10th International Scientific Conference
Technics, Informatics, and Education – TIE 2024
20-22 September 2024

Session: *IT Education and Practice*
Professional paper
DOI: 10.46793/TIE24.364S

Expanding the Possibility of Performing Laboratory Exercises Using Solutions Based on the use of SCPI and LoRa Networks

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Abstract: *Laboratory exercises are an important part of the teaching process at many faculties. However, despite the fact that today the implementation of laboratory exercises is carried out on modern equipment, the full potential of that equipment is often not used, that is, often some of the possibilities of modern equipment are not fully used in student practice. In the paper, it will be shown on two cases from practice how the student user experience can be expanded by using exactly those "forgotten" options. In the first case, a solution based on the full use of Standard Commands for Programmable Instruments (SCPI), which are implemented on most modern measuring devices, will be presented. The second case will consider the application of open source hardware and software supported by LoRa connectivity, which enables the expansion of the spectrum of exercises performed by students. It will be shown that both solutions can be implemented without a high level of complexity and large financial efforts for the higher education institution itself.*

Keywords: *Arduino, ESP, higher education, instrumentation, Linux, LoRa, SCPI*

1. INTRODUCTION

The modern teaching process conducted within various curricula and accredited study programs at different levels of study within higher education today implies different forms of teaching realization depending on the subjects themselves and defined learning outcomes. The mentioned forms of teaching implementation can carry different names depending on defined nomenclatures and different classifications used, or depending on higher education institutions where class itself will be realized. However, regardless of the mentioned specificity in defining teaching types, it is generally possible to see two general types of classes. The first type represents theoretical lectures and another type involves practical classes. Practical teaching can also be divided into two categories. The first category will include the exercises that are performed in the classroom and on which the solving of certain tasks from a certain area is practiced by calculation. The second category of practical teaching involves the realization of certain tasks within the framework of the foreseen exercises using some instrumentation and the performance of this type of practical teaching is practiced in specially formed laboratory spaces within the higher education institution provided for that purpose.

When talking about laboratory exercises, the way they were performed, until recently, generally meant that they were performed exclusively in special laboratory spaces and in strictly defined terms. This practically means that the students must appear at the defined time in the laboratory and that for a certain time they must carry out the planned laboratory exercise due to the limitation of laboratory spaces in terms of size, amount of equipment, and therefore the time available. It should be mentioned here that in the modern definition of the teaching process, in addition to the teaching implementation model within the premises of the higher education institution, there is also an online teaching implementation model, as well as a hybrid model that includes the combination of the previous two models.

The previously mentioned affects the transformation of the performance of laboratory exercises and the need to modernize them in order to respond to the modern challenges of the teaching process. In this sense, in addition to the performance of laboratory exercises in the mentioned traditional sense, which remains one of the dominant methods of performance, new approaches are also being introduced. The backbone of these new approaches is the increasing introduction of modern information and communication technologies into laboratory processes, as well as the introduction of new methods of realization of laboratory exercises based on ICT. It should also be mentioned that there is a desire to enable the implementation of laboratory exercises based on the principles of remote access to laboratory resources, that is, the possibility for students to realize their tasks using remote principles. In addition, there is a desire of students to obtain practically usable knowledge. Students want to work with equipment that they can encounter in real working conditions, in the field, in companies, institutions, to meet real problems that they can encounter in their future work and after schooling.

On the other hand, the aforementioned often represents additional financial efforts for higher education institutions, especially for those with more modest budgets. There is also the issue of allocating additional space for the implementation of laboratory exercises, hiring additional staff, additional quantities of various equipment, and the like. All this is especially expressed when it comes to larger groups of students in which each student should be given equal treatment and be provided with an equally high-quality approach to achieving learning outcomes.

The paper will show that there are still certain methods that can be applied to the existing classical equipment and that are feasible even with more modest budgets intended for the realization of modern laboratory exercises, and that can provide students with an insight into modern concepts and provide competitive knowledge for further performance. Two real use cases prepared for the improvement of the performance of laboratory exercises in the field of the use of measuring techniques, which can find useful value in a large number of engineering subjects taught at technical faculties, will be considered.

2. THE PROBLEM OF DATA TRANSFER FROM THE MEASURING DEVICE TO THE COMPUTER AND POSSIBLE SOLUTIONS

In relation to the considerations presented in the previous chapter, it is observed that the main task, which should be carried out in order to obtain a complete modern solution for the performance of laboratory exercises, is the integration of appropriate measuring instrumentation into the appropriate computer system in order to obtain a unified information system intended for the realization of laboratory exercises. Several cases can be encountered here.

It may happen that the corresponding measuring instrument does not have the possibility of direct connection with the computer. In that case, it is necessary to create a specialized solution for the acquisition of measurement data that will enable the connection of the instrument and the computer. Such a solution introduces additional complexity into the implementation of the targeted solution, and it can also represent significant expenses for the institution, since the entire measurement-acquisition system must be adequately designed. Also, the appropriate components of the system must be acquired and such a system must be incorporated into the desired solution. Therefore, this solution is not recommended in the implementation of the aforementioned laboratory solutions.

The higher education institution should opt for the acquisition and use of appropriate measuring equipment that has adequate communication capabilities that can be used for further integration. However, before presenting suitable options for the implementation of such a solution, it is necessary to point out the corresponding problems that should be avoided and in this case they may represent undesirable phenomena and solutions both for the institution itself and for setting up a functional laboratory solution.

Today, there is a whole series of measuring devices on the market that have exceptional modern communication capabilities. In recent years, there has been a trend of wirelessly connecting such devices to LAN networks, that is, using classic computer networks for further integration of such devices into larger systems. However, it should be noted here that it is often the case that the implementation of this type of connection of devices often significantly increases the price of the device itself. That often place devices in the category of highly professional devices that are not primarily intended for use in educational processes. The previously mentioned are complicating factors for the procurement of such devices by the majority of higher education institutions due to limited funds within the budget intended for the implementation of such projects. One should bear in mind the fact that it will rarely be the case of the procurement of only one device, but it will be necessary to in accordance with the scope of the teaching process, procure a larger quantity of the same or different measuring instruments.

On the other hand, there are measuring devices that are accessible for purchase by higher education institutions and that have appropriate communication capabilities. However, with such devices, the problem of further integration into laboratory systems may arise, since simplicity of implementation and ease of use by students is desired, while also enabling the overcoming of certain identified problems previously presented in this and the previous chapter. We will explain the above on the example of the Mastech MS8226 DMM (Digital Multi Meter) measuring device shown in Figure 1.

Figure 1. *Mastech MS8226 DMM*

MS8266 is a multifunctional measuring device intended for measuring different quantities in different measurement ranges, where the given range can be selected automatically or manually. What is characteristic of the mentioned device is the ability to act as a suitable data logger [1]. The connection with the computer is originally realized via an RS232 connection. It can also be made by using appropriate RS232 to USB converters, in which case the classic USB port on the computer is used.

Data logging from the measuring device works perfectly when using the connection and the dedicated software that is delivered with the device itself. Through the dedicated software, reading and recording data is performed in a limited format during the measurement. The problem arises when you want to implement functionality outside of the supplied software, that is, when the institution wants to develop its own solution that will be used by the given device. This practically means that the existing software will not be used. It is desired to connect the device to some other software that represents a laboratory exercise, remote access to that software, recording and display in the desired format, and the like. Mentioned are not possible to achieve with the supplied original software.

When you need to write your own program code that will enable work with the instrument, a problem arises. There is no official documentation that explains the way in which the connection with the instrument will be achieved at the level of the program code. In other words, in most cases there is no official documentation from the manufacturer of the measuring instrument that explains the communication protocol. In the specific case of the MS8226 there is no official documentation on the implementation of the serial protocol, so unofficial documentation from different channels such as the one described in [2] and [3] must be used for achieving integration goals. Figure 2 shows an unofficial representation of the Mastech MS8226 serial protocol.

```
Mastech MS8226 serial protocol

2400 8n1
14 Bytes , watch out for serial IR receiver sending junk 15byte strings
First four bits of each byte are position in message , from 1-14
Last four bits are data , each bit represents one element on LCD

  4     3     2     1      __a_
 __    __    __    __     |    |
|  |  |  |  |  |  |  |    f    b
|__|  |__|  |__|  |__|    |_g__|
|  |  |  |  |  |  |  |    |    |
|__| .|__| .|__| .|__|    e    c
    P3    P2    P1        |__d_|

Digits
0          10           20           30         40        50  |
01234 5678901 2 3456789 0 1234567 8 9012345 6789012345678901234 5
00110 1111101 0 0011111 0 0100111 1 1111111 00000000000000000100 034.8
00110 1111101 0 1011011 0 0111110 1 0011111 00000000000000000100 025.3
00110 1111101 0 1011011 0 0100111 1 0011111 00000000000000000100 024.3
00110 1111101 0 1011011 0 0000101 1 0111111 00000000000000000100 021.9
00110 1111101 0 1011011 0 0000101 1 0010101 00000000000000000100 021.7
00110 1111101 0 1011011 0 0000101 1 1111110 00000000000000000100 021.6
||||| 4444444 P 3333333 P 2222222 P 1111111 ||||||||||||||||||||
      efadcgb 3 efadcgb 2 efadcgb 1 efadcgb    d i s p l a y

Display
0         10        20        30        40        50  |
01234567890123456789012345678901234567890123456789012345
00110111110100000101111111010000010101000000010000000001000 nF
00110101101110000101000000101010110111000000010000000001000 uF
01110111110111111101011111010111110100000000000001000 1000 A
01110111110101111101111111010111110100001000000001000 1000 mA
01110111110101111101011111011111110110000000000001000 1000 uA
00110111110101011011001111101101101100000000000000000100 C
00010000001010000010100111111111111100000000000000101000 Hz
00010111110101111101011111010011111000001000000000001000 %
00010000000001111101011010001000000000000000001000000001000 Ohm
00010000000001111110101101000000000000001000000010000001000 KOhm
00010000000001111110101101000000000000000001001000000001000 MOhm
00010000000001111110101101000000000000000100000000001001000 Diode
00010000000001111101011010001000000000000001010000000001000 Beep
01011111110100000101000000101101111100000100000000001001000 mV
01111111110111111101011111010111110100000000000000001001000 V
01110111110111111101011111010111110100000000000101001000 Hold
01011111110111111101011111010111110100000000000100100 1000 Rel
ADAR-||||||||||||||||||||||||||||||||||||unKDmNPBFORHAVHXXCXX
CCUS          d i g i t s          i   e hEo  z
  T2                               o   e mLl
  O3                               d   p   d
   2                               e

51 is probably low battery
```

Figure 2. *Unofficial explanation of Mastech MS8226 serial protocol [3]*

As you can see from the above picture, there is an extraordinary complexity in understanding the serial protocol defined in this way. During a given serial transmission, the buffer that contains the read data at a given moment does not contain simple, easy-to-understand textual data. Data is coded in binary, and it is necessary to understand the coding method to adequately interpret it. At the same time, that method of coding depends on many factors and differs from device to device depending on which quantities can be measured by the device, which ranges are in question, how the given quantities are presented on the given device, display construction and the like.

In the case of the mentioned MS8226, the buffer consists of 14 or 15 bytes that are binary coded , so extraordinary efforts are needed to interpret what was sent from the device at the moment. This method is certainly not conducive to the realization of a laboratory system that will be intended for student training. That system requires simplicity of access and implementation, comprehensibility and the possibility of implementation in a way that is suitable for use by the students themselves, but also for the exercise implementer. Also, since it is a more complex software development, there is a great possibility that in the final implementation, the price of the solution itself will increase, which is not at all in favor of higher education institutions and their budgets.

Therefore, the question arises whether it is possible somehow to realize the laboratory system intended for use by students in some other simpler way. Fast, accurate and simple implementation with the maximum reduction of costs must be enabled, while at the same time the basic idea of such a system realized reflected in the availability and adequate use by students. A possible solution is offered in two directions, which will be presented in the following chapters.

3. USING OF SCPI (STANDARD COMMANDS FOR PROGRAMMABLE INSTRUMENTS)

The Standard Commands for Programmable Instruments (SCPI) [4] was created as a result of the desire to find a uniform way to connect measuring instruments and computers and relies on the IEEE 488.2 standard which already standardized codes, formats, protocols and common commands for those purposes [5]. An important feature that makes a significant difference in the usual practice described in the previous chapters and that enables overcoming the problems encountered with instrumentation is that the entire communication will be correlated with ASCII text. This practically means that all commands given using the SCPI measuring device will be in the form of a classic text string, and also any feedback, whether it is about actual measured data, error messages or status messages, will usually also be given as ASCII text [6]. Therefore, the use of SCPI enables simple, easy, comprehensible and unambiguous two-way communication with the measuring device. These makes it an ideal candidate for use in the implementation of various laboratory exercises in the field of higher education. Thanks to its unique characteristics, SCPI syntax can be easily integrated into numerous programming languages and development environments [7]. It offers a very simple way to integrate into already existing solutions, or the development of a completely new solution that can be started without the need for some more demanding resources.

As an illustration, the development of a laboratory exercise intended for students of technical faculties will be presented, in which the change in impedance depending on the change in the frequency of the electrical signal is observed. A RouShui 4091C LCR meter (shown in Figure 3), which enables the measurement of impedance values for given frequencies in the range from 10 Hz to 100 kHz [8], was used for the realization. The measuring instrument had only an RS232 port [9], so an RS232 to USB adapter was used for connection. The use of such an adapter in no way affects the implementation of the measurement process and the results of the measurement itself.

Figure 3. *RouShui 4091C 100KHz LCR Meter*

For the given frequency values, the value of the given impedance is measured based on the corresponding model connected to the LCR meter. Figure 4 shows an example of such a developed model for the purposes of implementing a laboratory exercise. It should be noted here that several different impedance models have been developed that are connected to the corresponding LCR meters. This was done in order to ensure the diversity of the obtained measured results among the students. If only one model is used, there would be a possibility to exchange results between students based on only one measurement performed. This would reduce the value of the learning outcomes because all interpretations would be based on identical results obtained. Based on the applied method, the student never knows which model is currently connected to the LCR meter, and therefore can only rely on the obtained results of the actual measurement procedure.

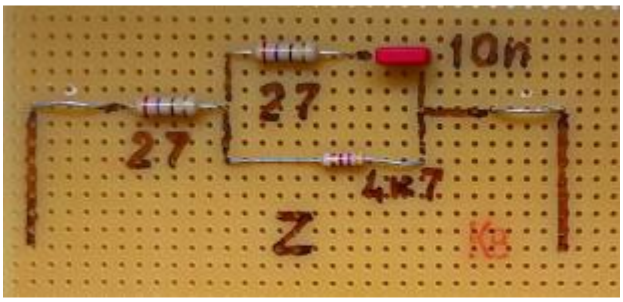

Figure 4. *Example of created model for impedance measurement*

The scheme of the laboratory experiment used by the students is shown in Figure 5.

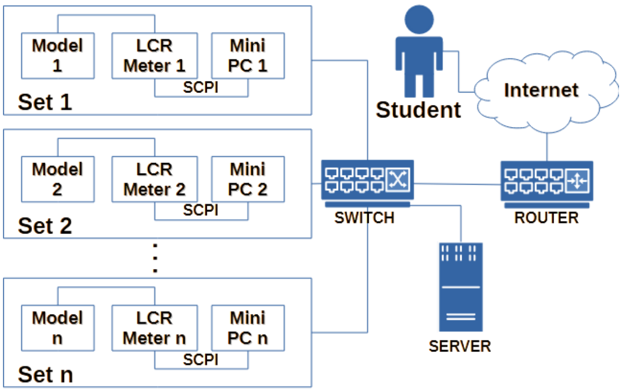

Figure 5. *Scheme of instrumentation for remote conducting of the experiments based on the LCR meter use*

The student remotely accesses the server of the higher education institution that serves the corresponding laboratory sets. The server enables the student to access the appropriate laboratory set that is currently available, that is the one on which the experiment is not in progress. After that, that laboratory set is declared occupied and a console is opened for the student which are located on corresponding mini PC which connected to the proper LCR meter of the laboratory set, on the basis of which the student sets the initial work parameters and starts the laboratory exercise. The measurement cycle lasts about 10 minutes, during which measurements are made for about 40 different frequencies. About 100 individual impedance measurements are performed for each of the frequencies, and then based on those measured values, the mean value of the measurement is calculated. All recorded mean measurement values for the corresponding frequency are stored in the corresponding database. At the end, a suitable Excel file is generated for the student about the completed laboratory exercise with all calculated mean values and corresponding frequencies. This file is later used by the student in order to realize his report on the completed laboratory exercise.

All communication with the LCR meter takes place using a mini PC that is connected using the same SCPI commands used with LCR meters [10]. For example, to set the appropriate measurement frequency, the corresponding SCPI command that is passed to the instrument will be:

FREQ *Frequency_value_in_Hertz*

Data representing the measured values from the measuring instrument are also obtained by sending the appropriate SCPI command to the instrument in the form:

FETCh?

on the basis of which the instrument sends a corresponding text record via serial connection that contains the measured values and which can be further processed as needed by reading them from the corresponding buffer of the serial port. The realization of the entire experiment is therefore based on the communication of the appropriate mini PC with the LCR meter using SCPI commands. These commands are incorporated into the appropriate program code developed in the Python programming language using the standard Python serial module that enables serial communication through the appropriate COM port.

What should be noted is that the entire system was originally developed for Windows operating systems, and then it was successfully developed with slight modifications for the Linux operating system. It should be emphasized that the only modifications concern the fact that the communication with the serial ports and the marking of the serial ports on Windows and Linux operating systems are different. The overall code, including the part related to the implementation of SCPI commands, remained unchanged.

4. CREATION OF OWN MEASUREMENT INSTRUMENTATION BASED ON OPEN SOURCE SOLUTIONS

Modern studying implies that students should be trained to work in real conditions in order to adequately respond to the challenges of the modern environment and expectations set by today's labor market. This means that in terms of setting up the laboratory exercises that the student needs to master, it is sometimes necessary to leave the traditional laboratory framework. This is quite a challenging task that poses many challenges to the higher education institutions. Some of them are the variety of equipment that the higher education institution must own, the spatial and temporal limitations of the laboratories, issue of fitting into the budget projections of the higher education institutions themselves.

Today, this task is easier to do than in an earlier period, thanks to the appearance of a large number of highly available open source software and hardware solutions. What makes these solutions accessible for the implementation of the mentioned tasks in the higher education environment is their affordability, very good documentation, the existence of various support through large online communities, availability on wider markets, including less developed ones, and having the possibility of easy integration into the most diverse solutions. All of this means that today these open source solutions are increasingly being used to accomplish a variety of tasks, not only in home conditions, hobby projects and the like, but that they are slowly being included in industrial applications [11, 12]. It is considered that they should be known and practiced through the system of higher education, since students will encounter, if not identical solutions, then at least similar ones.

One such exercise implemented on the basis of open source hardware and software will be presented below. The exercise simulates the operation of modern measuring stations used in industry to monitor environmental impacts. The developed environment consists of four battery-powered measuring stations, two of which measure temperature and humidity, and two of which measure the concentration of CO_2 gas. All measuring stations are connected via the LoRa network to the corresponding receiving station, through which the data is further transmitted to the LAN network and further, via the Internet, to the corresponding server where the received data is stored.

The entire instrumentation is based on the use of the Arduino compatible board shown in Figure 6.

Figure 6. *Arduino clone with integrated ATMEGA 2560 and ESP8266EX chip on one board*

This board is based on the use of the ATMEGA 2560 chip [13], which allows us to collect data from the appropriate connected sensors. The board has been expanded with appropriate WiFi functionality thanks to the integration of the ESP8266EX chip [14], so it can be connected wirelessly to a suitable LAN network.

To achieve the appropriate functionalities related to the LoRa network, the appropriate Arduino shield manufactured by Dragino company specialized for IoT solutions, shown in Figure 7 was used.

Figure 7. *LoRa shield for Arduino compatible boards*

The RF96 chip [15], which represents the Low Power Long Range Transceiver, was responsible for achieving the LoRa connection in this case. Since the solution was implemented on the territory of the Republic of Serbia, the entire communication is based on the use of the 868 MHz band in accordance with the existing and valid legal regulations.

Figure 8 shows the sensors that were used to obtain values from the environment in which they were located.

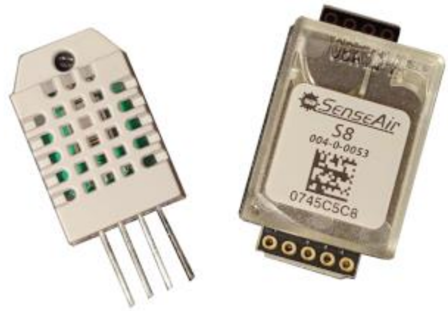

Figure 8. *Used temperature/humidity sensor (left) and CO_2 sensor (right)*

The measurement of temperature and humidity was realized using a standard DHT22 sensor [16] intended for the realization of different temperature projects using Arduino compatible boards. This sensor can also be found on the market labeled as AM2302. The CO_2 gas concentration was measured using the SenseAir S8 LP sensor [17] (SenseAir S8 sensor with identification number 004-0-0053).

Illustrative representation of one measuring station is given in Figure 9. In real operation the corresponding measuring stations are packed in the proper waterproof case. The receiving station is similar in design to the measuring station. There is no physical connection to any sensor at the receiving station. It is consisted only of an Arduino compatible board, a LoRa shield and an appropriate antenna.

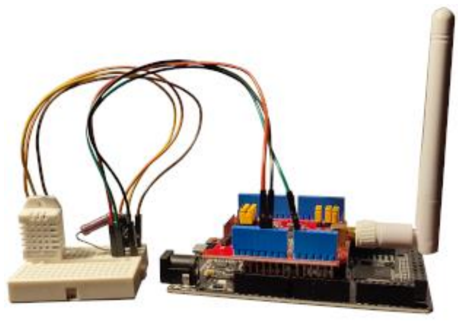

Figure 9. *Example of station for measuring temperature and/or humidity and transfer recorded data via LoRa based network*

At the measuring stations, appropriate LoRa 868 MHz antennas of length 90 and 275 mm were used, while at the receiving station, a corresponding LoRa 868 MHz antenna of 550 mm length was used. All measuring stations were arranged within the faculty campus at a maximum distance of 130 m from the receiving station with a suitable line of sight without significant obstacles that could interfere with the signal. All stations are powered via USB using batteries with a capacity of 10000 mAh (3.7 V/37 Wh) with an output of 5V/2A.

Measuring stations record data from appropriate locations and transfer them via the LoRa network to the receiving station. Thanks to the basic characteristics of LoRa transmission, the transmission is achieved at low speeds that are quite sufficient for data transmission, but that is why the energy consumption is very low and battery power supplies can be used, which enable smooth work of students. At the receiving station from the LoRa network, data is received and converted, and then, thanks to the Wi-Fi connection to the institution's LAN network, that data is stored on a specific server. Students access data from the server via the Internet using special dedicated software written in the Python programming language that enables adequate data export through appropriate Excel files. The students then analyze those files and, based on the analyzed data, prepare an appropriate report that will be proof of the completion of the laboratory exercise. The schematic representation of the key elements is shown in Figure 10.

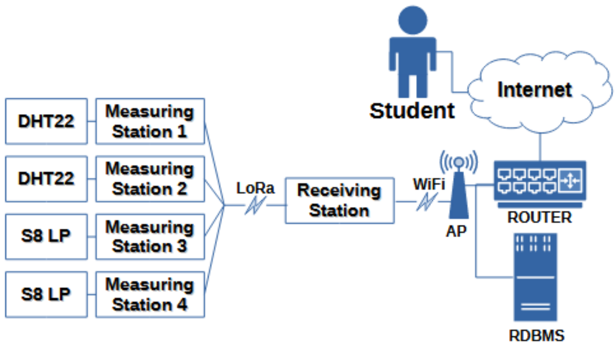

Figure 10. *Scheme of connectivity between key elements of the measurement instrumentation*

This setting enables students to get acquainted with much larger and more complex systems that can be encountered in real work, for example, like the National network of automatic stations for air quality monitoring of the Republic of Serbia [18]. Students can now become familiar with the functioning at different levels of implementation and use, from the data collection sensor to the processing of the collected data. In this way, students get to know the principles that are encountered today during real work in the field in industrial conditions. The segment of data acquisition in the field through specialized measuring stations is covered, as well as the aspect of data transmission from remote locations in the field to the point of receiving that data (collector). Then the students encounter different data transmission technologies (LoRa, WiFi) to the place of data storage. After that, the students get acquainted with the consolidation of data for a certain period of data recording, their analysis and interpretation, and finally, through their reports, the students specialize in giving appropriate explanations based on the collected data (statistical analysis, prediction, etc.). As one of the importance of using this kind of hardware and software environment in the work and education of students, it should be noted that by using this setup, students avoid working with artificially generated data, which is a common practice. Students complete their tasks in this way by using data obtained in real working conditions, that is, they perform all analyzes on real data sets. This further increases the knowledge and ability of the students because mistakes that can occur when using artificial data sets are avoided.

Such realization of the complex conditions in which the given exercise is carried out would previously require various efforts for a higher education institution. The introduction of open source technologies, as can be seen from the previous lines, can bring the realization of such an exercise to a level that is accessible to a large number of academic institutions, regardless of budget size intended to support the implementation of various teaching processes.

5. CONCLUSION

The modern teaching process involves approaching the real needs of the labor market. This practically means that there must be an aspiration that during the implementation of the activities provided by the curriculum, students will encounter real problems and tasks that they will apply as engineers of tomorrow within their work assignments. Sometimes it becomes a very complex task in which you have to overcome a whole series of challenges. One of the frequent challenges that higher education institutions face is the lack of laboratory space, the lack of a sufficient number of equipment for performing laboratory exercises, modest budgets intended for the purchase of equipment for performing laboratory exercises, and the like.

The aim is to enable, in addition to the traditional ways of conducting the teaching process, the implementation of the teaching process in accordance with the modern requirements of the time in which we live. One of those ways is the online teaching process, and it tends to fit laboratory exercises into that process. In the past, these procedures required a very large commitment of various resources, however, there are certain approaches that can make these procedures extremely accessible to higher education institutions.

Two such potential approaches have been discussed in previous chapters. One approach is based on the use of SCPI, which has been present for a long time on the market of measuring equipment, but which, in addition, has not been used to a sufficient extent in the domain of higher education. Although not the latest technology, SCPI certainly has a lot to offer the academic domain. This kind of approach can expand the functionality of measuring equipment in ways that are extremely beneficial to higher education institutions. In a very simple and flexible way, a completely new modern outfit can be added to the existing laboratory educational systems that can help in improving the existing learning outcomes.

Another approach based on the use of open source solutions has long been unfairly labeled as an approach exclusively for home use and hobbyists. However, here lies an underutilized and untapped potential for academic institutions that, with minimal investment, can give students an insight into the most modern processes encountered in today's industry and in other domains of human activity.

The mentioned solutions should definitely be seriously considered in the future, because they can be crucial when it comes to creating an educational model that is modern, competitive and oriented towards students as engineers of the future.

ACKNOWLEDGEMENTS

This research was supported by the Science Fund of the Republic of Serbia, grant No. 6706, Low-dimensional nanomaterials for energy storage and sensing applications: Innovation through synergy of action – ASPIRE and by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (contracts No. 451-03-65/2024-03/200131 and 451-03-66/2024-03/200017).

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