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AN AUGMENTED REALITY SYSTEM FOR IMPROVING HEALTH AND SAFETY IN THE ELECTRO-ENERGETICS INDUSTRY

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Abstract. *Occupational safety has a crucial role in every technological process in industry environments. Recently, smart mobile devices have become standard hardware that can help inform workers about their duties and procedures during work. In this paper, we present an augmented reality (AR) system for mobile devices as a tool for safeguarding health and safety, and the secure performance of tasks in a technological process by following virtual instructions in the workplace.*
In a case study, we explored the task procedures and defined the risk factors in the electro-energetics industry. Based on that, we implement a corresponding AR system that should be used to issue occupational safety and work instructions to workers during task execution. With that aim in mind, we designed a client-server architecture to project the related instructions on the screen of the mobile device, to ensure the confirmation of implementing them, as well as to keep a record of all the steps the worker performed. As an illustrative example, we present the application of the designed AR system to particular tasks in electro-energetics industrial plants.

Key words: *augmented reality, occupational safety, mobile systems, industry.*

INTRODUCTION

Smart mobile devices, such as mobile phones and tablet PCs, have become important tools for resolving many tasks in the daily work routine in many areas. In industry especially, there are many technological processes whose complexity demands a high level of knowledge and expertise from workers, as well as imposes considerable challenges in preserving occupational safety. The diversity of the devices and equipment that are parts of the technological process require detailed knowledge of specific elements involved in the process, and of the safety measures that have to be appreciated and consequently performed strictly as defined by various regulatory issues.

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In such situations, smart devices offer a convenient way to quickly provide the relevant information necessary for resolving a particular task with the undertaken occupational safety measures. The imperative is that the information should be presented in an intuitively clear way, to allow the simple implementation of related instructions.

According to that, the fast search for relevant information depends on the technology implemented in a particular smart device. Also, the presentation of such information, in terms of task completion, should be simple and clear enough. The interface between a user and the real word is provided by the relatively new and extremely fast-developing technology of Augmented Reality (AR). This technology gives the user augmented information by mixing the real image captured by the camera of the mobile device and the virtual content prepared to explain the context of the captured real space in real time [1].

Particular applications of AR have been developed for industry purposes, where this technology is primarily used to give assistive information to the worker [2, 3, 4, 5, 6] in fields such as maintenance and repair of various devices and systems [7, 8, 9], manufacturing and assembling [10, 11], collaboration, management and product design [12, 13, 14], and training procedures [15, 16].

Considerably fewer research efforts are devoted to the usage of AR in improving the occupational safety in industry [17, 18, 19]. Even less research in this area addresses human resource management. This observation was a motivation for our project focused on of the author towards an application of AR in combined human resources management and occupational safety improvement in industry environments [20, 21]. In this paper, we extend our research in the same direction, that is, towards further applications. The goal is to show that the same principles and the corresponding system as in [21] can equally be applied in another industry environment and with different tasks which should be performed under considerably stronger demands from occupational safety point of view.

For this research, we chose the electro-energetics industry in order to test our system for providing safety and work instructions by taking into account both the complexity of the task that needs to be performed and the expertise of the worker to whom the task is assigned. Compared to previous work reported in [21], main differences and new issues addressed in the present considerations can be summarized as follows.

Since the work procedures in the electro-energetics industry are very strictly formulated, in the present research we focus on preventing various exceedance situations which occur due to requirements to work with high voltage and strong current installations and systems. Another aspect we address in the present paper is an extension of the existing methods towards the usage of cross platform tools like EasyAR SDK [22], which is a tool for creating augmented reality mobile applications for both iOS and Android platforms. In the previous system, instead of the EasyAR, Vuforia [23] was used for marker tracking in our AR system. Further, the Symfony framework [24] is used on the server side instead of native PHP in previous work. This framework enables implementation of more sophisticated web service that can handle data stored on the server side. Also, it can be a server for applications based on different mobile platforms.

Regarding implementation issues, the difference with respect to the previous system [21] is that in the present case we include two image plaits instead of a fiducial marker to test the proposed solution for the AR system. This way, the worker can easily find the corresponding object of recognition to be informed about tasks in a more intuitive way without devoting much time to searching for it.

IMPROVEMENT OF THE PREVIOUS SYSTEM

Previous work was presented in [21] as an original solution in the design of an augmented reality system for the implementation of occupational safety instructions in an industry environment. This solution elaborates the architecture of the system and its application at the Thermal plant Ugljevik. The main goal was to reduce risk factors and prevent injuries by putting AR markers on the appropriately selected parts of the machine. In this way, by using the AR system, workers are led step by step thorough the safety and work procedures during task execution. Related to that, in the present considerations, we improve the system by reducing the number of markers and by giving the information about the task execution before the job starts. We enable cross platform solutions on the server side, as well as at the client side.

In this paper, the architecture of the AR system is discussed in detail, as well as the system realization specification. Since in [21] just the basic implementation issues are presented, here we also present the implementation details, since more complex and upgraded system components are used. In particular, on the server side we implemented a Symfony framework for REST service instead of using a native PHP for database connection. The service is used to give more universality of the system on the server side and it will result in independence in terms of changing the client application. This independence gives us the ability to use different mobile technologies such as Android or iOS on the client side. Our goal was to use a cross platform solution for the client part such as a Unity game engine that provides good support for augmented reality technology.

To show the independence and modularity of the system, we changed the AR module on the client side. This will show that by changing the system components and modules, the system architecture remains the same. On the client side, instead of using Vuforia for marker recognition, we used the EasyAR. EasyAR provides us with an image tracking solution that is used for recognition of image plates in industrial systems.

In the previous work multiple makers are arranged over the different parts of the machine, but in the current project we reduce their number. The markers provide the information on the exact place in the industry environment to which it is related, instead of classical mobile application elements such as normal lists. Instead of markers, in the present version of the system, we use two image plates for recognition of safety and work instructions, respectively. Placing two image plates next to each other at a very visible place reduces the time for finding markers. Further, if a plate is damaged, it is easier to replace that plate. The image plates are robust in the sense that they still can be recognized even when damaged until a reasonable extent. Recall that the fiducial markers are very sensitive to destruction.

By changing the type of industrial environment, we wanted to show that the concept proposed in [21] can be used in different fields of industry. In this paper, the case in point is the electro-energetics industry environment where protecting electrical installations from stress is a different kind of occupational safety issues than risk of injury when working on mechanical machines that was considered in our previous work [21]. This change of industry environment is intended to show that the system can be easily modified after which can be used in different exploitation circumstances. We will elaborate the whole system and its application to the electro-energetics industry in detail. The next section will provide a discussion about the advancements in the usage of the AR system.

FORMULATION OF THE PROBLEM

Work in the electro-energetics industry requires specially trained professionals because of numerous hazardous situations that can happen during everyday work. As a result, before beginning any task, special attention is paid to the safety measures. These measures are aimed at reducing the risk of injury, and hence reduce the time and costs caused by an improper handling or behavior in the industry space. Based on these measures and respective rules, special instructions, also including a description of the specific equipment parts, are issued to workers working under high voltage conditions.

Although carefully formulated and strictly prescribed rules are issued before any task, hazardous situations can happen. In the case of well-trained and experienced workers, mistakes occur due to their over confidence. Because of the monotony of any daily job routine, they often skip prescribed safety rules issued by the occupational safety officer. This can cause unexpected consequences that can lead to serious injuries, heavy defects in the industry space, and a time delay for completing the task.

Table 1 Safety and work instructions for changing the circuit breaker in an electrical substation

	Safety instructions	Work instructions
1.	Check the protective equipment.	Check the tool and its correctness.
2.	Disconnect installation from voltage source. Installation of the insulating substrate.	Turn off the main switch.
3.	Lock-off main switch and tag-out the locked installation.	Checking the absence of voltage.
4.	Ground and short circuit.	Circuit breaker replacement. Fix locate and repair faulty circuit breaker.
5.	Enclose from parts under voltage.	Check the circuit breaker voltage at the output. After installing a new circuit breaker, turn on the system again.

Sometimes the situation dictates that less trained and inexperienced workers have to undertake relatively complex tasks. In this case, they are exposed to risk if the proper information about the equipment and related safety instructions are not provided in a clear and easy to perceive manner.

The current job routine follows a certain flow of specific procedures. First, the safety officer informs the workers about safety measures that have to be applied before their daily activities. After that, the technology officer assigns the tasks that have to be done. Every step of each task is defined in the work manual for a concrete job. Work manuals are usually provided in the form of a sheet of paper with the text and drawings for each safety and work instruction. As an illustration, Table 1 shows the instruction steps for the safety rules on low voltage installation and work instructions for changing a circuit breaker in a typical electrical substation.

AUGMENTED REALITY IN SOLVING THE PROBLEM

Augmented reality is recognized as a technology which can improve the way of issuing working and safety instructions for the given task. This improvement includes direct interaction with the particular industry space through a camera on the mobile device, with the additional virtual information about necessary safety rules being projected. By recognizing specifically provided and conveniently positioned AR markers, safety and work instructions related to a concrete task and the equipment, as well as the tools to be used, are projected. As shown in Table 1, the safety instructions are projected first, and after their implementation is confirmed, the work instruction are projected.

Displaying AR instructions has multiple goals:

- Keep the attention of the workers to ensure they apply all the necessary steps during their work, by confirming the implementation of each issued instruction,
- Give more precise visual information directly at the work place which is supposed to be considerably more detailed and appropriate than the information which can be read in a hard copy printed instruction manual,
- Save the time of the safety officers in explaining the safety instructions, which is especially important when different tasks on different types of equipment should be assigned to a large group of workers,
- Keep the history of all the examined and realized task instructions in the database on an external server for subsequent analysis and monitoring of the job done.

Organization of the AR content to be projected follows the working procedures and related safety rules. It is assumed that, as is the typical customary practice, for each worker the related data about his education level, specific professional training, and work experience are provided as a part of his personal data record. Amount of information to be projected is determined for each worker individually according to his educational level and professional skills and expertise. Selection of the amount of information content is done by the technology and occupational safety officers during the assignment of tasks.

Therefore, highly qualified workers will get a reduced number of instructions focused on specific details of the working procedure and related safety measures, while general information will be omitted assuming that the worker is already well familiar with it. For less qualified workers, complete instructions will be issued in order to finish the job in a proper and safe manner.

AR SYSTEM FOR THE ELECTRO-ENERGETIC INDUSTRY

In this section we describe our AR system that can be used to overcome the above-mentioned problems regarding proper implementation of work and safety instructions related to various tasks in the electro-energetic industry. It should be noted that the proposed system can easily be modified and made applicable to various other branches of industry.

Organization of the system

The system is organized as a client-server architecture as shown in Fig. 1. The AR-based system present safety and work instructions in an electro-energetics environment where working under high voltage and strong currents is typical practice. The main role of the system, together with this particular requirement, determines its structure.

The server side consists of a database, which stores data about users and tasks, a multimedia repository containing virtual instructions in various multimedia formats, and REST service [25] which represents the software architecture that can control data flow during the client-server communication using a predefined format of communication. These transfers of data are between tasks stored on the server and workers that are using the client application.

The client side is realized as a software tool that consists the Communication (CM) module, that enables data to send and receive data from the server, the Task (TM) module implemented as a data structure that can store information about the current task of the worker and his safety and work instructions, the User interface (UI) module, which allows the user to navigate, and the Augmented Reality (AR) module, which provides task instructions to the worker.

Application of the AR system

Fig. 1 illustrates the basic functionality and application of the AR system.

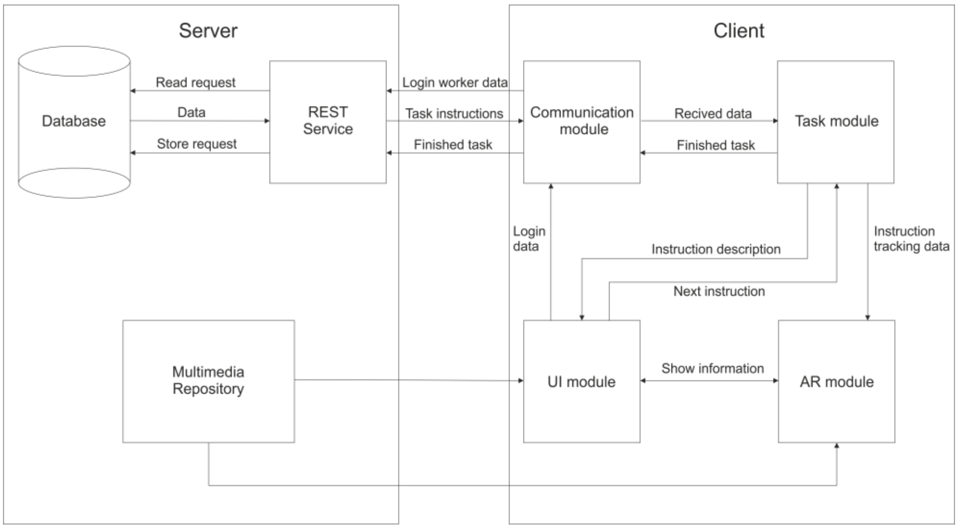

Fig. 1 The block diagram of the system

The system starts upon the worker logging onto it by using his identification data and password. This data is collected by the User interface module and forwarded to the Communication module. The Communication module prepares the login data in the proper format and sends it to the server via the REST service. Based on this data, the REST service checks if the user is defined in the List of workers. Upon successful authentication, the REST service searches in the database for the task that is assigned to the user. All of the tasks are integrated into the database and are accompanied by a list of related safety and working instructions. Every instruction consists of descriptive elements and linked multimedia material that is stored in the Multimedia repository. When task data are found in the database, the REST service prepares data in a format readable by the Client application.

The Communication module receives and processes data from the server side. Upon processing, the data are stored in the Task module and they are ready to be sent to the User interface and the AR module. The parameters of one instruction at a time are sent to these two modules. When a current instruction is completed, the next one is taken from the Task module.

The module User interface shows data that explain to the worker how to use the AR module. The explanation involves images and text in order to better guide the worker. At the same time, the AR module is activated with parameters about the object recognition and multimedia material that is shown during AR tracking.

Upon tracking, an interactive checking system is projected in order to confirm that the worker has seen the instructions. Confirmation allows the next instruction to be received from the Task module. After confirmation of all the task instructions, the data are prepared by the Communication module to be sent to the server. On the server side, the REST service receives the data and stores it inside the database.

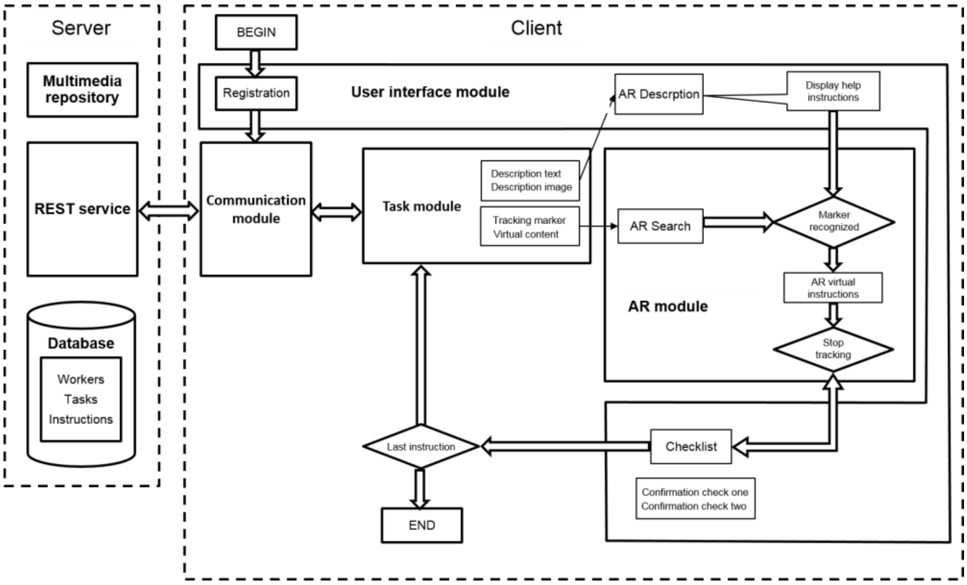

Fig. 2 Architecture of the system

Server

The server stores all the related data necessary for the application of the AR-system. Data are stored inside the Database and Multimedia repository. The transfer of data between the database and the client application is realized through the REST service. In the next chapters all of the necessary elements of the server side will be described. These server elements are given in Fig. 2.

Database

The database consists of the List of workers, List of tasks, List of instructions, List of realized tasks, and List of realized instructions. The List of workers represent data for authentication like the username and password. Also, for each worker, information about his qualifications and level of expertise is stored.

The List of tasks contains all the necessary data that describe possible tasks which could be assigned to the workers. This list is connected with the List of workers to determine a specific task for each worker. Also, the List of tasks is linked with the List of instructions to regulate safety and work instructions for each task assigned to a worker.

The List of instructions describes two instruction types, safety and work instructions. Safety instructions consist of data given by the safety expert, while work instructions are defined by the technology officer. Each instruction has a regular execution number, title description and defined target for recognition by the AR-module. Also, with the target information, a link is provided that points to the virtual material in the Multimedia repository which is used by the AR module during tracking.

The List of realized tasks stores the job data for each worker when he confirms completion of a task. Parameters about the date, time, type of the task, and the person who realized it are saved on this list. The list is linked with the List of realized instructions for more details about the finished task.

The List of realized instructions contains data about realization of each instruction. Stored data are the time of the beginning, time of completing, and the duration of the work.

REST service

The REST service is used to enable communication between the client application and the server side. Through the REST service, authentication and authorization are done so that the worker can get all the necessary data for task realization. When the service accepts the worker username and password, it compares them with the data in the List of workers. Upon successful registration, the service determines the task for the worker from the List of tasks. Based on the assigned task, the corresponding safety and work instructions are read from the List of instructions. The data collected and prepared to be sent to the client application are:

- Token for worker authorization,
- ID of the worker,
- Parameters of task ID, description and the title,
- Parameters of safety and work instruction ID, title, description, order number, AR marker, link to the multimedia file.

The client side accepts and processes the data after which they are ready to be used by the worker. When the worker completes all the safety and working steps, the data are sent to the REST service. The data sent back to the server to be stored in the List of realized tasks and the List of realized instructions are:

- ID of the worker,
- Parameters of the task ID, date of the start, date of the finishing, and duration of the task.
- Parameter of instructions ID date start, date finished, duration of the work.

Multimedia repository

The multimedia repository is used to store the virtual material related to the safety and work instructions. Each task has a separate folder where virtual material is stored. The virtual material is available in the form of a 3D model and a video file for instructions or an image for the description of a part of the instruction.

Video files are used for client application streaming during the marker recognition. They are recorded in *MP4* file format with *H264* video codec. The video resolution is 720p with a bit rate of 3000 kbps. The sound is recorded in *AAC* format with a frequency of 44.1 kHz and a bit rate of 64 kbps because only the narrative voice is recorded.

The 3D model file format depends on the amount of polygons used. The format 3DS provides better file compression for 3D model under 65000 polygons. The FBX format is used for 3D models for larger number of polygons. These models are included as a Unity [26] asset bundle, from which they are downloaded and used on the client's side after the service call is received.

All multimedia materials are linked to the client application through the links located in the List of instructions in the database. If necessary, the application downloads the material from the specified link and connects it to the application modules that will be used. For example, a module for augmented reality downloads or streams the video material from a particular link and displays it during AR marker recognition.

Client side

The architecture of the client side is determined by the mobile application defined by the four modules explained below (Fig. 2).

Communication module

This module allows the application to communicate with the server side in order to access data in the database. Also, this module prepares the data in the predefined format for sending. For worker registration to the AR system, the username and password should be sent. Upon successful registration, the task data obtained from the REST service are parsed in this module and sent to other modules for further execution. After the task is completed and confirmed, the data are parsed by this module and prepared to be sent to the REST service which transmits these data to the database.

Task module

The goal of the Task module is to store the data downloaded from the server and to forward them to other modules for execution. Data from the server are stored in the list of safety and work instructions. For each instruction, data such as the name, description, serial number, marker, link to the multimedia material, and employee qualifications are stored. For displaying instructions to the workers for task execution, data are transferred by the User interface module.

The AR module is supplied with data concerning the tracking, AR marker, and multimedia material. When a confirmation of the instructions is performed, this structure records data such as the start time, finish time and the time spent executing the instruction. When the last instruction is implemented, the executed task data is sent to the module for interacting with the REST server for further parsing and sending the data to the server database.

User interface

The Module User interface serves to define the visual elements of the application. This takes into account the application layout elements and their appearance.

The login form serves to register a worker on the system. The registration form is connected with the database through the Communication module. User data are forwarded to this module when the worker fills in the form.

After the registration has been completed, the necessary data are transferred from the server into the mobile application, and the Description part on the User interface module is projected. The description serves to show the information about the current instruction execution. In order to simplify the search for the AR marker in the environment and the workplace, the help function is implemented to displays the image of the active AR marker and explanatory text on the mobile screen.

The checking system is used to control instruction delivery in the proper order. Each safety instruction is followed by the work instruction. To process the work instruction, the safety instruction should first be confirmed. The checking system is activated when the AR tracking is finished in order to confirm that the current step is completed. Two steps of confirmation are implemented to prevent accidental validation of the given instruction. After a positive confirmation, the next instruction in the sequence is read. Then, after each safety instruction, the next work instruction is issued, and the AR module activated.

AR module

The AR module is the core component for user interaction with the real world. It is designed to project safety and work instructions over elements in the industry space. Each instruction stored in the Task module has a description, corresponding virtual material, and parameters for the AR marker.

The AR module in this application is realized by using the EasyAR SDK. The main idea is that the worker is obliged to use AR technology to inform himself about secure and efficient job realization before entering the substation. The application of the augmented reality technology implies the recognition of two plates attached on the entrance of the electro-energetic substation. During the recognition process only one image marker is active at the time and corresponds to the active instruction. Safety instructions is obtained by tracking first plate image while work instructions will be achieved image plate (Fig. 3).

Fig. 3 Augmented reality image markers above is safety sign (English translation of the text: Caution! Check the safety procedures.) below is working sign (English translation of the text: Caution! Check the safety procedures!)

As soon as the AR module starts over the picture of the camera, the User Interface shows a description above the image of the real world. The worker is informed to find the marker in the exact place in the industry environment. When the AR marker is recognized, this description vanishes from the screen. On the place of the recognized marker, the virtual instructions are shown. The worker is informed about the current task by the AR system directly at his workplace. Various multimedia formats can be projected over the AR marker in the form of 3D, video or image with the text. The AR marker related to the current instruction is active at the time, so the other markers cannot be recognized by this module.

When AR tracking stops, the system alerts the checking system to be shown over the display. The worker then goes through a double check system to get the next AR marker for tracking in order to get a new instruction. If he accidentally stops tracking and the checking system is displayed, the AR module is still active in the background. Accordingly, the worker can point the device camera at the active marker. Upon recognition of the active AR marker, the checking system will vanish from the screen and the virtual instruction will be projected during the tracking.

IMPLEMENTATION

The AR system using the Unity engine while the server part is realized by the Symfony framework.

The validation and verification of the AR system was made on the basis of the safety rules on low voltage installation and work instructions for changing the circuit breaker in the electrical substation described in Table 1. This instruction is intended for workers who are involved in the maintenance of electric medium and low voltage substations.

Table 1 consists of five security and work instructions that are needed to ensure proper and safe operation. Each instruction contains a single video file that is displayed through the augmented reality technology implemented in the AR system.

In order to use the AR system, an internet connection is required. The internet connection is used to download a task from the server, and streaming multimedia material from the Multimedia Repository. Also, an internet connection is required to send information about the completed task for entry into the database. If there is no Internet connection at the workplace, it is necessary to download the content of the task before the job starts. Downloading the material can be done at the office, from the Internet, before the worker goes into the field. Also, after completing his duties, a worker must access the internet, from the same room, to send information about the completed task.

Upon registration, the system requires the worker to recognize the first image marker to get first safety instruction from Table 1. Fig. 4 shows the screen of the mobile device through which the worker is instructed where to find and point the camera towards the first image marker.

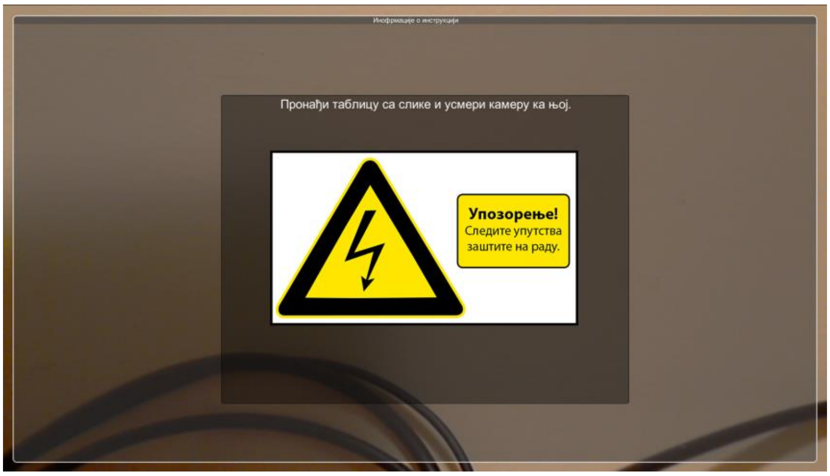

Fig. 4 Augmented reality searching instructions (English translation of the text above image: Find the plate from the image and point the camera towards)

When the marker is recognized, the worker gets first safety instruction in the form of a video instruction during tracking. At Fig. 5 is shown augmented reality projection of video material about the first safety instruction for checking protective equipment.

Fig. 5 Augmented reality instruction for checking the protective equipment

After the tracking, the worker performs verification through a checking system implemented in the AR system (Fig. 6). First step of verification is clicking the check box to verify that he was checked equipment according to the safety instruction. Second step of verification is using the button for confirmation. Then, the user is required to find the second image marker representing the next work instruction. By verifying this instruction, the system directs the user to go back to the first marker to execute the next safety instruction. In this way the user is guided through all instructions related to the current task.

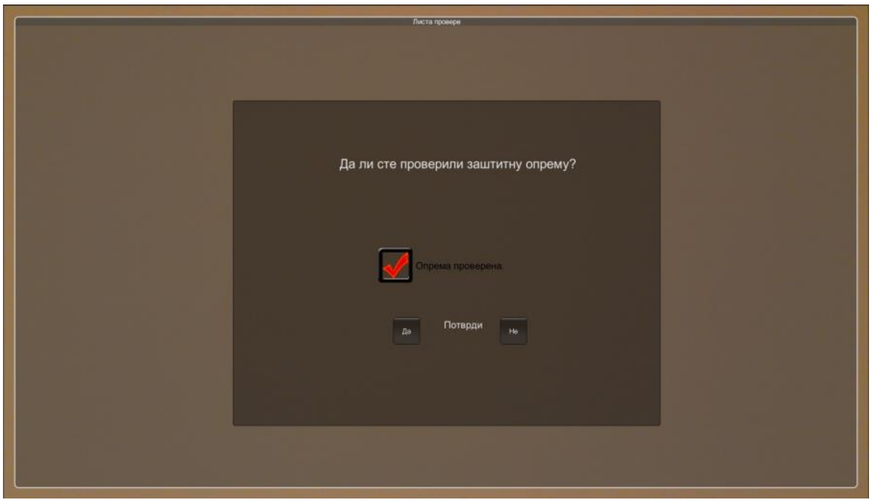

Fig. 6 Usage of checking system for confirmation of occupational safety instruction (English translation of text above: Did you check protective equipment?, middle: Equipment check, below: Yes, Check, No)

CONCLUSION

As a continuation of our previous work, on which this paper relies, we present in detail the usage of the AR system in the case of the electro-energetics industry. By following the previous methodology, we specified custom problems that concern the daily job routine. Based on that, we determined that tasks can be provided through a sequence of virtual safety and work instructions.

Client-server architecture for implementation of such a system has been described. For the server side we used the REST service for issuing task elements for client application. Client application is organized in several modules where the central part is dedicated to the module of augmented reality. This module is used for worker interaction with industry space in order to get virtual instructions at the workplace. The worker has to confirm every step after each instruction.

Presently there are no possibilities to test the system on the wide range of tasks in the environment accessible by the author. The proposed system however was experimentally tested by few workers for the case of changing the circuit breaker in an electrical substation. The system was presented to experts working in the area of electro-energetics systems and comments approving its usage are obtain. It is expected that a system based on augmented reality technology will be an efficient aid for issuing safety and work instructions.

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