APPLICATION OF OPEN SOURCE SOLUTIONS IN THE REALIZATION OF LOW-COST TEACHING LABORATORIES

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Teaching in engineering study programs includes practice that often takes place in laboratories. The implementation of these laboratories is often accompanied by certain limitations and complexities. This paper will show how some of these problems can be overcome by using open source solutions on the example of one such laboratory for basic and master academic studies in the mining engineering program, where students are given practical skills in of working with sensors, process monitoring, and similar activities.

Keywords: hardware, measurements, monitoring, open source, sensors.

Introduction

Higher education institutions that carry out their educational activities in the engineering field, mostly base their teaching activities on two basic concepts: theoretical and practical. Theory classes are conducted mainly in the form of lectures, where students are introduced to the basic theoretical concepts that need to be mastered in order to obtain the necessary knowledge from a certain subject. However, for future engineers, the practical application of acquired knowledge is equally important, and in this sense, students also take part in another form of teaching, better known as practical teaching. Practical teaching, depending on the requirements of each individual subject, can be realized in two ways: within classrooms, if the subject is, for example, certain arithmetic exercises, or within adequate laboratories if, for example, it is about getting to know the principles of operation of certain machines and devices, setting them up, performing certain operations on them and the like. Each laboratory represents a special entity with its complexity, special conditions and all other peculiarities that distinguish it.

In this sense, we also have different implementations of laboratories, where individual laboratories can be implemented in an extremely simple way or have a very high degree of complexity of implementation. Certainly, the most difficult to implement are, for example, chemical, nuclear, metallurgical laboratories and the like, where strict measures must be observed in terms of safety and health at work. In contrast to those, today there is a whole series of laboratories that, thanks to the progress in digital and computer technology, can now be implemented in much simpler conditions with much milder procedures related to safety and health at work, and where the risk of working in such laboratories is reduced to some minimal conditions.

This paper will focus on such laboratories, since it is exactly the type often used by technical faculties in the teaching of engineering subjects. However, there should be no misperception about these laboratories. Although easier to perform, these laboratories also have certain problems during their implementation. One of the key problems during the implementation of the aforementioned laboratories for all higher education institutions is the economic factor encountered during implementation. The equipment used in such laboratories can often be a large financial expense due to its specificity, especially when it comes to equipment that is not widely commercially represented and available. Also, since a larger number of planned sits for the realization of work within one laboratory is often required, this means that in most cases only one piece of equipment will not be procured, but certain quantities of each part of the equipment used during the creation of the laboratory will be procured. Since the work in the aforementioned laboratories is based on the use of computers and adequate equipment connected to computers, we must note here that there will be a certain additional increase in costs, since the purchase of equipment in terms of hardware should be planned, but the purchase of certain software must also be foreseen, which additionally increases costs equipping the laboratory.

Taking into account the above, the paper will show how hardware and software concepts based on the open source approach can reduce the costs of equipping such a laboratory without losing the quality of teaching that will be conducted in such laboratories. As an example, the solution of one such laboratory will be shown for the implementation of practical classes in the subjects Process measurement technique in the 4th year of basic academic studies [1] and Automation of technological processes in the 1st year of the master academic studies [2] of the Mining Engineering study program at the Technical Faculty in Bor. Within such a laboratory, students will learn about the basic concepts of automation, work with sensors, measurement process, distribution of results and similar modern aspects of engineering encountered in various production processes.

Implementation

Although the term open source is mostly associated with software, it is applicable to both software and hardware products. Essentially, the application of the open source concept implies the use of such things whose way of realization is publicly available and whose modification and redistribution is not limited by various factors that are mostly encountered in commercial solutions of various vendors. From such a statement it can be seen that there is great potential of using open source solutions in the realization of different teaching processes. Bearing in mind this convenience of solutions based on the open source approach, it was decided that the solution presented in this paper uses the open source approach equally in the software and hardware domains of implementation.

It was essential to create such an environment in which students can become familiar with the modern basics of sensors, measurement and automation. Accordingly, a measurement process was designed where students will implement a specific solution based on the use of temperature, humidity and gas concentration sensors, transfer the obtained data using the appropriate network technology and read them remotely. In this way, students of mining engineering get to know the techniques and technologies that are represented in the modern implementation of various mining facilities, whether it is about exploitation or processing of mining raw materials.

A schematic view of the conceptual hardware implementation is given in Fig. 1, where three key components of the proposed solution can be seen: measurement and data transfer unit, receiving and storage data unit and the client that reads and analyzes the obtained data.

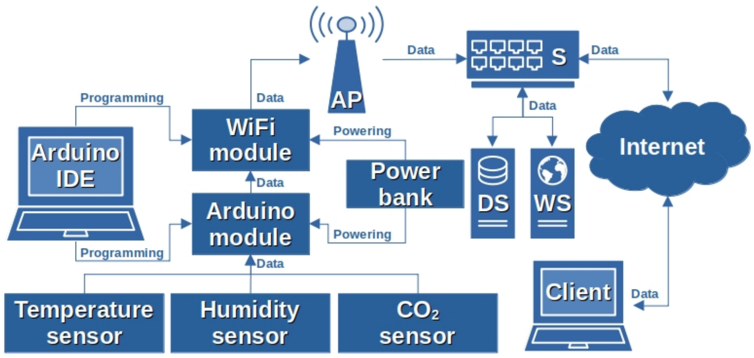

Fig. 1. Conceptual hardware implementation:
AP — access point; S — switch;
DS — database server;
WS — web server

The first level for *measurement and data transfer unit* consists of necessary sensors. The sensor for measuring temperature and the sensor for measuring humidity are integrated into one DHT22 (also known as AM2302) sensor [3] (shown under Fig. 2, *b*). This type of sensor design enables, in addition to cost reduction, to familiarize students with different forms of integrated solutions that can be encountered in specific system designs. CO_2 concentration was measured using the appropriate SenseAir S8 LP sensor [3] (shown under Fig. 2, *c*).

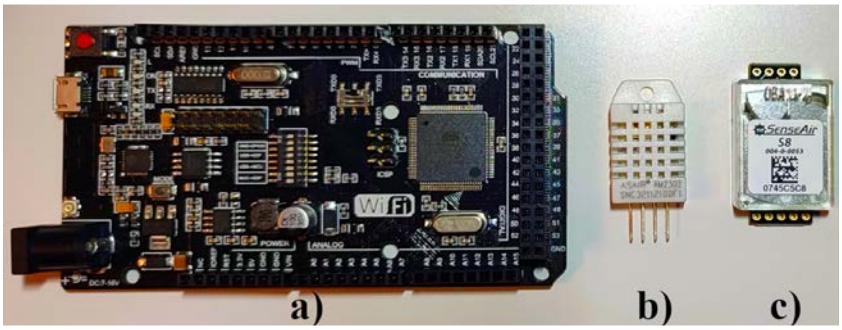

Fig. 2. Measurement components:
a — Arduino compatible board; *b* — temperature and humidity integrated sensor; *c* — CO_2 sensor

At the next level, the data obtained by reading from the mentioned sensors is collected. For the needs of education in this domain, one of the world leaders in the field of open source hardware and accompanying open source software, is Arduino, and that is why the Arduino MEGA 2560 board was initially chosen for connection with sensors [5]. The board itself can be used in various projects, even the more demanding ones, as it has, among other things, 54 digital input/output pins, 16 analog inputs, 4 UARTs (hardware serial ports) and a USB connection. It is planned that further connection with the rest of the planned system is realized by a separate module based on the ESP8266 chip [6], like the famous ESP-01 module [7]. However, an integrated solution was also approached here, since a sufficiently large number of well-documented Arduino-compatible cards have appeared on the market, which also integrate WiFi functionality within the same card using the aforementioned ESP8266 chip. Accordingly, one such card was used in the final solution, which essentially combines the Mega 2560 card and the card with the ESP8266 chip (shown under Fig. 2, *a*). It should be noted here that the card is powered during operation using a 5V/1A USB power from a suitable power bank device with a battery capacity of 10000 mAh which ensures stable operation during several sessions of exercises with appropriate instrumentation.

The first part of the *receiving and storage data unit* represents the appropriate access point within which the appropriate wireless connection is created, thanks to which we can connect the previously mentioned WiFi module and transfer the collected data from the lowest level, that is, from the appropriate sensors to the appropriate LAN. That data is then structured in an appropriate way and stored in a dedicated database. Access to the stored data is possible from any location that has an Internet connection thanks to the implemented web server. In order to reduce the costs of implementation, and since it is a laboratory environment intended primarily for learning, the database server and web server were implemented within the same computer that will represent that dedicated server.

As a final result, the *client* can access the given data, download it and further process it, that is, perform further analysis of the received data in accordance with the desired requirements. Also, in this way, appropriate monitoring of the entire system can be performed on the client side, if the appropriate software is implemented that will display data in real time.

During the software implementation of the proposed solution, certain knowledge from the field of introducing open source software into the subjects of the mining engineering program presented in the papers [8, 9] was used as the already proven concepts.

For programming MEGA 2560 and ESP8266, Arduino IDE has been used on the laptops based on Linux distribution named Fedora Workstation. The said IDE has been installed with the standard sets of libraries distributed through standard Arduino community channels, so the whole environment was stable and proven from the development standpoint.

Access point was also equipped with a Linux-based open source firmware named dd-wrt for compatible WLAN devices including the device used in this particular case.

The server side of the project was implemented using the LNMP stack, which practically means that for the server operating system the Linux distribution was again used, which in this case was Fedora Server, for the web server Nginx was used, the database was implemented in MySQL RDBMS, and for data processing PHP is used on the corresponding base. ER models were used to model the database, which were also developed in open source software called MySQL Workbench and were then translated into specific databases implemented in the MySQL server using appropriate engineering methods [10].

As can be seen, the software that is used within the realized laboratory, whether it is software in the production sense, or the one that has been used and is used for the purpose of development, has been realized entirely in open source domain. This enabled, among other things, minimizing the costs of the used and implemented software as much as possible, i.e., the costs of the software were reduced to zero. Since there are no software costs either during development or during the actual exploitation of the laboratory, this creates a financially sustainable solution for the implementation of the teaching process, since, for example, there are no software licenses that need to be renewed during a certain period of time, or which grow by increasing the number of planned seats in the laboratory and the like.

Conclusion

The paper demonstrates that it is possible to set up a laboratory to be used in the teaching process by applying open source solutions both in terms of hardware and software. As already mentioned, the software for such a laboratory will cost nothing at all. The estimated hardware costs of equipping the presented laboratory in the Republic of Serbia, as per February 2023, are from 3,500 to 4,000 euros for a laboratory with 10 seats (laboratory intended for the work of 20 students). As we can see, the costs are acceptable considering the size and purpose of the laboratory itself. However, it should be taken into account here that the presented solution offers easy adaptation to mobility, so this kind of laboratory can easily be implemented as needed in existing classical classrooms. Also, it should be noted here that these open source solutions follow the corresponding open source solutions in terms of available additional content on the Internet, literature, the existence of very active communities and the like. Thus, the realized benefits of introducing open source concepts are raised to a higher level when observing the educational process and should be taken seriously into consideration as one of the factors that can contribute to raising the quality of the educational process in the volatile environment, in which the process itself is realized.

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Застосування рішень з відкритим кодом в організзації дешевих навчальних лабораторій

Інженерні навчальні програми передбачають практичні заняття, які часто відбуваються в лабораторіях. Впровадження цих лабораторій часто супроводжується певними обмеженнями та труднощами. У доповіді показано, як деякі з цих проблем можна подолати за допомогою рішень з відкритим кодом на прикладі однієї такої лабораторної реалізації для базового та магістерського навчання в програмі гірничої інженерії, де студенти отримують практичні знання в області роботи з датчиками, моніторингу процесів тощо.

Ключові слова: апаратне забезпечення, вимірювання, моніторинг, відкритий код, датчики.