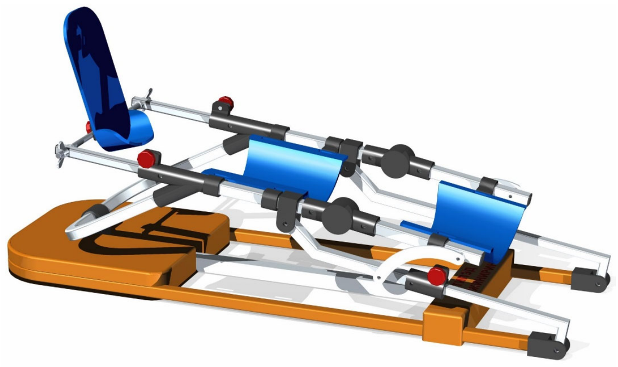

Fig. 1. The visual appearance of the mechanotherapeutic simulator

To ensure the flexibility in configuration and security, inherent in modern IoT devices, the developed device has the following features:

- The simulator is controlled by devices that support connection and data exchange via Wi-Fi (mobile phones, slates, laptops, and PCs);
- The device allows software and hardware reset of the settings stored in non-volatile memory;
- The possibility of simultaneous control of several devices with individual operation settings for each device using just one remote control;
- The ability to set a unique name of the device, storing it in the non-volatile memory;
- The device operates using an electronically switched brushless DC motor with a driver and a planetary gearbox;
- Implemented electronic control system fixes the boundaries of the carriage movement and blocks the rotation of an electronically switched brushless DC motor in the direction leading to the carriage going beyond the corresponding boundary, but allows moving in the opposite direction and reloading the control unit;
- The simulator allows setting a one-time execution of several operation modes performed sequentially.

3. Wireless Control System for a Mechanotherapeutic Simulator

The developed mechanotherapeutic simulator can operate in two modes – in the access point mode and the client mode. In the access point mode, only one Wi-Fi control device can connect to the simulator. This is implemented for security purposes so that only one user, rather than several, could control the device. In created network, the device must have a static IP address, so it will be known in advance to the user who wants to connect to the device.

In client mode, the device connects to an already created network. These network parameters are reported to the device in advance and stored in its non-volatile memory. For the device to be controlled in this mode, a Wi-Fi device creates a server in this network. However, for the device to connect to this server, it needs to identify its current IP address. To do this, the user's Wi-Fi device sends a message to all devices connected to this network via a broadcast channel. The device receives this message, takes the IP address of a given device from this message, i.e. the IP address of the server, and connects to this server. Unlike the first mode, several devices can be connected to this server. In terms of the Wi-Fi-providing device, the first operation mode can be called single-user, while the second mode is multi-user. An illustration of the described operating modes is shown in Figure 2.

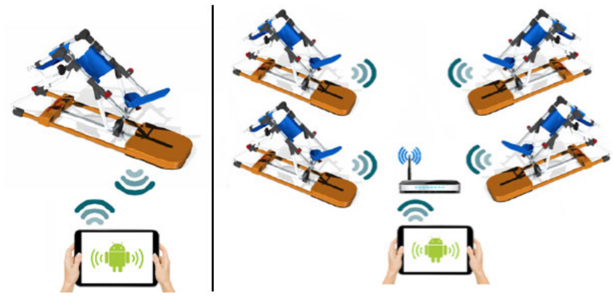

Fig. 2. Operating modes of the device: single-user (on the left), multi-user (on the right)

For the device to generate its Wi-Fi home network or connect to another network, it must be equipped with a special wireless module. Such a module in this work is the ESP-12E module, built based on the popular ESP-12EEX chipset [6]. The module contains an SOP-210mil flash memory chip, which stores the module's software. Each time the power is turned on, this software is automatically loaded into the ESP-12EEX chip. The 4 MB flash memory is quite enough to store full-fledged software applications controlled by an extensive set of text AT commands and to implement complex encryption and authentication algorithms based on WPA2-Enterprise security certificates. The central computing core of the module is a 32-bit Tensilica L106 processor embedded inside the ESP-12EEX chipset. The power of the processor core is sufficient for operating complex user applications of digital signal processing [7].

4. Mechanotherapeutic Simulator's Software and Client Application

It is the software of IoT devices that provides those rich opportunities for integration into information systems, which provide rapid technological development in this area. One of the most important tasks of the implemented project was to create a specialized user-friendly application for mobile devices operating on iOS and Android systems. These systems essentially differ from each other, but at the same time, they have similar algorithms for executing tasks, for example, in the field of organizing multithreaded code execution.

Special algorithms, namely, UDP, Client, and Server subroutines were implemented to control mechanotherapeutic simulators using a mobile device. Each of these subroutines has a separate open network socket. Therefore, for the correct and safe functioning of the application in which these algorithms are implemented, it is necessary to execute each subroutine in a separate thread. The interaction of threads is illustrated in Figure 3.

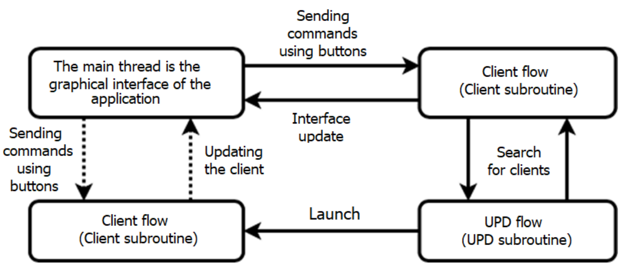

Fig. 3. Flowchart of the interaction of threads in the software of the mechanotherapeutic simulator

As can be seen from the above flowchart, sending a command to the device and subsequent updating of the application interface occurs due to the interaction of the main thread and two additional ones, in which the algorithms of the Server and Client subroutines are executed. It is worth noting that the Client thread is dependent on the UDP thread because the start of the Client subroutine depends on the fulfillment of the conditions of the UDP subroutine algorithm. Therefore, the interaction arrows between the main thread and the Client thread are displayed as a dotted line.

Another feature of the application developed for controlling mechanotherapy simulators is using a non-blocking network socket based on Java NIO. When using Java NIO, input-output threads are non-blocking, and the mobile device can communicate with all devices on the network asynchronously, regardless of which of the devices has sent it a message at the moment.

The application has a main screen (Figure 4), which displays a list of devices connected to a Wi-Fi device, a control panel which is used to control the device, as well as a unit for connecting the device, in which one can configure the device to work in one mode or another.

The main screen consists of an upper Action bar and a list that displays devices connected to Wi-Fi. If the list is empty, then a special text message is displayed instead, by which the user is informed what exactly he needs to do to include the desired device in the list. The upper action panel consists of the name of the application and the action button, by clicking on which the device connection block is displayed. In the case when there are connected devices, or the device has just connected, the list consists of cards, each of which contains a picture of the device, the name of the device, and it's status at the moment (connected or disconnected).

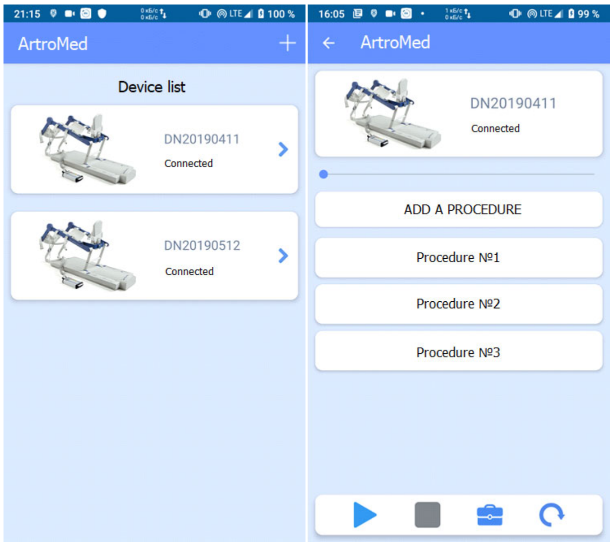

Fig. 4. The main screen of the user application (left), the window for setting up medical procedures on a specific simulator (right)

If one clicks on one of the cards showing the particular simulator on the main screen, the control window for the selected simulator will be displayed (Figure 4, right). The window consists of several parts. The first part is informative, it shows the user information about the simulator: its name, condition, picture, as well as the current position of the carriage of the mechanical part of the device, represented as a slider. It should be noted that when the device is in the state of executing the start command, the carriage of the mechanical unit changes its position over time. This change is recorded by the application every half a second and graphically displayed on the screen as a change in the position of the slider. The second part of the window is the procedure assignment interface. It consists of a single button and a list of procedures. If the list is empty, a text message is displayed notifying the user that a procedure must be added to work with the simulator.

To switch the device from one operating mode to another, it must be configured. For example, for the device to operate in "Client" mode, it needs to receive the name and password of the network to which it should connect. Then a special command, responsible for changing the mode, should be sent. All these actions are performed on the mobile device using the application in a special unit for connecting the device.

The unit for connecting the device consists of several windows. If the device is operating in the access point mode and it needs to be configured to work on another network, i.e. to switch it to the "Client" mode, then the device connection unit first displays a special window to the user, which displays an instruction according to which it is necessary to connect to the device's home network. After connecting, a window is displayed (Figure 5) for entering the parameters of the network to which the user wants to connect the device. Two parameters should be entered – the network name and its password. If the parameters are entered correctly, a special indicator confirming the correctness of the input data will light up in the form of a green tick next to each parameter.

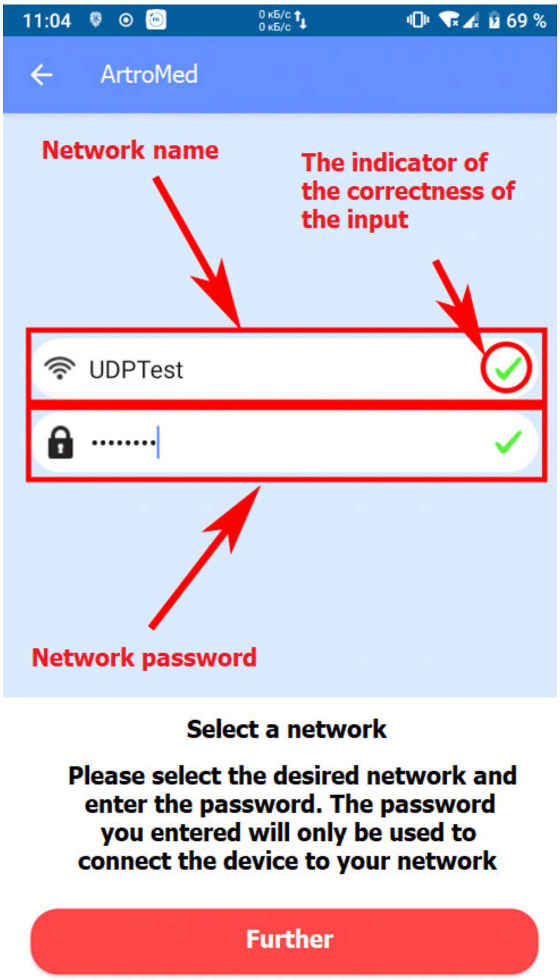

Fig. 5. Network settings of the mechanotherapeutic simulator

Note additionally that using wireless technologies imposes special requirements to ensure the network security of medical devices.

5. Conclusion

The developed software architecture of the mechanotherapeutic simulator and the client application meets the basic requirements for IoT class devices. Due to the upgraded interface and the use of wireless technologies, it is possible to significantly increase the efficiency of medical staff (one operator can control several simulators, including remotely), as well as to improve the safety of medical equipment (due to the ability to monitor the condition of the device in real-time through a mobile application), and improve the user experience of patients (when using devices at home).

The mechanotherapeutic device, developed at Pitirim Sorokin Syktyvkar State University serves both to solve the specific task of providing the medical industry with inexpensive domestic equipment, and to demonstrate the possibilities of applying the IoT concept in devices in a sphere, where today mainly traditional approaches to interface and industrial design are used.

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