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Physical Medicine Devices with Centralized Management over Computer Network

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***Abstract*—Physical therapy cabinets are provided with various devices which shorten the time needed for patients' recovery and healing. These are the devices which use diadynamic currents, interferential currents, ultrasound waves, vacum impulses, pulsed electromagnetic fields, etc. The aim of this paper is to develop a new generation of devices for physical medicine, based on the existing products of Elektromedicina company, with key feature that allows the devices to become a networked modules in the centralized system for physical therapy. Both local and remote aspects of setting the treatment parameters on the devices, as well as the monitoring of treatment progress on the centralized control station will be implemented. This paper addresses the system's architecture, network communication protocol, and user interfaces both for devices and centralized server console. The application layer protocol for communication of control station and physical therapy devices is developed. The proposed protocol provides plug-and-play capability of physical therapy devices by handling devices discovery. The initial implementation proved that the networked physical therapy devices can respond to all requests in a timely manner.**

I. Introduction

Physical therapy assumes the examination, treatment, and instruction of human beings to detect, assess, prevent, correct, alleviate, and limit physical disability, bodily malfunction and pain from injury, disease, and any other bodily and mental conditions. It includes the use of physical measures, activities, and devices, for preventative and therapeutic purposes [1].

The cabinets for physical therapy are provided with various devices which shorten the time needed for patients' recovery and healing. These are the devices which use diadynamic currents, interferential currents, ultrasound waves, vacuum impulses, pulsed electromagnetic fields, etc [1]. There are about 150 medical institutions in Serbia which have cabinets for physical therapies, with about 3500 devices being used. Well-known world wide manufacturers of such devices are Gymna-Uniphy, Shock Master, Enraf Nonius and Siemens, while Elektromedicina d.o.o. is the manufacturer with the highest number of sold devices in Serbia.

A typical physical medicine cabinet has tens of stand-alone devices for different purposes. Usually the patients are sequentially treated with different physical therapy devices, applying different procedures for prescribed period of time. Typical scenario for the patient to be treated is to apply several different methods in one day, and to repeat the same procedure every other day for one or two weeks [1].

Each device has treatment parameters that are set according to the prescribed therapy. Depending on the treatment, and development of patient recovery, device parameters are in the most of the cases set manually on each device before each treatment.

A lot of efforts with different goals have been done in recent years to interconnect different medical devices [2], [3]. The goals are mainly oriented to data acquisition and alarming of hazzard situations. In the most of the cases developed systems are proprietary and patented [4], [5]. However, there is a set of open standards for network communication of medical equipment, such as X.73 [6], [7].

In 2011, partially supported by the Ministry of Education, Science, and Technological Development of Republic of Serbia, under the Grant No TR32012, the project "Intelligent Cabinet for Physical Medicine - ICPM" was launched at Faculty of Electronic Engineering, University of Nis, Serbia. The aim of the project is to develop a new generation of devices for physical medicine, based on existing products of Elektromedicina company. Key feature of the new generation of devices is to allow the device to become a networked module in the centralized system for physical therapy. The devices should be integrated into a centralized system for network management and data acquisition, based on the adjusted modification of open X.73 standard [6], in the same manner regardless of the type of the device.

In this paper three new features that make the integrated centralized system for physical medicine and introduce new added values to the devices for physical therapy are presented: (1) remote semi-automatic or automatic setup of parameters and devices control; (2) the ability to automatically record the progress of the treatment; (3) new user interface and management console for centralized control station. Automatic control of the devices refers to setting of treatment parameters on the specific device in the scheduled time for the patient. Within the framework of the ICMP the new generation of devices for physical medicine is developed. The functional features of the previous generation in the sense of standalone operation were retained.

This paper focuses on the design of the system's architecture, design and implementation of the protocol for network communication, and the design of user interface for both devices and the centralized control station.

The paper is organized as follows: Section 2 gives a brief overview of Elektromedicina's previous generation of physical therapy devices and discusses the requirements for the new generation of the devices, in Section 3 new user interface for the new generation of physical medicine devices is presented, Section 4 is devoted to the system's architecture and network communication protocol, in Section 5 user interface of the management console on the centralized server is presented, in Section 6 the implementation results are discussed, while in Section 7 the concluding remarks are given.

II. Background and Integrated System Requirements

Typical cabinet for physical medicine contains numerous standalone physical therapy devices of different types. It is common that one patient is treated by different devices [1]. Six different types of Electromedicina's devices that are included in the ICPM are: Eksposan^{TM}, Magnemed^{TM}, Intermed^{TM}, Vakumed^{TM}, Diaton^{TM} and Sonoton^{TM} (Fig. 1). The devices are specialized to treat different parts of human body using different physical agents. Each device allows an operator to choose an initial set of therapy parameters, and to monitor and change their values in the course of the therapy.

Figure 1. Types of Electromedicina's devices that are included in the ICPM

The block diagram of a device for physical therapy, regardless of its type, is shown in Fig. 2. The operator attaches the applicator to the patient's body and sets the therapy parameters using the user interface, as it is shown in Fig. 2. The type of applicator depends on the type of the device. Devices like Diaton^{TM} and Eksposan^{TM}, which use different types of electrical current for the treatment, are equipped with electrodes, while Vakumed^{TM}, Magnemed^{TM} and Sonoton^{TM} use vacuum pumps, electrical coils, and ultrasound applicators, respectively.

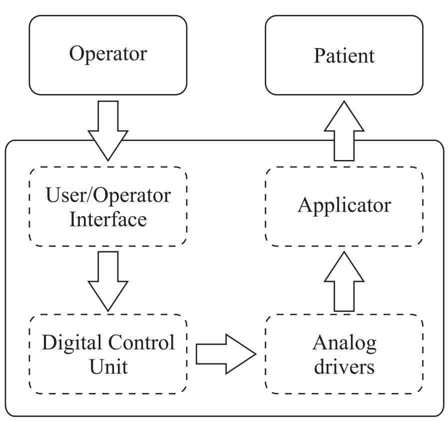

Figure 2. The block diagram of a device for physical therapy

The main project goal for the Integrated Centralized System for Physical Medicine (ICSPM) is to redesign existing physical therapy devices of Elektromedicina d.o.o company by introducing networking capabilities, providing interconnectivity for the support of system integration. The integrated system should provide: managing of physical therapy database, automatic synchronization between the devices, and recording and updating the history of patients therapy. The devices should be monitored and managed by the unique control station within the ICSPM. Centralized system should contain a database of patients' records with defined therapies and the course of the recovery. One of the goals of centralization is to integrate devices in such extent that, after the identification of the patient, the parameters are automatically sent from central manager to the device, and the treatment is continuously monitored.

The main requirements are:

1) the devices should have an extension which allows them to be monitored and managed by the unique control station within the ICSPM;
2) ability to manually or automatically over computer network set the parameters on each device;
3) the scheduler;
4) a database with patients' records, with scheduled treatments, treatments history and device parameters for each treatment;
5) common user interface for all device types.

Having in mind the significant number of produced devices by Elektromedicina company, decreasing of costs for transition to the new technology becomes the issue of the great importance. The cost-effectiveness led us to reusing of analog drivers and applicators (Fig. 2).

In order to fulfill the requirement for the new user interface on the devices, as well as the ability to connect the devices to local Ethernet network, microcontroller-based logic was attached to the existing analog drivers. The block diagram of the ICSPM device is shown in Fig. 3. Gray shaded blocks in Fig. 3 represent modules which are added in order to fulfil the requirements. Chosen microcontroller is Microchip PIC18F877 J60, with built-in Ethernet controller.

The user/operator interface, shaded in Fig. 3, is completely redesigned in order to provide the possibility for setting of device parameters for treatment, as well as new parameters related to network operation.

III. User Interface of the New Generation of Physical Therapy Devices

As there is usually a barrier in medical staff acceptance of new computer systems and technologies, part of the research was devoted to the ergonomics of new system. The central part of the Human-Computer Interaction (HCI) research was devoted to methodologies and process for interface design and implementation, quality estimation, and development of model for intuitive interaction. In order to overcome the barrier for the acceptance of the ICSPM devices by different types of medical staff, the common user interface for the devices is designed. The interface is driven by microcontroller, as it is shown in Fig. 3. The chosen interface is 2x16 character display.

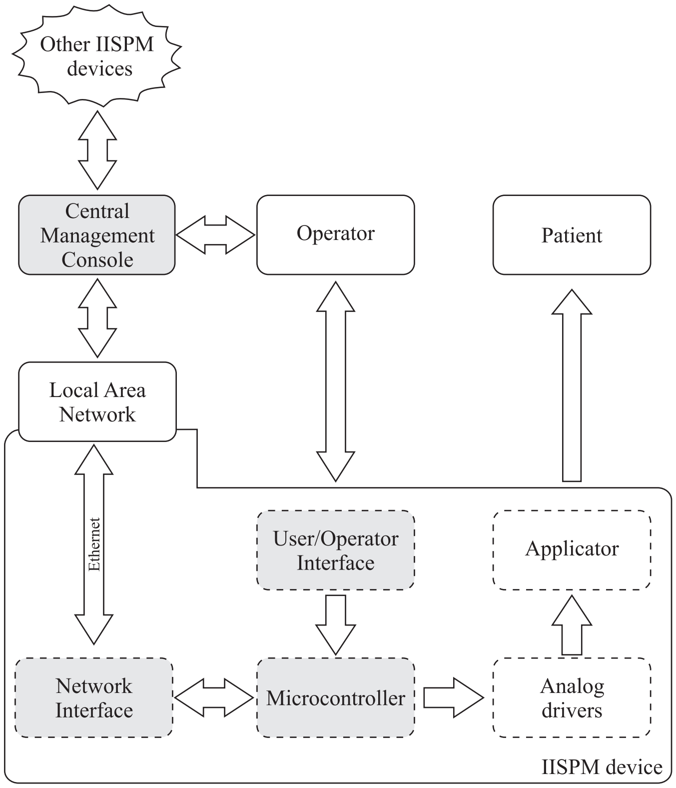

Figure 3. The block diagram of an ICSPM device

Having in mind that there are six different types of physical medicine devices with different functions and different parameters, and that all of them should be supported by a single user interface, the starting point in the interface design was analysis of the current user interfaces. Table I gives the summary of keys provided on the front panel in the previous generation of the devices with their functions. As it can be noticed from the Table I, Intramed has the largest number of keys, 7 in total. However, instead of start and stop button, which should be present in each device, the other keys are reserved for the parameters setup. If we put the parameters setup options within the user menu, then the requirement for common user interface on all devices can be achieved. In this case all six devices should have the following five keys:

1) *start/stop* – controls the beginning and the end of the therapy,
2) *up* – moving up within the menu, or parameter value increase,
3) *down* – moving down within the menu, or parameter value decrease,
4) *enter* – enter the selected menu item, or remember the parameter value,
5) *back* – one level up in the menu, or cancel the parameter value.

The menu is organized as shown in Fig. 4.The initial screen in Fig. 4 gives the operator the basic information about the device type, notifying that the device is in ”ready” state. The most common task performed on the device is starting of the therapy. Within the designed menu, this is provided with the most recent parameters, which are recorded as *”predefined therapy 1”* option (Fig. 4). The therapy can be started from the *ready* state by pressing the *start* key twice (Fig. 4). While the therapy is in progress, pressing the *start* button will cause the first parameter to be displayed in ”full-screen” mode, letting the operator to change the value by pressing *up/down* keys. The real-time parameters displayed during the therapy on Vakumed^{TM} are shown in Fig. 5a, while the screens for parameter changing are shown in Fig. 5b.

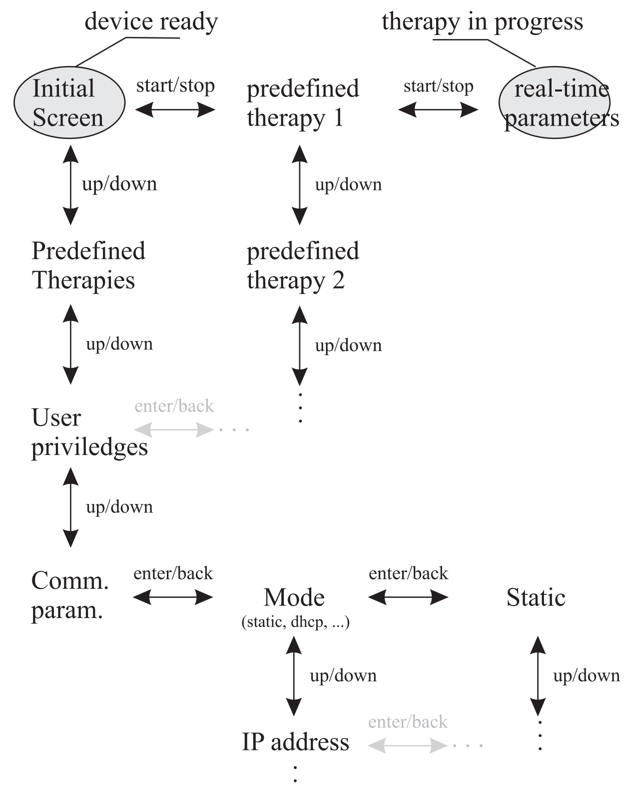

Figure 4. The organization of the user menu on the ICSPM device

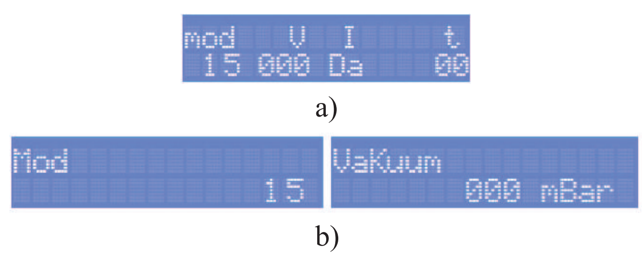

Figure 5. Parameters display in real-rime during the therapy

From Fig. 4 can be noticed that a part of the interface is devoted to the communication parameters. By moving down through the main menu, starting from the initial screen, operator can reach the menu item *”Communication parameters”*, where the network parameters can be set.

IV. Data Acquisition and Control Protocol

In order to be able to setup treatment parameters remotely in semi-automatic or automatic manner over computer network and to record the progress of the treatment in the ICSPM, each device is provided with the Ethernet network adapter that

TABLE I. THE SUMMARY OF THE CONTROL FUNCTIONS ON THE FRONT PANEL IN THE PREVIOUS GENERATION OF THE DEVICES

	Eksposan^{TM}	**Intramed**^{TM}	**Sonoton**^{TM}	**Magnemed**^{TM}	**Vakumed**^{TM}	**Diaton**^{TM}
key 1	start / stop	start / stop	start / stop	start / stop	start / stop	start / stop
key 2	modulation type	select function (pm,if,g)	select function (k,i1,i2)	channel selection (1,2)	pulse mode (15,30,60)	select function (g,pg,d)
key 3	select function (sp,e1,e2)	frequency change type	-	-	constant mode	-
key 4	-	upper/lower frequency	-	-	water	polarity (+,-)
key 5	set F current (up/down)	time (0-60 min.)	time (0-19 min.)	time (0-95 min.)	vacuum intensity (0-600 mbar)	time (0-15 min.)
key 6	set G current (up/down)	current (0-60mA)	intensity (0-3W/cm^2)	frequency (0-50Hz)	-	base current (0-5mA)
key 7	-	frequency (1-200Hz)	-	magnetic field (0-10mT)	-	dose current (0-29mA)

is embedded in the chosen PIC microcontroller (Fig. 3) [8]. The ICSPM is designed as hub-and-spoke topology, having the control station as a hub, as it is shown in Fig. 6. In other words, devices can communicate with the control station only, but not with each other.

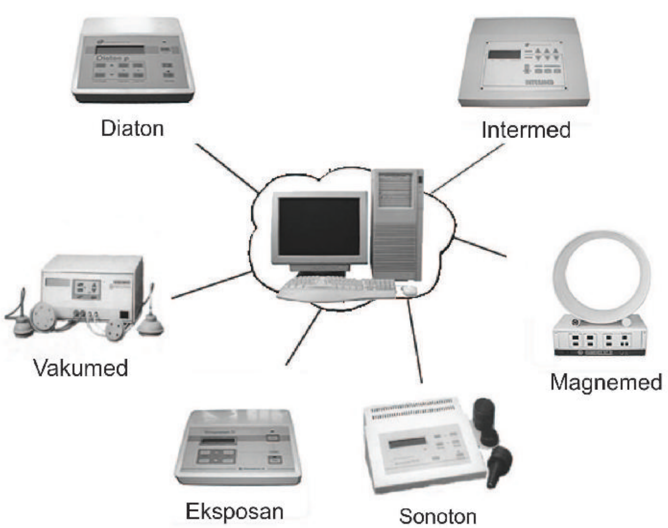

Figure 6. The topology of the ICSPM

The design and implementation of communication protocol is inspired by a set of standards X73 PoC-MDC [6]. To operate in a coupled manner, two devices follow the next four steps: connection, association, configuration and operation. In the phase of connection, the device queries local network for discovery of the control station. During the phase of association the device registers its ID within the control station and retrieves the network ID [6], [7]. In the phase of configuration the device queries the control station to retrieve physical therapy database. It analyzes the type of therapies and updates its local therapies database. In the operation phase the device sends periodic hello packets and can be polled by the control station to start, stop or change therapy parameters.

The coding and decoding of messages in X73 is found not to be applicable in straightforward manner for the particular embedded microcontroller, due to complexity [2]. The protocol message coding is simplified to reflect the number and type of physical therapies parameters [8].

The communication protocol between the physical therapy device and the control station is designed to use UDP transport layer protocol with port numbers 161 and 162. As UDP protocol doesn't offer transmission and flow control, the basic sequencing and acknowledgment of messages are provided at the application level.

The message format is shown in Fig. 7. There are 18 different message types, which are used in different scenarios for different purposes. Sign "D" in Fig. 7 stands for field delimiter.

0 2	3	4 8	9	10 N+10	N+11
Code	D	Device ID	D	Message	End

Figure 7. The message format

The following scenarios are identified:

- starting of the therapy with predefined parameters from the control station;
- recording the event if the therapy is started/stopped from the device itself;
- pausing or stopping the therapy from the control station;
- changing the therapy parameters from the control station;
- recording the event if the parameters are changed from the device itself;
- periodic interchange of status information between devices and control station;
- sending of unsolicited messages about starting or stoping of therapies, changing parameters or changing of device states from the device;
- new therapy registering if it doesn't exist in the control station database.

The complete list of message codes and detailed description of the message exchange during each scenario can be found in the technical report [9]. For the sake of illustration, a UML sequence diagram for one of the mentioned scenarios is presented in Fig. 8. The scenario illustrated in Fig. 8 is the scenario of starting the therapy on a device from the server.

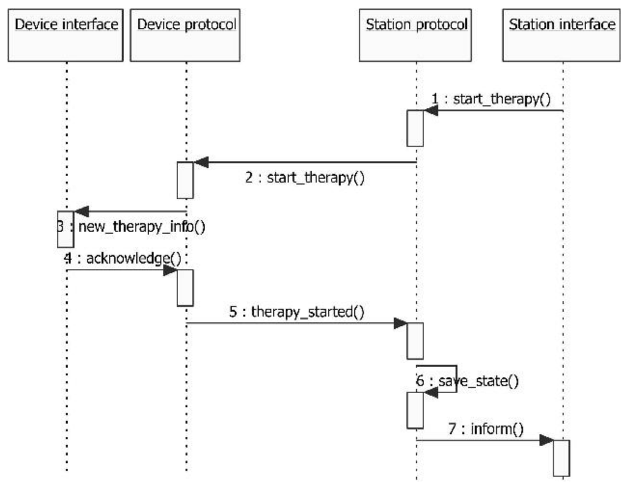

Figure 8. The sequences of messages sent over the network when therapy on a device is started from the control station

After the command is received to start the therapy on the particular device (Fig. 8), the user interface on the station notifies the module which implements the protocol on the control station to send a start message to the device (*start_therapy()*, Fig. 8). The module that implements the protocol on the device side, gets the message, takes the necessary steps, and confirms the start to the control station. It should be noted that this scenario must precede by the message exchange which connect, and associate, the device to the control station [9].

Beside these similarities, the implemented protocol has less overhead compared with full X73 protocol stack.

V. Control Station Management Console

The management console of the control station is shown in Fig. 9. Due to importance of particular parts of the user interface, patient data management, as well as the information about available devices are omitted. Once the patient is identified, and its record is opened, the operator on the central control station gets the screen shown in Fig. 9.

The screen is divided in 5 sections. In order to be able to reference the sections of the figure, the sections are enumerated by numbers 1 to 5 in Fig. 9.

The main design goal was to provide all patients data, including the data about scheduled therapies once the record is opened. These data are provided within sections enumerated as 1 to 3 in Fig. 9. Section 1 shows the basic information about the patient, while sections 2 and 3 give the information about scheduled treatments and the history of treatments, respectively.

Sections 4 and 5 display the current status of the devices in the ICSPM. The status of the devices on which the therapy is in the progress is shown in section 4, along with the elapsed and estimated time for the treatment. If the device is in ready state, and the treatment isn't running, the device isn't displayed in this section. In addition, section 5 displays the event messages about the devices, such as: new device detected on the network, therapy parameters changed on the device using the interface of the device itself, etc. These messages are visible for the short period of time, and then they disappear from the list of events.

If there are no therapies in progress, and there are no events from the devices, sections 4 and 5 are hidden, and the screen contains sections 1 to 3 only. As it is mentioned earlier, section 2 displays the scheduled treatments for the patient whose record is opened, putting the first coming treatment on the top. The first coming treatment is the only one that has buttons for start and edit, the therapy parameters next to it, on the right side, as it is shown in Fig. 9. When the treatment is started, the start button icon switches to stop button, the edit button remains the same, and the progress is shown in the section 4 of the screen.

The third row in the section 2 shows the type of the device (Fig. 9). The first coming treatment is the only one where the particular ID of the device is shown, because in this point control station has the information which device is available. This is not the case with the treatments scheduled for some future time. The problem of availability of the devices in particular period of time is addressed in the scheduler part of the interface, but it addresses only the number of available type of the devices, and do not associate the patient to the device until the time for the treatment comes.

Having all relevant information available on the same screen met one of the basic rules of HCI design, and indirectly gave the opportunity to the institution to choose between regular and touch screen while implementing the ICSPM.

VI. Implementation Results

The physical therapy devices are upgraded with a microcontroller-based board, using Microchip PIC 18F87J60 with integrated Ethernet controller (Fig. 3). The protocol stack is compiled using MikroC compiler within MikroC PRO IDE and runs on MikroC TCP/IP stack in OSA cooperative multitasking real-time operating system (RTOS) for Microchip PIC controllers. The size of the compiled protocol core is 44KB. The corresponding component, as well as the user interface on a control station, is developed in C# with .NET 3.5.

For the sake of illustration, Table II, gives the total number of different messages that can be exchanged between a device within ICSPM and control station through the network, and the total number of different events caused by the messages within the control station, as well as within the device itself.

TABLE II. The number of messages exchanged between the system modules

Message	# of different messages
Device protocol → Station protocol	15
Station protocol → Device protocol	19
Station protocol → Station interface	20
Station interface → Station protocol	8
Device protocol → Device interface	15
Device interface → Device protocol	15

Table III shows the number of messages exchanged for one working day of 10 hours, between 12 physical therapy devices

Figure 9. The management console of the control station

and control station, when the therapies are scheduled on every 30 minutes. Having in mind that the average message size is 80B, and that total quantity of data exchanged per day for the given example is less that 1MB, it can be concluded that the protocol is very efficient both in terms of network throughput and, more importantly, the burden that it causes on the limited-capability microcontroller.

TABLE III. THE NUMBER OF MESSAGES EXCHANGED OVER THE NETWORK IN THE TYPICAL CABINET

Scenario	# of messages	# of repetitions per day	data sent [KB]
Device registering	5	1	0.4
HELLO messages	2	3600	562.5
Starting of therapy	2	20	3.2
Stopping the therapy	2	20	3.2
Parameters change	2	100	16.0
Synchronization	24	1	1.9

VII. CONCLUSION

Physical therapy cabinets are provided with various devices which shorten the time needed for patients' recovery and healing. In this paper a new generation of devices for physical medicine is presented. The devices are based on existing products of Elektromedicina company, with key additional feature that allows the devices to become a networked modules in the centralized system for physical therapy. Both local and remote aspects of setting the treatment parameters on the devices, as well as the monitoring of treatment progress on the centralized control station with data acquisition are implemented. The paper presents the ICSPM as an integrated system, keeping the focus on the system's architecture, network communication, and user interface on both devices and centralized server console. The new user interface on devices and the user interface of the control station are presented. The application layer protocol for communication of control station and physical therapy devices is developed. The protocol design is led by the concepts of IEEE ISO/IEEE X73-PoC-MDC series of standards. To deal with limited resources of a microcontroller-based interface, which is attached to each physical therapy device, adopted concepts are simplified accordingly. The proposed protocol provides plug-and-play capability of physical therapy devices through handling of devices discovery and synchronization of therapy databases. The initial implementation proved that the networked physical therapy devices can respond to all requests in a timely manner.

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