Augmented Reality in Education 4.0

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***Abstract*—Global progress in the industrial field, which has led to the definition of the Industry 4.0 concept, also affects other spheres of life. One of them is the education. The subject of the article is to summarize the emerging trends in education in relation to the requirements of Industry 4.0 and present possibilities of their use. One option is using augmented reality as part of a modular learning system. The main idea is to combine the elements of the CPS technology concept with modern IT features, with emphasis on simplicity of solution and hardware ease. The synthesis of these principles can combine in a single image on a conventional device a realistic view at the technological equipment, complemented with interactive virtual model of the equipment, the technical data and real-time process information.**

Keywords—augmented reality; Industry 4.0; learning system; Education 4.0

I. Education for Industry 4.0

The emerging technologies have a huge effect on the education of people. Only qualified and highly educated employees will be able to control these technologies [2].

Future workers will need to be highly trained in the emerging technologies but also, as importantly, in the values associated with using those technologies. In the future, we must not only possess the ability to develop the technology but also know whether, when, and where to use that technology. That kind of thinking is both reflective and interdisciplinary [4].

Hence, with Education 3.0, rules, policies, strategies, and even facilities and arrangements must change perspective, providing opportunities for new and emerging learning approaches. Such approaches also alter the way in which disciplines evolve within the learning process [3].

Educationalists debate the many ways in which the content of education – at all levels – and the process of learning, will need to change over the years coming. In article [5], the author also intends and offers his insight into the direction of education in the near future, and mentions it as Education 4.0. He presents the view that education in the future will be a lifelong affair as the introduction of new technologies within the Industry 4.0 concept is very fast.

In Slovakia, like elsewhere in the world, teachers are thinking about the impact of Industry 4.0 on tertiary education. An article [1] by Huba and Kozák describes its impact on learning in the multidisciplinary fields at the Slovak University of Technology. The issue presented in the article, focuses on education in the field of mechatronics. It is an example of how to manage the teaching process within such a field in the 21st century. Authors demonstrate possibilities of implementing this Industry 4.0 concept and Internet of Things (IoT) into the education process in order to facilitate the involvement of university graduates in the industry.

We are offering ways of applying some modern technologies to the education process of vocational subjects. However, our future goal is to further expand the use of new technologies in tertiary education. It is important because students will join the workforce with high-quality education. Graduates could be then well placed on the labor market because the ever-expanding automotive industry and its affiliated supply companies in Slovakia will need such highly qualified staff.

II. Augmented Reality in Education

Augmented reality (AR) is a live direct or indirect view of a physical, real-world environment whose elements are "augmented" by computer-generated or extracted real-world sensory input such as sound, video, graphics, haptics or GPS data [6], [11]. It is related to a more general concept called computer-mediated reality, in which a view of reality is modified (possibly even diminished rather than augmented) by a computer. Augmented reality enhances one's current perception of reality, whereas in contrast, virtual reality replaces the real world with a simulated one [7], [8], [11].

Opportunities posed by the use of AR in teaching are also dealt with by these authors [9], [10] and [11]. They describe the advantages and disadvantages of its use in teaching and usage in different scientific disciplines. They also compare the impact of using AR versus conventional learning on students.

In teaching of technical subjects, the use of AR is an advantage facilitating the teacher's work. When using AR applications in a laboratory, it is not necessary to explain every component of the device used by the student during the seminar. This information is available in real time on their smart devices (mobile phone, tablet, and notebook). Students are thus lead to greater autonomy of work in the laboratory. Of course, these applications need to be supplemented by communication modules with a teacher who, if required, can correct any ambiguities and help students.

III. LEARNING SYSTEM FOR MODERN INDUSTRIAL AUTOMATION

Our project is focused on the implementation and utilization of the Industry 4.0 concept with a view to modernize the teaching of subjects in the field of industrial automation in specialized laboratories. One of these laboratories, Laboratory of Control Systems for hybrid processes, is designed in accordance with Industry 4.0 concept so as to offer students progressive methods and elements in the education process. In a set of technical resources used for the teaching of subjects in the field of industrial automation we can include the hybrid manufacturing system AFB from Festo Didactics (Fig. 1) the block diagram of which is shown in Fig. 2.

Fig. 1. AFB Training Factory in Laboratory of Control Systems

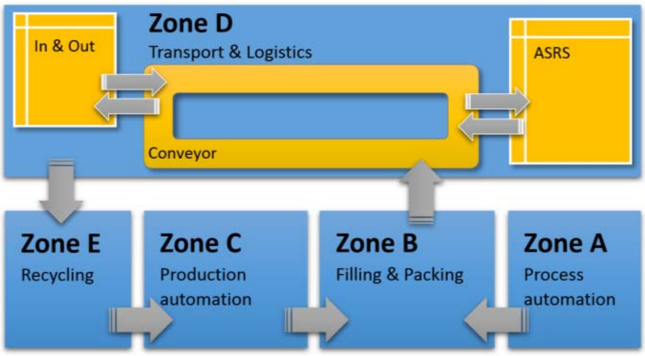


Fig. 2. AFB Factory zone diagram

Due to the complexity of the AFB Factory system, at the initial phase of the project, the development was focused on the part labeled Zone A. This zone represents an automated material pre-processing station and represents process automation (PA) elements. It consists of two parallel branches for the processing of liquid and solid (bulk) goods (BG). The subject of this paper are workstations for processing the solid goods. This part of the system consists of three workstations.

1) Quality Control (AFB PA BG_QC)

Solid material is moved via a belt conveyor to the inspection slide. Three optical color sensors check each single material piece. Material of defined color (representing defective pieces) is blown into a separate container by a fast switching valve. Other (in our case yellow) material is transported to the next station via a pressure conveyor system. The pressure conveyor system uses a stainless steel hopper with a flexible hose and rotary receiver. The pressure conveyor can be switched on by a pneumatic valve. Process value in this station is count of material pieces, which represents quantity-oriented material batch processed in this station and is transported to Vibration Conveyor station.

2) Vibration Conveyor (AFB PA BG_VC)

Solid material is transported with a shaker conveyor out of the supply tank. Shake conveyor in this case can be used for material cleaning or material sorting by its size. The station contains the pneumatic service unit for pressure transportation. The material is transported to the next station via a pressure conveyor system. The pressure conveyor system, like the Quality Control station, uses a stainless steel hopper with flexible hose and rotary receiver. The pressure conveyor can be switched on by a pneumatic valve. Process value in Vibration Conveyor station is the time, which represents time-oriented material batch processed in this station. This material batch is subsequently transported to Dosing station.

3) Dosing (AFB PA BG_D)

Solid material is transported with a screw conveyor out of the supply tank connected to industrial weighing system. The material is transported to the next station via a pressure conveyor system, which uses a stainless steel hopper with flexible hose and rotary receiver. This pressure conveyor can be switched on by a pneumatic valve. Process value in this station is the material mass, which represents processed volume-oriented batch of material and is transported to Zone B of AFB Factory.

B. Learning system structure

The proposed concept of learning system design allows improvement of teaching the subjects focused especially on industrial automation using technological concept CPS (Cyber-Physical Systems). The system architecture is database-oriented. The database can contains teaching materials of various education fields. The system can be used by students as well as pedagogues during the learning process itself, but also during home self-study. The system supports student's autonomy and their analytical thinking and serves as a teacher's help tool in the education process [11].

The system has a modular structure, as is shown in Fig. 3. This proposed concept enables the students to use their own tablets or smartphones together with CPS technologies (VR, AR, QR code) for identification of individual components or entire subsystems used in solving tasks. They can get manuals, connection schemes, technical documentation and other, as a relevant information about the component or device. The system allows them better understanding functions of these technical objects by using the CPS philosophy [11].

The learning system architecture is based on an open source Content Management System WordPress, whose modular structure perfectly meets the requirements for such oriented systems [12]. The database of learning system core is implemented in MySql server environment and is enhanced by a custom data model of the learning part of whole system. The possibility of creating the communication module between the core of the learning system and the process level of the AFB Factory is provided by expandability of the system core by user's javascript or php modules, plugins or snippets [11], as is shown in Fig. 4.

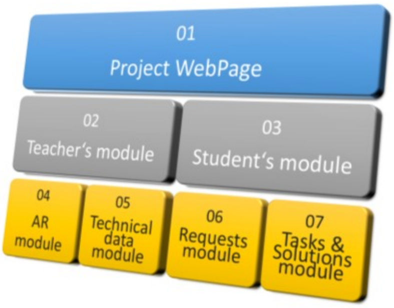


Fig. 3. Modular structure of learning system

Data sharing from the process level to the AR module is realized by the application webserver request to the PLC webserver of a particular workstation. Specific workstation is identified by the QR code implemented into the station AR marker. These data are then processed by an application on the client side, whether in a simple graphical form, or are used to change the properties of objects of the virtual scene. The visual part is supplemented with the technical data of the selected technical element and its superior unit (workstation) which are retrieved from the database located on the application server.

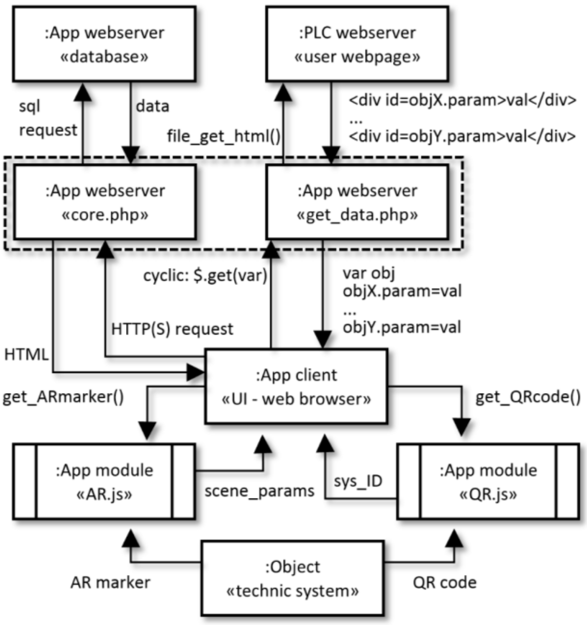


Fig. 4. Communication diagram of augmented reality part of learning system

Final learning system is a resulting product of combination of above-mentioned technologies into one unit. It allows displaying the near-real-time process data from industrial automation objects together with their technical information in a common web browser. It is all done with minimal hardware and software requirements and known as mixed reality [11].

C. *Reaction of the system in real environment through traffic analysis*

The display of real-time information from PLC in local area network depends primarily on the quality of the transmission infrastructure. Due to the real-time way of displaying data from the PLC, it is important to know the delay of displayed data in application against real processing time. Total processing time is influenced by several parameters, especially the quality of transmission paths, the number of hops between the endpoints and total network load.

In this case the communication model depends on physical structure of local area network, together with the placement of individual objects and parts of the realized learning system.

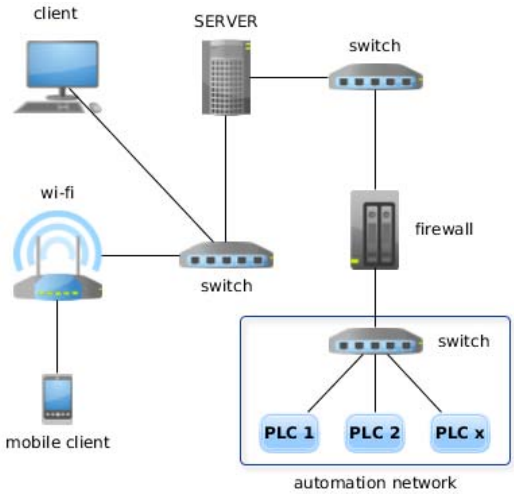


Fig. 5. Learning system network infrastructure

According to the Fig. 5, it is clear that the system is located within a complex network environment with lots of components. Overall system delay is a sum of TCP handshake, client request and server response. The server response time includes values like communication with PLC, reading values from PLC and their processing on the application server side. Accurate assessment of individual part latency and its impact on overall latency is relatively difficult. In this case, for the sake of simplicity, it is not necessary to know the partial latency times in each part of the network, but the total time of the client's request to and the response from the server is sufficient. The easiest way to determine network latency between two points is to use the ping command in the operating system environment. The disadvantage of this method is the dependence on the ICMP protocol and the specific TCP port. This method is also not suitable for transferring larger blocks of data. Standardized packet size transferred by ICMP in IPv4 networks is different. Most importantly, the packet consists of 20 bytes of IP header, 8 bytes of ICMP header and payload which can be variable, but often the packet reaches 64 bytes. Variable payload is limited by maximal transfer unit size (MTU) in Ethernet v2 networks, which is approximately 1500 bytes by default.

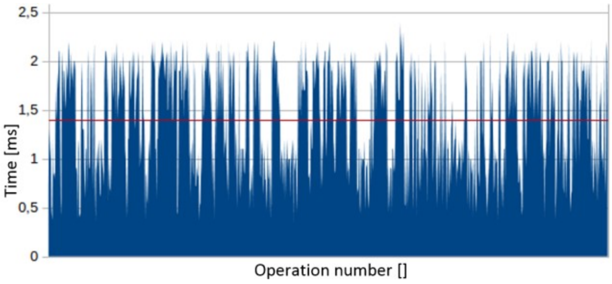
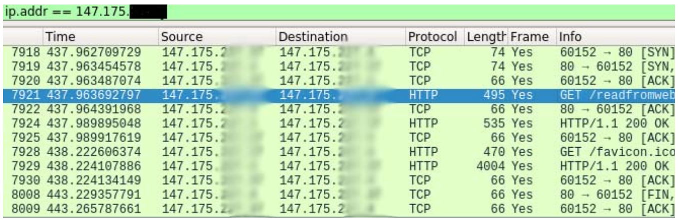


Fig. 6. Ping latency between client and server

The latency of ping measured in the network between client and server is shown in Fig. 6. The ping size was chosen near the maximum size of transfer unit, which is 1450 bytes. The red line represents the middle value, which is approximately 1.4 milliseconds, and confirms a good condition of connection between client and server.

Another possibility of network analysis is an application response in real operation measurement. To measure the total time of client request to PLC, passive monitoring of TCP/IP communication protocol between client and server can be used. Every data transfer in TCP/IP networks is starting with SYN states, SYN/ACK states of TCP protocol by establishing and FIN/SYN/ACK by terminating the connection. It is possible to measure the time elapsed from the beginning of the communication until the end of the transmission by using the appropriate tool. A network monitoring software Wireshark can be suitable tool for this case [13]. Thanks to the every packet time stamp, it is possible to relatively accurately determine the beginning and the end of whole communication.



ip.addr == 147.175.[redacted]

	Time	Source	Destination	Protocol	Length	Frame	Info
7918	437.962709729	147.175.2	147.175.	TCP	74	Yes	60152 → 80 [SYN]
7919	437.963454578	147.175.	147.175.	TCP	74	Yes	80 → 60152 [SYN,
7920	437.963487074	147.175	147.175.	TCP	66	Yes	60152 → 80 [ACK]
7921	437.963692797	147.175.	147.175.	HTTP	495	Yes	GET /readfromweb
7922	437.964391968	147.175.	147.175.	TCP	66	Yes	80 → 60152 [ACK]
7924	437.989895048	147.175.	147.175.2	HTTP	535	Yes	HTTP/1.1 200 OK
7925	437.989917619	147.175.	147.175.	TCP	66	Yes	60152 → 80 [ACK]
7928	438.222606374	147.175.	147.175.	HTTP	470	Yes	GET /favicon.ico
7929	438.224107886	147.175	147.175.	HTTP	4004	Yes	HTTP/1.1 200 OK
7930	438.224134149	147.175.	147.175.	TCP	66	Yes	60152 → 80 [ACK]
8008	443.229357791	147.175.	147.175.	TCP	66	Yes	80 → 60152 [FIN,
8009	443.265787661	147.175.	147.175.2	TCP	66	Yes	60152 → 80 [ACK]

Fig. 7. Network communication monitoring by Wireshark

In the example case, depicted in Fig. 7, the communication started in time 437.9627 sec. with TCP packet number 7918 and data where acquired in browser in packet number 7924 with timestamp 437.9898 sec. After receiving data the communication continues with next packet with number 7925 and timestamp 437.9899 sec. That means that the communication lasted approximately 27 milliseconds.

Overall performance analysis, depicted in Fig. 8, shows the times recorded during 100 values downloaded from the server to the client application. Red line-marked median means that the time of processing the requirement of the server to the client's case to load one process value from one PLC takes on average 27.4 milliseconds.

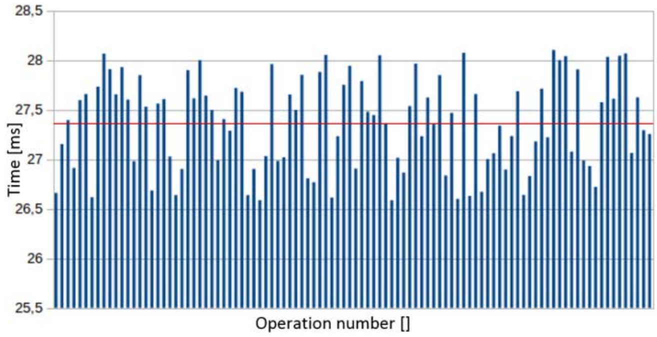


Fig. 8. Network performance analysis

D. Augmented reality module

A virtual scene is created by 3D web framework A-Frame [14] and consists of schematic models of industrial automation objects as parts of superior units. Example of Dosing station (Fig. 9) virtual model is shown in Fig. 10. Object behavior can be implemented in two ways. Either by direct animation of elements of technical object model, or by involving complex animations into the model and by their following parametric activation. The created virtual scene is subsequently embedded into augmented reality by open source project AR.js [15]. The information about the examined object is carried by personalized hybrid AR markers. This technology is also used for virtual scene repositioning and reorienting with regard to the observer [11].

Fig. 9. Zone A - Dosing station

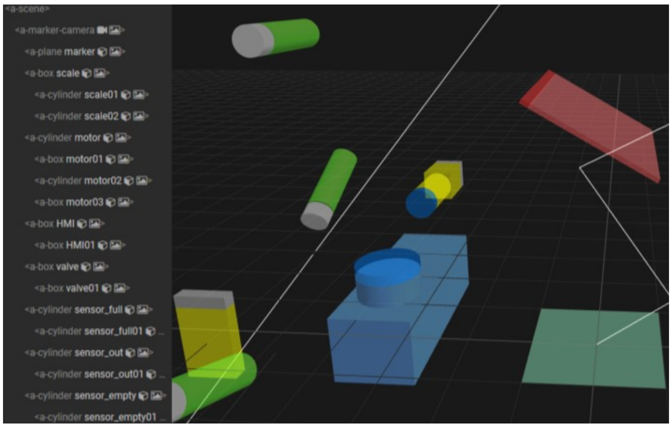


Fig. 10. Virtual model of Dosing station

Virtual model of processed part of Dosing station contains essential elements of industrial automation, listed in TABLE I. These elements are represented as interactive objects linked into records stored in a database of the main learning system.

TABLE I. STRUCTURE OF DOSING STATION VIRTUAL MODEL

Real object	**Virtual object**	**Database object (Table Objects)**
Single point load cells for static and dynamic weighing HBM PW18C3	<a-box scale> blue	Object_ID: 11 Name: Single point load cell
Brushless DC motor with an integrated speed control Dunkermotoren BG 65 SI	<a-cylinder motor> yellow	Object_ID: 12 Name: Brushless DC motor
3x Capacitive proximity sensor Bernstein KCB-M18PS/010	<a-cylinder sensor_full> <a-cylinder sensor_empty> <a-cylinder sensor_out> green	Object_ID: 13 Name: Capacitive proximity sensor
Solenoid valve CPE14-M1BH-3GL-QS-6	<a-box valve> yellow	Object_ID: 14 Name: Solenoid valve
HMI Panel SIMATIC TP700 Comfort	<a-box HMI> red	Object_ID: 15 Name: HMI Panel

A wide spectrum of hardware can be used in the learning process. The learning system in form of web application can be viewed using many different devices: desktops, tablets, and phones. The design of the whole proposed learning system, especialy its augmented reality part have to meet the requirement in order to be responsive. This requirement in our case is realised with utilisation of W3.CSS, modern CSS framework with built-in responsiveness [16]. Preview of augmented reality part of final web-based learning application is shown in Fig. 11 displayed on smartphone, or in Fig. 12 displayed on PC monitor.

Fig. 11. Augmented reality in education on smartphone

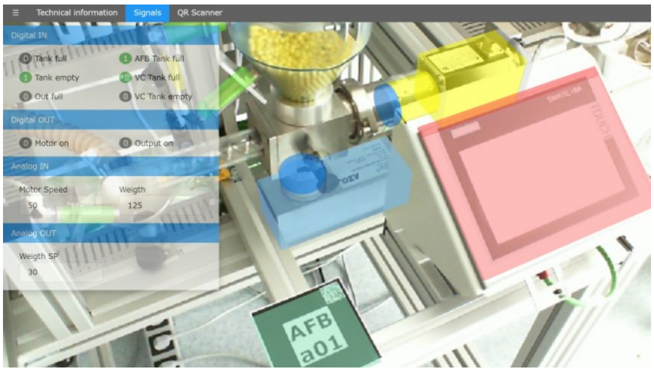


Fig. 12. Augmented reality in education on PC

IV. CONCLUSION

The design and implementation of interactive learning system, involving modern technologies and principles, is a partial objective of an ongoing project. The project deals with increasing efficiency and popularity in the teaching of technical subjects, specially focused on industrial automation. The way how to improve student's theoretical knowledge when working with real technical objects of industrial automation in specialized laboratories is augmented reality. Our primarly goal was to show, how it is possible to use popular and modern information technologies on ordinary mobile devices without the need for specialized software or hardware. In the proposed system, every learning object is represented by its virtual model, that is processed and mixed with the real image of the real technological object in web environment. The information about the examined object is carried by personalized hybrid AR marker technology, which is also used for virtual scene repositioning and reorienting with regard to the observer. All the mentioned technologies form an interactive scene based on real view. This scene provides all required information stored in the learning system database. The scene is also supplemented by near-real-time process data from the control parts (PLC) of each technological subordinate system of presented production line.

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