Conceptual model of IoT-based Laboratory for study the Electrical Engineering and Electronics

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Abstract

Abstract - The popularity of IoT has been growing rapidly in recent years. This is due to the reduction in the cost of devices that take place in IoT solutions, the creation of user-friendly software development systems and the development of cloud services. This, in turn, has led to the transition of the educational process to a completely different level, where higher education students can obtain most of the knowledge (both theoretical and practical) remotely without the need to physically visit the classroom. In this regard, a conceptual model of IoT hybrid laboratory is proposed, in which students have the opportunity to conduct their research both remotely and in patiently. The structure of the control system and general operating scenarios are described. The issue of optimizing the use of electricity in the proposed laboratories, which is associated with an increase in electrical load several times relative to classical laboratories.

Keywords 1

Conceptual model, Arduino; Raspberry; IoT, IoT-based Laboratory

1. Introduction

The Internet of Things is a concept of building an environment in which static physical objects (mechanical, digital, people, animals and other objects) are connected to the World Wide Web and can communicate with each other and exchange information to solve everyday problems [1-3]. The main idea of IoT [4,5] is that these objects can interact with each other, perceive and collect data from the environment without the need for human intervention or the need to communicate with her. According to researchers, IoT infrastructure could reach 1.5 billion devices in 2022 [6-9]. Given that the prices of microcontrollers have fallen to the prices of everyday food [10], it is possible to automate and monitor all processes in life. This trend has not bypassed the learning process either [11]. In particular, there is a growing tendency to conduct remote experiments without spending time on physical visits to laboratories, which does not reduce the workload of laboratories and staff, but also allows not to reduce the quality of training, because students still work with real equipment. However, this approach makes it difficult to monitor all devices in such laboratories. Requires control of equipment that is not currently used, but consumes electricity [12]. In addition, given that the

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laboratories conduct not only remote experiments, but also the actual presence of students, it is also necessary to control the level of lighting and air conditioning in the room.

For such purposes, the concept of IoT is best suited, which will allow for mixed experiments in laboratories, with some students working with equipment and others conducting experiments remotely in parallel. The system fully controls the energy consumption and the turn of the experiments. This will save electricity in general in the laboratory and increase the number of students involved without increasing the physical presence of people.

2. Related work

In [19], a comprehensive approach to the implementation of a hardware laboratory based on FPGA and ignited as a service in a hybrid cloud. This laboratory can also be scaled in the public cloud with the possibility of free connection of IoT devices, which are implemented using FPGA [15]. The presented laboratory uses FPGA to work with peripherals and cloud services.

The implemented controller on the FPGA simultaneously works with the server and receives commands, as well as, on the other hand, receives data from sensors, which are sent to the cloud using the Internet protocol [16]. After that, cloud services use FPGA to store, store data, analyze and visualize data. In order for such an environment to work at the IoT level, the student first prepares IoT peripheral designs in Verilog-HDL and server-side software. In addition, Docker [17] and Docker Swarm containers were used for the operation of the system. This part is implemented in Go in the form of templates and each student can easily customize them for their own needs. Using Docker tools also reduces application development and human resource usage time. Thanks to the microservice architecture, the laboratory can dynamically change its configuration according to the workload of students. There are several work strategies in this system: students can conduct experiments on their own or join group experiments. But first, the student must develop their own Verilog-HDL for each FPGA, as well as management software to process data and work with the cloud using Docker tools that will implement the IoT infrastructure.

Another implementation of the remote laboratory [11] is based on the most popular systems for development and prototyping, namely Arduino and Raspberry PI. The main module of this system is the Arduino debug board, which serves as a means of data collection and control for other devices. In this implementation, the board is connected to the LED cube, mechanical crane, sensor, etc. Execution of all functionality is performed on the Arduino board, and the assembly and download of executable code is implemented using Raspberry PI. Hardware communication between the two devices is via a USB port. The number of devices that can be connected to the Raspberry PI is limited by their technological capabilities. At the same time, the laboratory administrator once a week sets up stands for research according to user requests, indicating the port - the device file that will be used by the Arduino board, the device name - the device ID that will be displayed on the website where the Arduino processor type is specified, the programmer is the type of programmer according to the processor to be used, Baud is the connection speed and the termination program. This program configures the device with its default configurations. Thus, the laboratory allows students to create a full-fledged system of measurement or control. In addition, the system uses webcams so that the student can visually check the behavior of the test (device) that he performed (created).

The system [12] is a smart laboratory, where all devices are connected to a set of intelligent IoT equipment, and the whole set is placed on a single printed circuit board. All physical parameters in the laboratory are measured in real time and can be viewed on the information panel. Data transfer between all devices is performed using the MQTT protocol. All devices are connected to the Wi-Fi module ESP 8266 and act as MQTT clients, the tool for visual programming of data streams Node-RED (Raspberry Pi 3) acts as an MQTT broker (server). The user can use the smartphone to turn on / off any device in the laboratory via the MQTT server. Also, the condition of the equipment and information about the consumed electricity can be seen on the control panel. The ThingSpeak IoT service was used for data processing and transmission. This whole complex allows you to significantly reduce electricity consumption in the laboratory.

Another interesting implementation is the learning management system using IoT described in [13]. This system implements software and hardware, as well as IoT devices, which are used for interesting experiments in the field of chemistry and robotics. This system is also essentially a module and integrated into the Moodle LMS system, which uses IoT devices and services that improve the learning process for both teachers and students. With this application, students can use Internet of Things sensors and robotic tools to remotely perform an experiment via LMS (Learning Management Systems). At the same time, students gain full control over the equipment and devices for the experiment. In addition, during the experiment, the student always has access to real-time information about the characteristics of the environment and the parameters of the experiment using sensors of the Internet of Things. All these indicators are transmitted to the LMS through the IoT module. The proposed application is integrated into LearnSmart LMS, which is based on Moodle.

The authors of [14] proposed a remote laboratory for the study of photovoltaic systems for remote experiments. The system consists of 3 subsystems: power electronics, sensors and communications. The remote lab is controlled by a dsPIC30F microcontroller, which acts as an intermediary between the web server and the power system. The communication subsystem consists of two parts: communication with the application on the PC via EM203 and communication with the power system and sensors via dsPIC. The graphical interface was implemented in Visual Basic Programming for date storage, user identification, development of measurement strategies, power system management. The maximum duration of one session is one hour. But in reality, the experiment can be performed in 30 minutes, in addition, for each lesson is offered double the time in case students have problems, or there is a need to conduct more tests. Another interesting feature of this system is the feedback of students and teachers through the system or service feedback on the experiment.

From the literature it is clear that there are two main areas of development of smart laboratories:

- the first is the so-called virtual laboratories, where all work with the equipment is performed remotely and students do not have direct access to the equipment, which in some cases is necessary, for example, when monitoring power equipment;
- the second - smart laboratories that provide comfort in a real laboratory and optimization of the workflow and electricity consumption. But they in turn impose restrictions on the number of students who can experiment with real equipment.

For example, if several research stands are connected to a specialized PC and the student uses only one, then why is it not possible for another student to be able to use the free stand remotely. Therefore, it is proposed to combine these two concepts and develop a smart laboratory where students could work both permanently and remotely. In addition, the system should optimize the energy consumption of such a complex. It is also advisable to use an artificial intelligence system for the so-called deferred experiments, which is described below, as well as introduce into the system a submodule of equipment accounting [20] based on NFC technology.

3. System structure

Given the previous work, it is proposed to develop the concept of a smart laboratory, which would combine the capabilities of a remote laboratory and a regular classroom for practical training. In addition, it would be advisable to integrate a system of control and management of electricity consumption by devices located in the laboratory. Due to the fact that such a concept involves complex management of facilities, it is proposed to use as a management manager the ANN apparatus, which would work in conjunction with the IoT cloud service. Figure 1 shows a simplified structure of such a laboratory. As can be seen from Figure 1, the system is divided into two subsystems - control of electrical appliances to ensure comfort in the room and control of training stands. These two subsystems are independent of data transmission and control channels.

The control subsystem of electrical equipment includes all the equipment that provides the educational process, namely the projector, air conditioners and laboratory heating, lighting and other equipment needed to ensure a comfortable learning environment in the laboratory.

In the current implementation, the control subsystem includes the following equipment:

- Smart projector for presentation of lectures or other teaching materials
- Smart Condition for air conditioning control and temperature control in the laboratory room.
- Smart Light - intelligent lighting control system in the laboratory

Additional control systems can be included in the current subsystem based on the wishes of lecturers and students or faculty management.

Each such device, such as a projector, according to Figure 2, is equipped with additional modules - a smart meter for electricity consumption and a specialized relay to control the operation of the projector.

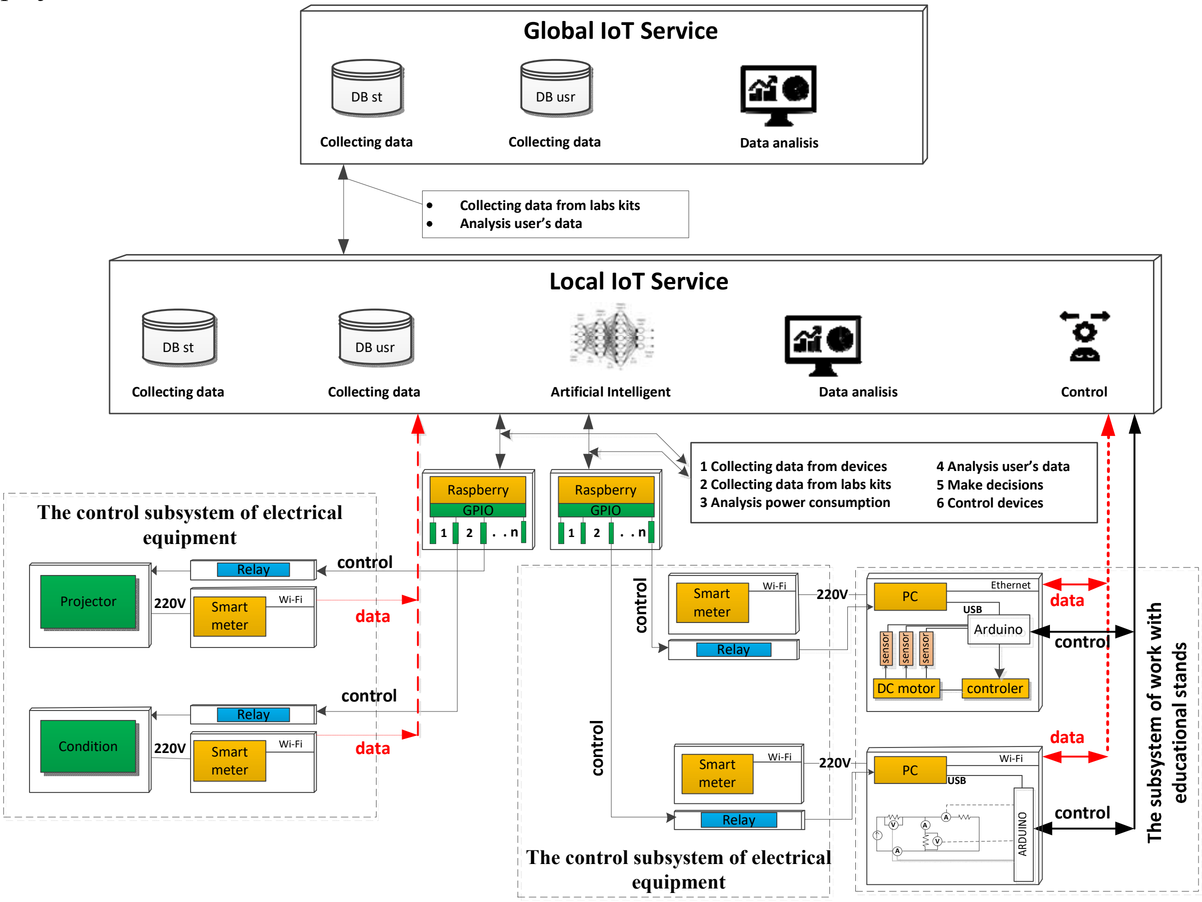

Figure 1: Simplified structure of IoT-based Laboratory

Data collection from the SmartMeter and relay control is performed via a network control controller, such as a Raspberry Pi or BeagleBone board. Such a device serves as a gateway between the IoT service and the equipment. Its main functions include collecting data on the state of the equipment (data is read directly from smartmeters or from the cloud, or simultaneously) and control the inclusion of devices (commands from the local IoT service).

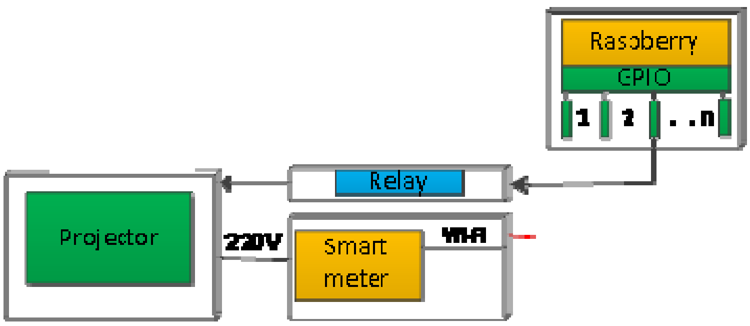

Figure 2: Smart Projector System Structure

The subsystem of work with educational stands works on a similar principle. The stand consists of a PC, where the necessary software to remote access and communication with a debug board (in this case Arduino) or other controller is installed in accordance with the tasks of the stand, sensors and controls. For example, we will consider a stand for Investigation of the simplest DC circuits, the structure of which is shown in Figure 3. The stand includes a PC with software installed, board for getting electric values from investigated DC circuit, a set of sensors for measuring the current and the voltage, etc.

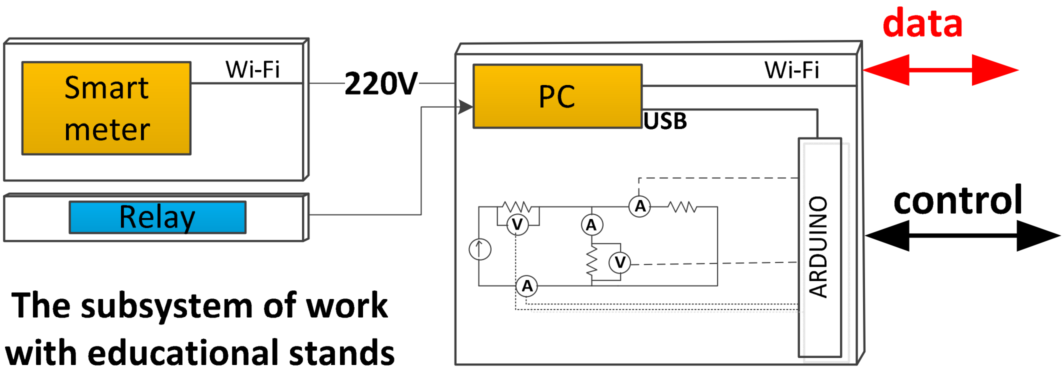

Figure 3: "Smart" stand for Investigation of the simplest DC circuits

To measure the electricity consumed by the stand, a smart meter has been introduced, which sends data on the power consumption of the PC and the controller or the computer power control relay together with the stand. All data is collected and sent to a local cloud service where the student can see the measurement results. Communication with the local cloud service and the PC is provided by a secure local area network (Ethernet).

Figure 4: Local IoT Service

The local IoT service, presented in Figure 4, consists of the following subsystems: 1) user database, which contains information about users and their access rights; 2) databases on measuring equipment and experimental data for each user and stand separately; 3) apparatus of artificial neural networks to control all elements of the laboratory in automatic mode [18]; 4) a set of software for analyzing user data; 5) specialized software for equipment management in remote control mode and in remote experiment mode.

The system also provides a global IoT service for working with remote users, the structure of which is shown in Figure 5. This subsystem has limited functionality. The system has user and device databases, as well as a data analysis system. That is, users can see the results of their experiments, perform data analysis and order a so-called remote experiment, when measurements will be performed only when the stand is vacated. In this implementation, the user will not have direct access to the equipment, but only pre-order the experiment according to the configuration specified by him.

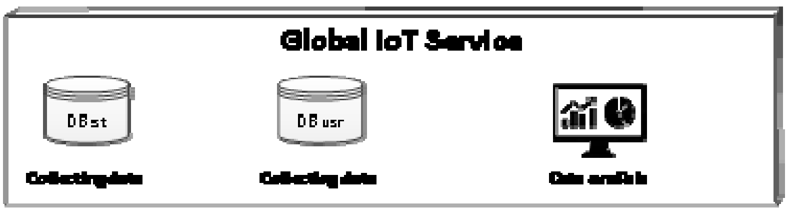

Figure 5: Global IoT Service

This layout enables dividing the work process in the laboratory and ensuring the security of the whole complex [21], because remote users will not have a direct access to the PC and the stand.

In addition, learning should take place where students spend the most time. Today it is social networks. The introduction of social networks [26-28] in a smart laboratory will allow first of all the placement of a variety of materials:

- Announcements - a function when it is necessary to inform as many students as possible in a short time about changes in the educational process (change of class schedule), competitions, Olympiads that will take place in the near future;
- Survey - allows you to take into account the wishes and suggestions through various surveys;
- Photo album - a function that allows you to place educational material in drawings, illustrations, photographs. This is necessary in order to speed up and facilitate the assimilation of educational material;
- Video - this feature allows you to demonstrate the experimental basis for the learning process;
- Materials for learning - diagrams, tables, text material, interesting facts, etc. (everything that reflects the subject of study).

The social network allows the teacher to better remember students (correlate names and faces in the audience), understand their interests and allows them to jointly create and improve the course. Instead of simply consuming information, students become developers and experts in a virtual learning group environment (creating messages, discussions, resources, and more).

Thus, the use of social networks can give the learning process more interactivity, positively affect the results of cognitive activity of students, become an effective means of increasing motivation and quality of learning, organizing teamwork, joint project activities, individualize the student's virtual learning space.

4. Description the stand for Investigation of the simplest DC circuits and experiment for it

The stand (see Fig. 3) includes a PC with the following software: LabVIEW [22] and Arduino_cc [23]. LabVIEW is a system engineering software for applications that require testing, measurement, and control with fast access to hardware and data analysis. The process of developing a SCADA system in LabVIEW is simpler than in "traditional" development tools. It is also a fundamentally different programming language called "G" and is a functional language that is similar in concept to C ++. Arduino_cc is an integrated cross-platform Java development environment that includes a code editor, compiler and firmware transfer module. The environment is based on the programming language Processing. It is similar to the Wiring language. In general, it is C ++, supplemented by special libraries. This combination is chosen because different students have different levels of programming skills and it is desirable for beginners to use the Arduino environment, and senior students can develop projects of a more complex level, where it is advisable to use LabVIEW. The Arduino Expansion Shield for Raspberry board was chosen as the hardware data acquisition and control module [24] because it has more functionality than standard boards and the ability to integrate with the Raspberry Pi.

A classic voltage divider circuit is proposed as a research electrical circuit (Figure 6)

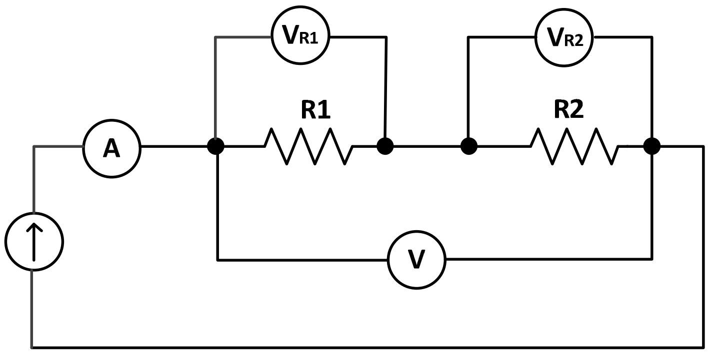

Figure 6: Voltage divider

The stand is based on the previous scheme and includes the following components:

1. controller of data collection from sensors and supply voltage control. In this particular implementation (Figure 7), an Arduino board is proposed, but you can also use another module based on different microcontrollers;
2. analog current sensor Arduino 30A ACS712 on the Hall effect;
3. analog voltage sensor (V1 ... V3);
4. variable resistors R1 and R2 based on digital potentiometer X9C103S.

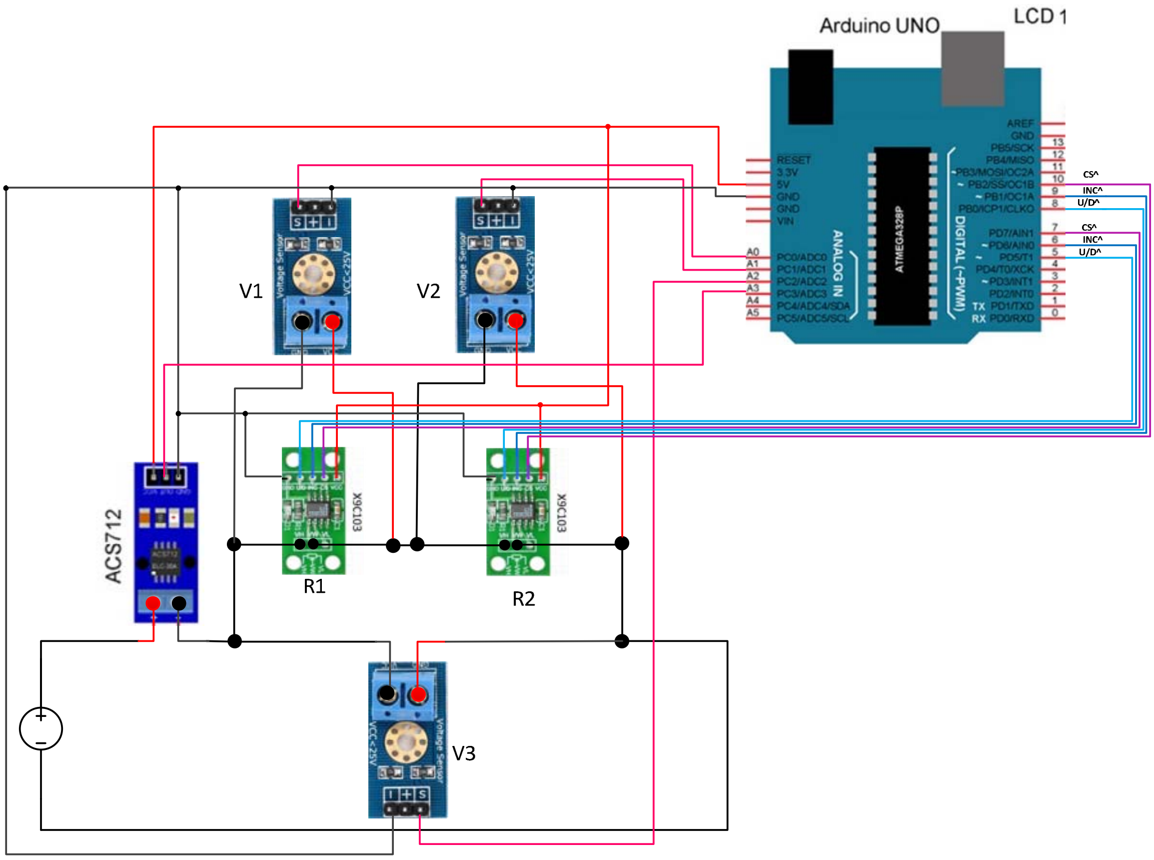

Figure 7: Measurement part of stand

4.1. The experiment

The essence of the experiment is to experimentally check the basic relationships of electrical quantities for DC circuits with series connection of resistors. Student Increasing the value of one of the resistors from 100 * (Number of students) Ohm to 200 Ohm in 20 Ohm steps, fills in table 1.

Table 1
Basic parameters

R1 Ohm	R2 Ohm	I, Amps	V, Volts	VR1, Volts	VR2, Volts
700	200	0.0133	12	9.31	2.66
700	220	0.013	12	9.1	2.86
700	240				

4.2. Software for experiment and remote access

Figure 8 shows the concept of a graphical user interface for conducting an experiment. Despite the simplicity of the interface, it fully provides the necessary functionality and is a network client, and provides control of the queue of experiments and access rights of users (students) to the measuring stand, collection of measurements and control of the change in resistance on digital potentiometers for a specific student card.

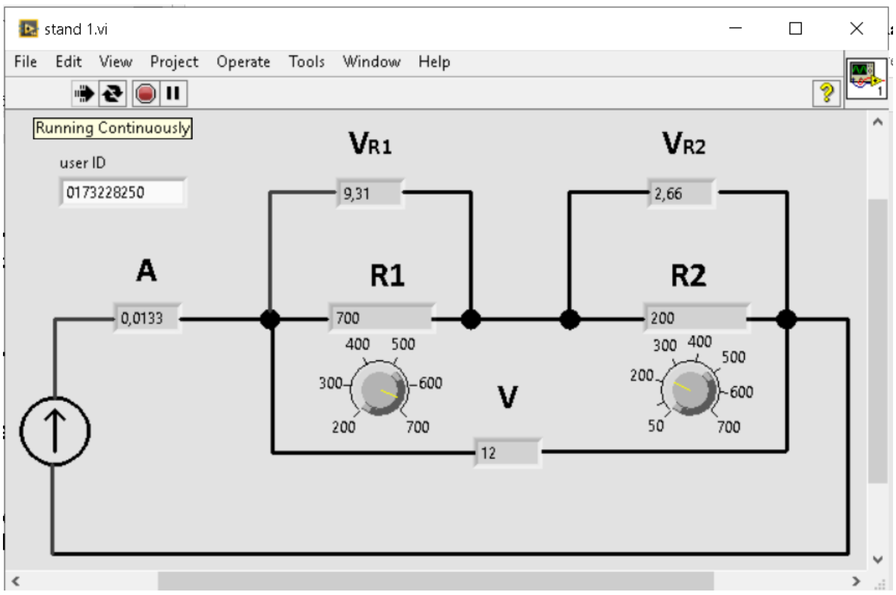

Figure 8: User interface for experiment

In addition to this, the program transmits data to a foggy service for remote access and control. There are two options for working:

1. When a student conducts an experiment locally, the control interface on the fog service will become inactive and will be asked to stand in the queue for the experiment, although the process itself will be visible to other students.
2. If the control and experiment are removed, the main interface on the PC will also become inactive and the student will be asked to enroll in the queue or select another free stand in the laboratory.

All parameters will be collected by the Arduino board and transferred to the PC, from where, after pre-processing (if necessary), they are transferred to the local IoT service.

The control system of the PC itself includes two devices:

1. DELOCK 25242 power supply control controller: ATX Power Supply Controller or its analogue, which will be connected to the Raspberry Pi (see Figure 2);
2. smart current-consumption meter smart-MAC [25], which will independently transmit data to the local IoT service on the electricity consumed by a specific PC.

This information is needed to analyze the total power consumption of the laboratory stands and to further intelligently control the PCs and stands described above, as well as to automatically control the on / off and start of the PCs themselves.

5. Basic functions and algorithms of IoT laboratory

From the above structure of the system (see Fig. 1), the laboratory must have many scenarios for working with users and operating scenarios. In addition, the structure and algorithms of work in this system should be divided into two main classes - algorithms of the subsystem of control of educational equipment in the laboratory and algorithms of software operation of test benches, where research will be conducted (Fig. 9).

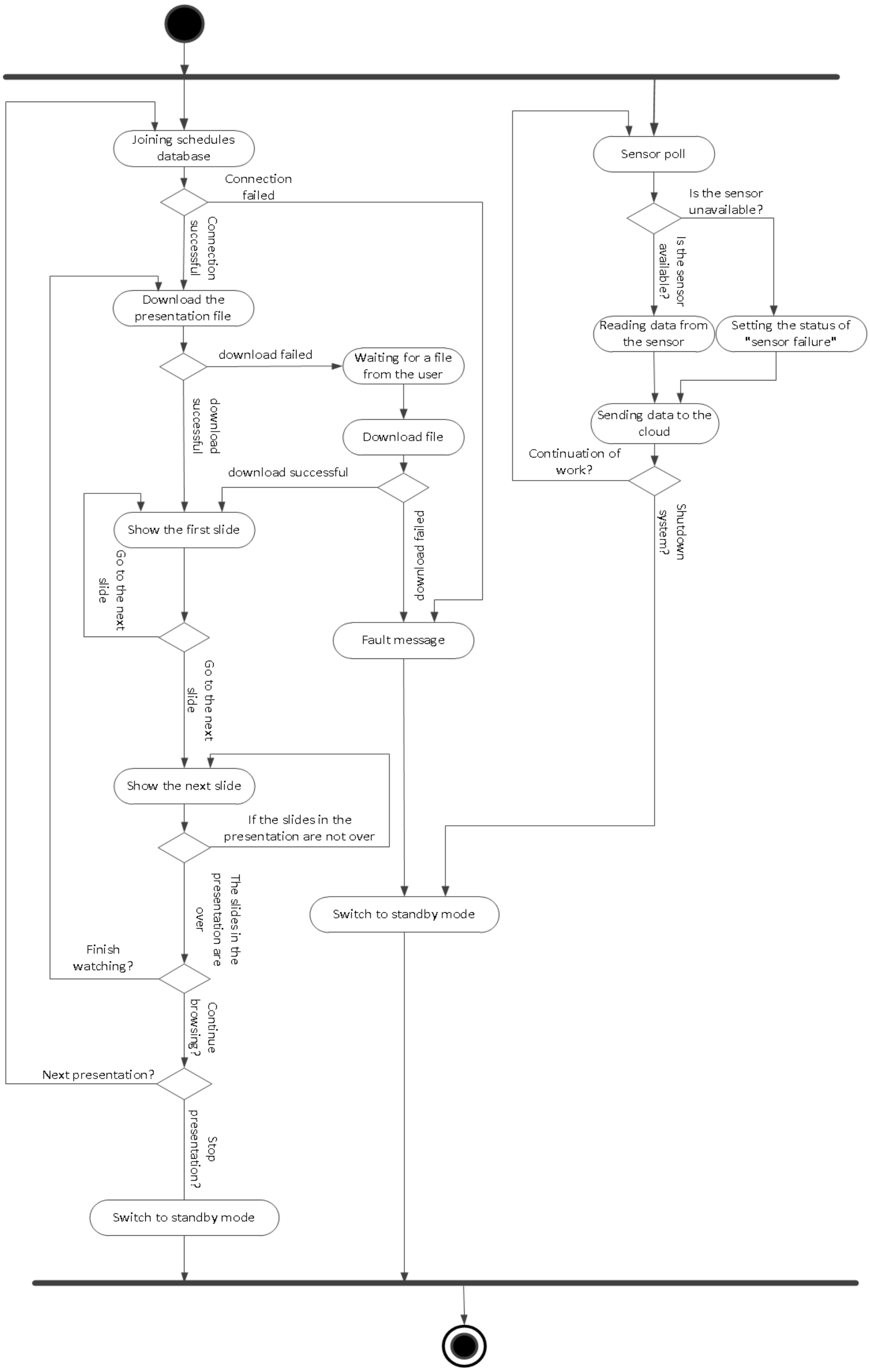

Figure 9: Activity diagram of smart projector system

The main functions of the control system of educational equipment include: control of equipment operation, equipment management, collection of data on the use of equipment, collection of energy consumption statistics of classroom equipment for each device separately and in total.

Below is a scenario of the projector, which is located in the laboratory. The main controller of the projector control is a script that operates on a local IoT service and has access to a database of schedules in a particular laboratory, where it loads the time of laboratory, also downloads presentations of laboratory classes, if already downloaded by the teacher. If (before a certain lesson the teacher) did not download the presentation files, the system simply turns on the projector in standby mode relative to the schedule, and the teacher can use the Web interface to download the presentation or directly connect to the projector and give a presentation. In parallel with the projector works a smart electricity meter, which sends data on energy consumption by the projector. These data are collected on the local cloud service for further analysis by the laboratory administrator (if necessary), as well as for reporting to the accounting department.

6. Conclusions

In this paper, the authors proposed a conceptual model of a training laboratory based on IoT, which combines the functions of a remote laboratory and a regular classroom for practical classes. The general structure of such system and the basic modules of functioning are presented.

Despite the fact that only one test bench is described, it is planned to implement about 10 test benches for each PC (see Figure 1) for different types of tests.

The subsystem of control and management of electricity consumption by the equipment working in the laboratory and the scenario of operation of measuring stands is described. Scenarios for managing objects in this system and working with users are revealed.

In further works, the authors plan to implement the main modules of the system and the use of Artificial Neural Networks for intelligent control and protection of the system as a whole.

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