UDC 004.738
https://doi.org/10.31891/csit-2022-4-6

YAROSLAV KRAINYK
Petro Mohyla Black Sea National University

DEVISING ARCHITECTURE FOR REMOTE EDUCATION ORGANIZATION BASED ON A SINGLE-BOARD COMPUTER

The presented paper sets the goal of providing computer engineering courses based on a single-board computers (SBC) with the organization of the remote education process. The devised approach relies on the connection to the local area network (wired or wireless) of the university, making the board accessible to the internal users, and creation of a network tunnel between the remote user and connected parts. These actions are accompanied by assignments of necessary permissions to the users of the system. First, the requirements of each involved actor were considered and as a result of that further understanding of the network communication process, network management and administration, software requirements, etc. was acquired. According to these results, analysis of the capabilities of SBC in terms of its connectivity was performed and, finally, the architecture was realized on the available hardware with regard to the peculiarities of the specific subject. The article establishes all the necessary details on the implementation of the proposed architecture and discusses results of the testing performed as a part of the specific course. During the testing stage, the deployed system based on FriendlyARM Nano Pi allowed us to organize the course on Real-Time Embedded Computer Systems and successfully finish all related activities under circumstances of remote education. It was demonstrated that the proposed organization is reliable as demonstrates conceivable performance even under condition of multiple simultaneous connections to the target board. From the administrative point of view, the solution is highly configurable which is a huge advantage for the lecturer and for the administrator. The devised architecture has a potential in terms of improvement and scalability because it consumes relatively low network capacity and is easy to deploy under any circumstances.
Keywords: Single-Board Computer, Remote Education, Network, Architecture, Remote Access

ЯРОСЛАВА КРАЙНИК
Чорноморський національний університет імені Петра Могили

РОЗРОБКА АРХІТЕКТУРИ ДЛЯ ОРГАНІЗАЦІЇ ВІДДАЛЕННОГО НАВЧАННЯ НА ОСНОВІ ОДНОНОПЛАТНОГО КОМП'ЮТЕРУ

У представленій роботі запропоновано вирішення питання забезпечення навчальних курсів з напрямку комп'ютерної інженерії на основі одноплатного комп'ютеру (ОК) для можливості віддаленого навчання. Запропонований підхід базується на використанні внутрішньої мережі університету (дротової або бездротової) для того, щоб забезпечити доступ всередині цієї мережі, а також розгортанні мережевого тунелю для віддалених користувачів та пов'язаних компонентів. Ці дії супроводжуються налаштуванням параметрів доступу користувачів до системи. У роботі проаналізовані вимоги усіх сторін, що будуть використовувати та забезпечувати функціонування системи. На основі цього отримані вимоги щодо процесів мережевих комунікацій, мережевого адміністрування, вимоги до програмного забезпечення та інші вимоги. З урахуванням цих результатів проведено аналіз щодо можливостей ОК та реалізовано систему відповідно до отриманих вимог на основі наявного апаратного забезпечення та вимог цільового курсу. Робота представляє деталі відносно реалізації запропонованої архітектури та розглядає результати, які отримані під час розгортання системи. Описана система була розгорнута на базі ОК FriendlyARM Nano Pi для проведення курсу Вбудовані комп'ютерні системи реального часу та успішно забезпечила проходження курсу студентами за умов віддаленого навчання. Продемонстровано, що система є надійною з точки зору продуктивності та за умов одночасного підключення багатьох користувачів. З точки зору адміністрування система надає широкі можливості щодо конфігурування, що є значною перевагою для викладача та адміністратору. Розроблена архітектура має потенціал для подальшого вдосконалення, оскільки вона потребує відносно незначних мережевих ресурсів та може бути легко розгорнута з урахуванням наявних для цього можливостей та вимог і обмежень мережевої інфраструктури.
Ключові слова: одноплатний комп'ютер, віддалена освіта, мережа, архітектура, віддалений доступ.

Introduction

With COVID-19 outbreak pandemic situation, education happened to be in the situation where remote tools and technologies are becoming indispensable for the whole educational process. On-line platforms with multiple features, tools for on-line meetings have gained notable popularity during the last period.

During studying engineering disciplines, the deficiency of such tools is getting to its top extent. Since they suppose direct communication with laboratory equipment, this field of education is one of the most vulnerable to this situation. Experimental stage and work with development boards requires availability of this equipment to students.

The goal of this paper is to establish a solution for remote educational process organization that allows usage of a single-board computer during the remote sessions. It should provide necessary capabilities to ensure that multiple students can work with the equipment simultaneously.

The contribution of this paper is in the following:

- established an architecture for remote educational course organization based on a Single-Board Computer (SBC);
- the architecture incorporates networking and processing features of SBC to organize communication with other parts of the system;

– the proposed solution is scalable and can be applied to the multiple boards deployed in the network of the university.

The rest of the paper is organized as follows. The next section reviews contemporary researches that are concerned with technical aspects of remote education organization. The next third section manifests information technology for single-board computer remote access organization. Results and discussion section exhibits practical experience of the proposed means. The conclusions section summarizes the main points of the proposed information technology.

Related work review

While remote education was under big focus before the pandemic situation [9, 10] and advanced notably in the quality and content, the pandemic situation actually pushed it to one of the top trends in science, social life, and technology.

Remote education is developing in multiple vectors [1, 2, 5, 7]. The means involved in this process are also constantly improving. For instance, the society witnessed a huge success of on-line communication platforms such as Zoom and Google Meet. However, for the case of engineering courses, it is preferable to provide continuous access to hardware without presence of the lecturer. Hence, the solution should not rely only on the communication platforms.

There are many well-known systems developed by the leading universities that establish remote access to the hardware located in the internal network. For instance, in TU Dortmund University, within the development of project ELLI [2], remote and virtual laboratories have been deployed. The main topic of the laboratories is Industry 4.0 and engineering education in general. They maintain access to the industrial equipment and handle control of the available technologies. However, while being an advanced example of remote access to educational environments, it concentrates on the manufacturing process.

The remote laboratory of Maintenance 4.0 [3] exemplifies how remote access may be granted to complex equipment. The solution is based on five-layer architecture with the MIMOSA database. However, this architecture cannot be applied for courses where direct communication with hardware is preferable. Administration and programming tasks should be executed on the hardware platform.

The ArPi project [4] has deployed a low-budget educational system based on Raspberry Pi computer and Arduino boards with Ethernet shields integrated into the local network. The system has sophisticated API for communication and a huge set of connected devices. The control system is implemented using hyper-text protocol and is accessible as a web-project. However, ArPi Lab project mainly focuses on the work with Arduino controllers. Raspberry Pi plays the role of a server and cannot be programmed during the course. Since single-board computers are more powerful devices, it is preferable to have additional access to such devices.

The analysis of the actual curriculum of the leading universities in the field of computer engineering demonstrates that they presume work with single-board computers as one of the options for hardware platforms. SBC provide necessary balance of convenient software infrastructure and low-level access to the hardware interfaces [8]. Moreover, as they use Linux-based operating systems predominantly as a main software layer, the transition from desktop software development to development of software for peripheral devices should be smooth and fluent.

One of the latest trends in education is a burst of popularity of virtual reality (VR) [6] and augmented reality (AR) tools. They provide improved digital experience for situations when visual experience is important. However, in case of engineering courses that suppose work with hardware basis and software development, use of AR or VR may be impractical. Thus, students need the technology that allows them to connect to the hardware remotely and execute programming actions.

Therefore, the problem of maintaining computer engineering courses based on SBC with extended access to hardware is still relevant. Remote access to the hardware is the key component for such courses organization. The rest of the paper is dedicated to the solution of this problem using available infrastructure of the university.

Information technology and architectural solution for remote access organization

It is a common case that universities have complex internal network infrastructure that is protected and not accessible from the outside except public resources due to security reasons. When the student has access to the network, all educational resources deployed inside should be completely available. However, as those resources are not accessible from the outside, it poses a huge problem to keep the educational process stable for all participants of engineering courses.

Recently single-board computers (SBCs) like Raspberry Pi, Orange Pi, Nano Pi, etc. have achieved extreme popularity in the engineering educational environment due to their powerful features alongside with affordable price. In fact, many of them are powerful enough to perform complex computations. They facilitate support of novel software libraries and can communicate with external devices. Therefore, they are highly exploited in many university courses.

First, let us explain how SBC may be used in the educational process. The use-case diagram is shown in Fig. 1.

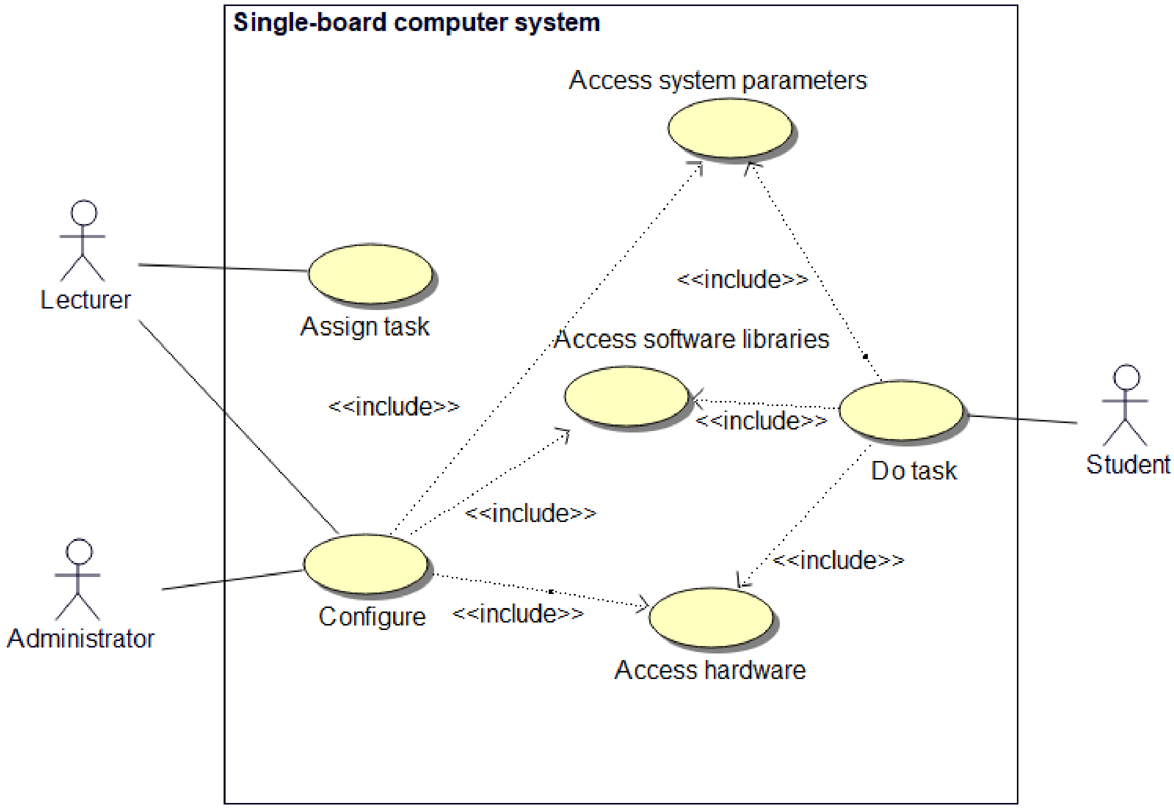

Fig. 1. Use-case diagram of the devised system

Three roles are present in the system. The lecturer assigns a task and has access to the configuration parameters. The lecturer also can configure the system to prepare it for students. This task may be delegated to the administrator. Notice that execution of “Access...” use-cases from the student’s side is not the same as from administrator’s side because of different levels of permissions. For example, while administrator and lecturer has complete access to hardware, the student is limited to its limited set and cannot execute critical functions. The lecturer can install any software while the student can only use software and libraries that are installed. The student’s permissions are restricted to the level required to execute assigned tasks.

Local network integration. To provide remote access to the SBC hardware, first, it needs to be integrated into the local network of the university. Generally, university LAN provides both wired and wireless connections. The first one creates a basis for network distribution on the complete campus. The wireless utilizes resources of the wired network and provides connectivity for user devices (smartphones, laptops, etc.). They rely on Ethernet and Wi-Fi technologies respectively. Hence, there are two options on how to connect SBC to the internal infrastructure. The decision about the medium to connect with should be done according to the requirements to the reliability of connection and throughput. Available interfaces are also to be taken into consideration because many SBCs do not have an Ethernet port.

Hereinafter, three different cases are considered:

- wired connection;
- wireless connection to the secured network;
- wireless connection to the ad-hoc network.

The last two options may demonstrate different situations as even one university student can have both variants depending on the network architecture.

Wired connection. In this case, a conventional configuration file /etc/network/interfaces needs editing. Policy for retrieving IP-address (DHCP or static address), gateway, and network mask are the minimum parameters set to prepare.

To configure connection to the Wi-Fi, it is possible to use wpa-supplicant tool. Its main goal is to simplify the process of configuration of wireless interfaces and automate it. The most convenient way to pass settings to the utility is to prepare a configuration file.

Configuration file for wpa-supplicant tool has a format shown in Fig. 2. First, let us examine configuration for an ad-hoc network.

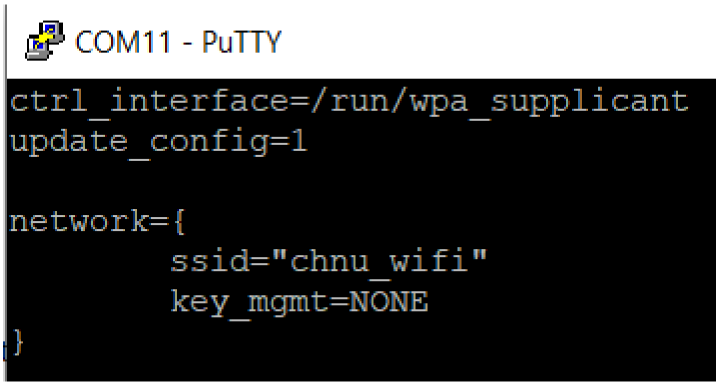

Fig. 2. Content of WiFi configuration file

Ad-hoc network supposes that the user does not need to enter credentials to access its resources. They are quite widespread in various social institutions. It is also quite common for universities to provide such services. As can be observed in Fig. 3, the value of the key management setting is assigned to NONE so no credentials will be used during connection.

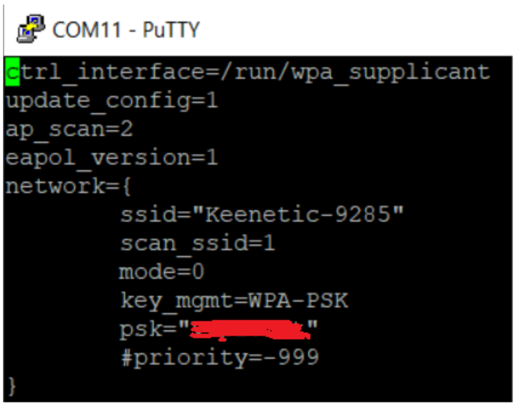

Fig. 3. Configuration for a secured network

To apply the setting during the startup stage, the wireless interface of the SBC has to be prepared by the following lines in /etc/network/interfaces (Fig. 4).

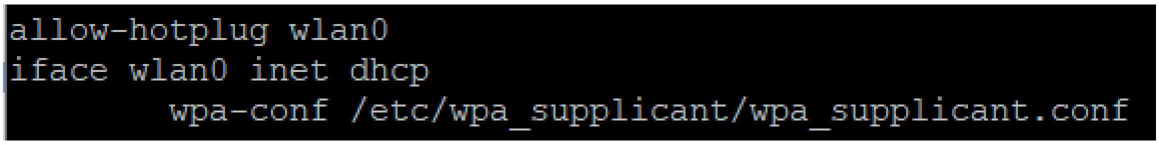

Fig. 4. Excerpt from the network interfaces configuration file

The last line executes configuration stored in the .conf-file.

If a DHCP system is used for IP-address assignment, the address of the board can be reserved exclusively to the SBC to avoid continuous changes. Thus, the address will be known in advance.

Access to the board. The access to the board is established using a common protocol for remote access, Secure Shell (SSH). Therefore, the port 22 must be open for external connections. As long as additional protocols are required, they may be installed by the administrator. To be able to interact with the SBC, the user needs credentials. Due to the security reasons credentials for each permitted user is generated before the start of the course when it is confirmed that he/she attends the course. In this way, no external students will consume resources of the SBC.

In general, the students receive a numerical identifier and associated password to access all university electronic resources. It is convenient to use the numerical identifier to grant permissions to the SBC. To automate this task the script that generates credentials and creates system users should be available to the administrator and the lecturer.

Besides being able to login and execute general commands, the student of the engineering course is supposed to work with hardware components. For instance, access to the I2C or UART by default has only the user with administrator privileges. Without additional configurations, the ordinary user cannot read or write data to/from the device. The permissions can be granted in the following way. First, the list of resources should be identified. Second, each item of the list should be checked for vulnerabilities from unexperienced user's actions. Third, the logging system should be turned on to collect information about all system actions so the possible source of the problem may be detected by logs analysis. As soon as those conditions are met, the administrator can traverse all required resources and provide access to all users or the specific group of users of the system using chmod command. Once again, to automate this task all commands may be placed into a script that runs during the startup.

On the other side, not all settings and permissions can be assigned in advance because the system is dynamic and new instances of devices/modules may appear during the board work. For instance, controlling pins through the virtual file system sysfs leads to creation of directories with restricted permissions. In this case, the lecturer provides permissions by request.

Software libraries. Apparently, students should not have permissions to install new software to the SBC. On the other hand, it is a vital point of multiple learning steps to have an opportunity to write the software part and execute it. Hence, at the preliminary stage, all necessary libraries and programs (compilers, script languages, etc.) should be installed and tested. Typically, the standard setup process configures correct access to the utilities to all groups of users. In opposite, this can be configured by the administrator during the preparation stage.

Remote access. Previously, the remote access to the SBC from outside of the university has been outlined as the main problem. To ensure remote access for students, features of the tunneling protocol are exploited. Point-to-Point Tunneling Protocol (PPTP) is the protocol that allows remote access organization to the dedicated resources in the internal infrastructure. It requires creation of a Virtual Privacy Network (VPN) with PPTP as a communication protocol. Actually, the student connects to a dedicated server that also runs VPN to accept clients' connections. As soon as connection is provided, the client can access internal network resources as if they are within the same network. Hence, the scheme of remote access organization is shown in the Fig. 5.

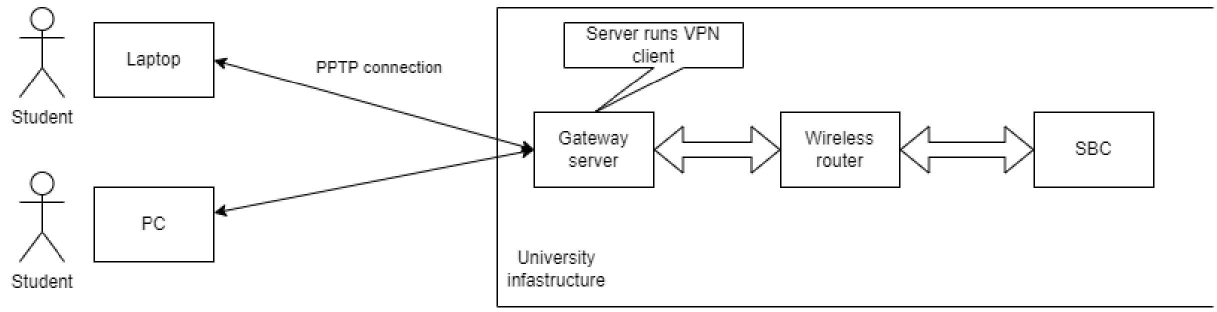

Fig. 5. General network communication scheme for the proposed architecture

Notice, that in order to secure the server, the administrator of the internal network should generate credentials and associate them with the user that has no privileges to harm the whole system in any capacity. Otherwise, the system becomes vulnerable to external attacks. Additionally, to decrease the load of the server, the administrator may limit the number of simultaneous connections.

As soon as VPN is configured, the client can connect to the SBC via SSH-protocol. The lecturer or administrator can execute necessary activities by being on premise (e.g. using UART) as well as having access to the SBC from the remote location.

Results and discussions

During the experimental stage, Nano Pi Neo Air board was used. FriendlyARM Nano Pi Neo Air is a contemporary SBC with rich set of characteristics. It supports WiFi-connection but has no port for wired connection. It has enough memory (512 Mb RAM) and computational resources (quad-core with frequency up to 1.2 GHz) to ensure simultaneous work of a students' group. Because of his small form-factor (40x40 mm) it consumes almost no space and its installation may be done practically anywhere providing a reliable level of WiFi-signal.

All configurations have been done using serial connection to the board. Since there are two wireless networks in Petro Mohyla Black Sea National University (Mykolaiv, Ukraine) that match both described cases, connection was prepared for both networks.

The access to the SBC was provided to the students of Real-Time Embedded Computer Systems (master level). During the course they managed to do laboratory tasks with internal infrastructure of the SBC, connected components, software programming and debugging. The brief list of tasks that were assigned to the students included the following items:

– Introduction to the file system organisation, device identification in the file system;
– Identification of the available commands and their location;
– Work with preinstalled utilities to communicate with a six-axis sensor via I2C interface;
– Deployment of the dummy driver and is demodulation;
– Compilation and execution of a software program that controls connected LEDs or processes measurements from the above-mentioned sensor;
– Usage of the debugging capabilities of the system.

The following peak values of the Nano Pi parameters were observed under condition of approximately 20 simultaneous connections to the SBC:

- RAM usage - 50%;
- CPU usage - 83%.

As demonstrated the values, the peak observed value was relatively high, however, most of the time CPU resources are occupied not more than 10% of the maximum value. The measurements were received from the calls of cron service that initiated logging of the specific parameters into a log file. Additionally, those numbers prove that the solution provides necessary level of scalability despite constraints of the SBC device. While adding one more SBC to the network by the same scenario does not imposes significant difficulties, the benefits of having multiple instances can ensure better load balancing for the resources of SBC deployed.

Conclusions

In this paper, the architecture for remote educational infrastructure organization for engineering educational courses based on SBC usage has been established. The architecture allows complete remote access to the hardware located within the university network. The deployed instance of Nano Pi Neo Air was used during the testing stage. The results demonstrate that students can have access to the computer and have sufficient experience to do tasks remotely.

References

1. Kans M., Campos J., Hakansson L. A remote laboratory for Maintenance 4.0 training and education // IFAC-PapersOnLine, 2020. – Vol. 53, Iss. 3. – P. 101-106. DOI: https://doi.org/10.1016/j.ifacol.2020.11.016
2. Grodotzki J., Ortelt T.R., Tekkaya E. Remote and Virtual Labs for Engineering Education 4.0: Achievements of the ELLI project at the TU Dortmund University // Procedia Manufacturing , 2018. – Vol. 26. – P. 1349-1360. DOI: https://doi.org/10.1016/j.promfg.2018.07.126
3. Gullu A., Aki O., Kuscu H. Remote Access for Education and Control of Mechatronics Systems // Procedia - Social and Behavioral Sciences, 2015. – Vol. 176. – P. 1050-1055. DOI: https://doi.org/10.1016/j.sbspro.2015.01.577
4. Kaluz M., Cirka L., Valo R., Fikar M. ArPi Lab: A Low-cost Remote Laboratory for Control Education // IFAC Proceedings Volumes, 2014. – Vol. 47, Iss. 3. – P. 9057-9062. DOI: https://doi.org/10.3182/20140824-6-ZA-1003.00963
5. Ugur M., Savas K., Erdal H. An internet-based real-time remote automatic control laboratory for control education // Procedia - Social and Behavioral Sciences, 2010. – Vol. 2, Iss. 2. – P. 5271-5275. DOI: https://doi.org/10.1016/j.ifacol.2015.11.212
6. Esquembre F. Facilitating the Creation of Virtual and Remote Laboratories for Science and Engineering Education // IFAC-PapersOnLine, 2015. – Vol. 48, Iss. 29. – P. 49-58. DOI: https://doi.org/10.1016/j.ifacol.2015.11.212
7. Xu H., Sun Y. Remote classroom system for Chinese linguistics teaching based on FPGA and embedded system // Microprocessors and Microsystems, 2021. – Vol. 81. DOI: https://doi.org/10.1016/j.micpro.2020.103785
8. Post L.S., Guo P., Saab N., Admiraal W. Effects of remote labs on cognitive, behavioral, and affective learning outcomes in higher education // Computers & Education, 2019. – Vol. 140. DOI: https://doi.org/10.1016/j.compedu.2019.103596
9. Bawa P. Learning in the age of SARS-COV-2: A quantitative study of learners' performance in the age of emergency remote teaching // Computers and Education Open, 2020. – Vol. 1. DOI: https://doi.org/10.1016/j.caeo.2020.100016
10. Garg S., Diwakar A., Upadhuay S.K., Kumar G., Singh G. EFFECT OF COVID-19 ON SCHOOL EDUCATION SYSTEM: CHALLENGES AND OPPORTUNITIES TO ADOPT ONLINE TEACHING AND LEARNING // Humanities & Social Sciences Reviews, 2020. – Vol. 8(6). – P. 10-17. DOI: 10.18510/hssr.2020.862

Yaroslav Krainyk **Ярослав Крайник**	PhD, Associate Professor, Head of Computer Engineering Department, Petro Mohyla Black Sea National University, Mykolaiv, Ukraine https://orcid.org/0000-0002-7924-3878 e-mail: yaroslav.krainyk@chmnu.edu.ua	кандидат технічних наук, доцент, завідувач кафедри комп'ютерної інженерії, Чорноморський національний університет імені Петра Могили, Миколаїв, Україна.