Computers in Industry 85 (2017) 1–10

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

The application of augmented reality technologies for the improvement of occupational safety in an industrial environment

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ARTICLE INFO

Article history:
Received 8 February 2016
Received in revised form 28 September 2016
Accepted 16 November 2016
Available online 28 November 2016

Keywords:
Augmented reality
Occupational safety
Mobile devices
Virtual reality
Real world interaction

ABSTRACT

In many branches of industry, occupational safety experts identified two main causes of worker injuries related to the usage of modern electro-mechanical machines and systems: inadequate training and insufficient work experience, and monotonicity of the tasks often performed repeatedly. In this paper, we present a system based on augmented reality (AR) technologies that can be useful in reducing these factors of risk at work and decreasing the error rate and preventing injuries. The system that is implemented on mobile devices is intended to project augmented reality instructions directly at the work place. A worker is led by the AR-system step by step through various work and safety procedures that should be performed. Each procedure consists of steps specified by a series of instructions accessed through an interactive check list. To ensure the safeness, if a confirmation is missing because of a skipped, incompletely, or wrongly performed step of a procedure, the AR-system blocks further implementation of the procedure and returns the worker to the previous step until the correct actions are carried out. At the same time, interactive work with the checklist breaks the monotonicity of the job. The system is personalized according to skills of a worker by taking into account his professional training and work experience. Depending on that it is determined the amount of data to be displayed to a worker helping even less skilled workers to perform a task.

As a case study, the proposed approach is implemented as an instructional and occupational safety system for work at a universal lathe, which is an element of many technological processes of Thermal Power Plant Ugljevik in the Republika Srpska, Bosnia and Herzegovina, where this AR-system was experimentally implemented and verified.

1. Introduction

The advent of technology and the reduction of cost of mobile hardware (smart phones, tablets, PCs) affects the development of interactive applications designed for these devices. The technology of augmented reality (AR) provides new forms of interaction on mobile devices. This technology allows the user to enrich picture of the real world as captured by the camera on the mobile device by virtual computer generated objects [1]. Augmented reality technology has been applied in various fields such as medicine [2], presentation of historic and cultural heritage [3], and education [4].

Numerous applications exploiting augmented reality technologies have been developed for industrial purposes, see for example [5] and the references therein.

According to the literature review, we can notice two categories of AR-systems aimed at application in industry, systems aimed to provide help in maintenance and training. Maintenance oriented systems usually offer virtual information by providing help in solving a particular problem or performing predefined steps in the regular checking of a machine directly at the work place. Therefore, these systems can be viewed as an improved electronic version of manuals with built-in expert knowledge. Due to this, being guided by AR-supported instruction manuals, even non-specialist can perform tasks that previously were reserved for specially trained workers.

The AR-based training systems are primarily focused on the educational component by providing virtual guidance combined with the real experience in the industry space.

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http://dx.doi.org/10.1016/j.compind.2016.11.004
0166-3615/

There are numerous reasons for the application of AR technologies in industry. For example, the usage of written manuals in the form of booklets is usually inconvenient at the work place, and then often avoided or neglected by workers that tend to rely on their knowledge and experience. Due to the complexity and variety of machines and different models of the same machine that often have to be handled by the same worker, some details of the expert knowledge are often missing in written manuals, or the proper manuals are wrongly distributed between co-workers.

At the same time, even well-trained and experienced workers might make mistakes caused by the monotonicity of the job, due to which some steps of the procedures are easily forgotten or intentionally omitted.

All this might cause mistakes and potentially lead to injuries if some of the procedure steps are overlooked or performed incorrectly. The audio and video information provided by the AR-based manuals combined with the request for an interactive verification of performed steps can prevent such situations.

In this paper, we present an AR-based tool intended for application in industrial processes with a twofold goal: to ensure correct implementation of all the steps in the production or maintenance procedures, and to increase the occupational safety by an interactive verification procedure.

We implemented safety instructions which are issued by the proposed AR-tool whenever necessary during the educational or work process, and have to be followed step by step by using an interactive checklist. This list is connected with the database on the server side from which the instructions are read and where the correct implementation is recorded. In the case of missed, incompletely, or wrongly performed steps, the AR-system blocks further implementation of the procedure and returns the worker to the previous step until the correct actions are carried out.

This fusion of work instructions and occupational safety instructions ensures that the tasks will be performed correctly by appreciating the occupational safety requirements. Therefore, the proposed system can be used to educate less skilled workers that are forced to answer questions in the interactive checklist. At the same time, by answering questions, experienced workers are forced to maintain their concentration and obey and strictly follow all the occupational safety measures.

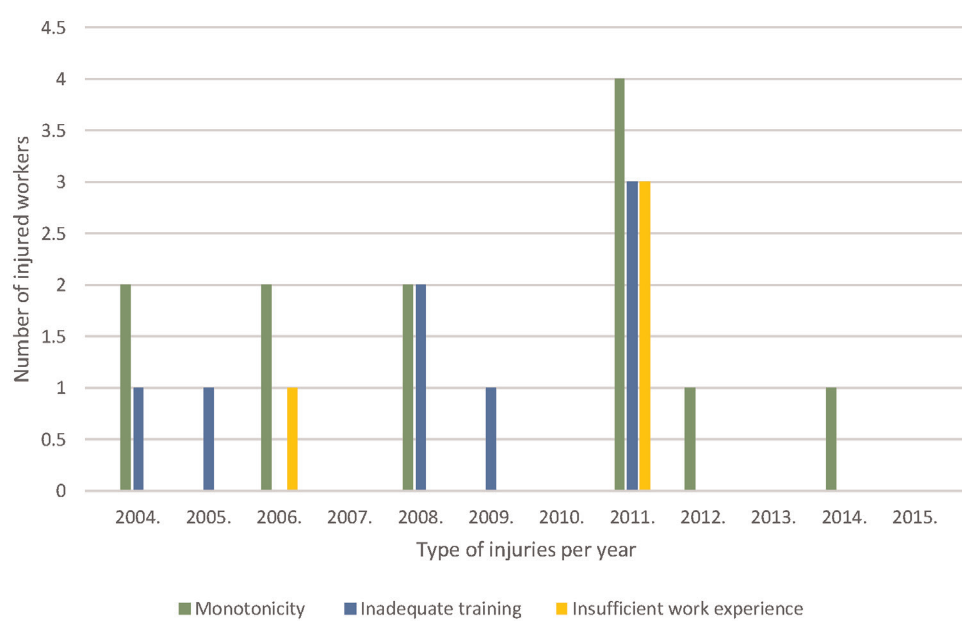
For the sake of clarity, the presentation in this paper is based on the example of the proposed AR-system implemented as a manual for the work at the universal lathe with all the required data taken from a concrete industrial site, the *Thermal Power Plant Ugljevik*, in Republika Srpska, Bosnia and Herzegovina. This, however, does not impose restrictions on the applicability of the proposed AR-system, since after a simple modification the same system can be used in different situations. The modification mainly consists of the replacement of the lists of work and maintenance instructions and lists of occupational safety measures prescribed for the concrete applications [6]. Clearly, a corresponding change in the database queries is required, while the logical structure of the system, its software elements, as well as interaction with the underlined mobile platforms and servers remain unchanged.

2. Related work

In the literature, there are many systems and projects that are related to augmented reality technology applications in industry. For example, an approach towards the integration of augmented reality tools and embedded intelligent maintenance management systems is presented in [7]. A factory environment was mixed with virtual objects in real time during maintenance activities based on the CARMMI model. A data structure was created based on this model to provide the information, using augmented reality technology to facilitate management for performing the maintenance tasks. Test cases illustrating the created structure and the concept are shown to confirm their usefulness [7].

In [8], besides different techniques of virtual reality applications for simulations and implementations in industry, the discussion is focused on the importance of respecting the order of instructions by using interactive checklist procedures. In this paper, all of the steps of the Product Lifecycle Management are followed by an immersive checklist using a VR environment and interactive simulations. Tests are applied to a real industrial environment combining the specialized interactive tools for hands free movements and gesture recognition during industrial procedures.

The paper [9] shows how augmented reality can be integrated into Building Information Modeling system (BIM) environments. The project presented in this paper concerns the Liquefied Natural



Graph 1. Number and causes of injuries per year.

Gas (LNG) construction site in order to monitor and control such complex activities. Data gathered in this way enable more efficient access of information and faster correcting of errors during assembly tasks. Workers are able to see and compare current and planned future progress. Also, communication and collaboration between workers with different expertise and at various geographical locations is enabled in order to improve productivity.

Environmental safety in combination with augmented reality during emergency situations is discussed in [10]. This paper describes mobile evacuation guidelines for nuclear accidence, aimed at increasing mobility during the accidence. The authors implemented geographical information by using virtual maps and augmented reality to improve escape guidelines. As it uses mobile devices, the effectiveness of the emergency assistance can be increased. In this way, people can easily find shelter without using paper maps and without waiting for relief staff following escape routes to move to a safe location.

In [11], an augmented reality tool is proposed which allows the simple creation of virtual content for applications in industrial procedures. This system consists of two parts, an easy-to-use editor and a viewer for AR procedures. Organized in this way, the AR system allows non programing users to create AR applications in order to organize the repair maintenance and assembly tasks. Also, advanced visual effects are provided by creating a depth map by using Microsoft Kinect, which allows occlusion management during content creation. Validation of this system is done by an evaluation which showed that AR tools can significantly reduce error rate during assembly tasks.

The presented works show lot of novelties and potential involvement of new technologies in the sphere of industry. However, there are many other issues that can be integrated in order to make progress in these areas where augmented reality meets industry space. In this paper, we made a fusion of some of ideas from the mentioned publications, while paying an especial attention to the safety of the workers.

3. Industrial context—motivation and analysis

The work presented in this paper is motivated by an analysis of the former and current occupational safety situation in the *Thermal Plant Ugljevik*, Bosnia and Hercegovina, on the example of daily routine work. The data are obtained from the Maintenance and Repair Unit (MRU) which is an organizational unit in the *Power Plant Ugljevik* intended for ensuring a continuous, uninterrupted, and proper functioning of various electro-mechanical devices and production systems. Therefore, the non-stop activity at MRU is of great importance for an uninterrupted industrial process. Due to the great variety and diversity of devices that have to be maintained and repaired, the MRU is equipped with several so-called universal combined lathes accompanied with various tools and gear which make them applicable in performing different task specific to the main activity of a thermal power plant.

Graph 1 shows the number and causes of injuries per year in the decade 2004–2014. An explanation for this situation is that younger and less experienced operators usually do not read enough carefully, and consequently do not perform the related occupational safety instructions that are different for different tasks. The well-experienced workers, however, often become overly self-confident and then do not strictly follow the occupational safety instructions, relying on their skills. Another factor is the monotonicity of the job when the same operations have to be performed many times, which causes a decrease in concentration and increases the possibility for accidents.

This analysis led to the idea of automatizing the procedure, and require the operators to implement occupational safety (OS) instructions and confirm their implementation before starting work and maintenance (WM) instructions. The augmented reality solution, which gives on site context awareness, is aimed to show sequentially the tasks that should be performed with specified safety measures. When OS and WM AR-instructions are performed, the worker is required to send a confirmation. After that, the worker is allowed to proceed towards the implementation of the next instruction as specified in the protocol for the corresponding task. In this way injuries at work should be prevented or at least reduced.

In order to develop the protection system, we analyze tasks and risks during the working process. In current practice, the tasks are organized to sequentially perform a series of instructions. The instructions are organized as ordered sets, starting with OS instructions, the order of which is determined by the predefined occupational safety measures. Then, it is necessary to follow the WM instructions specific for the task that is to be performed. It is assumed that the worker, operator on the combined lathe should be well-trained and informed on both OS and WM instructions and the order of their implementation. For that goal, the corresponding manual in the form of a printed book is attached to each combined lathe. In spite of that, the occupational safety officers at MRU observed that operators on the combined lathe often experience injuries. Therefore, they recommended the automatization of related procedures, which is the subject of this paper.

Table 1
Work and maintenance instruction list and instruction check.

Work and maintenance instructions	Instructions check
1. Connect the machine to an electricity source.	Check whether the machine is prepared to be turned on, whether the work space is clear and the appropriate tools properly set up. Check the connectors and the position of the switch.
2. Insert the key and start the machine.	Is the material tightly positioned? Did you insert the key and start the machine?
3. Place the operating part in the machine and align it.	Is the operating part in the machine? Is it centered?
4. Start the rotating workpiece that holds the operating part with the handle down and twist the gauge that defines the depth of removal.	Check the starting position of the working part and recheck the selected depth of removal.
5. Alter (set) the blade, centering a certain depth of removal and initiate the automatic function protocol.	Has the blade changed? Has the depth been determined? Is it the blade set at automatic function?
6. Starting the machine.	Has the machine correctly (slowly accelerating) started to work?
7. Turn on water supply.	Is the water turned on and the pipe secured?
8. Stopping the machine.	Has it stopped (slowly attenuating)? Has the machine been released? Is there need for a new procedure to be executed?
9. Turn off the machine by pressing the red button.	Check the light signal which indicates that the machine is turned off. Has the off switch been pressed and secured?

Table 2
Occupational safety instructions.

	Occupational safety instructions	Risks
1.	Assume the proper body posture, combined with breaks and occasional light exercise.	Risk of indirect voltage contact with parts of the electrical installations and equipment under voltage.
2.	Prevent the risk of indirect voltage contact with parts of the electrical installations and equipment under voltage.	The risk of incorrect installation.
3.	Wear clothing with short sleeves if possible. Long sleeves must be pressed tightly to the arm. Be sure to remove any watches, bracelets and similar ornaments from the hand.	Insufficient protection from rotating or moving workpieces.
4.	Keep fingers away from moving any moving workpieces work. Use appropriate tools to remove any links.	Efforts or physical stress (manually transferring load, pushing or pulling loads, various increases in long-term physical activity).
5.	Remove the key for chucks (chuck key) immediately after tightening and put it to the side.	Inappropriate handling of the key and key removal.
6.	Start the lathe at minimum speed with a slight increase.	Insufficient protection from the rotating or moving parts when the machine is turned on and off.
7.	Water must always be flowing to allow cooling, and also because of the dust that is inhaled. Avoid contact with the coolant.	Risk of the harmful influence of the chemicals and cooling liquid.
8.	Avoid leaning over the rotating jaws. The lathe must not work with the key in the jaws.	The additional tools were not removed prior to the machine being turned on.
9.	The machine should be turned off after the moving parts have stopped moving and the cooling system has been turned off.	Risk of indirect voltage contact during the shutdown phase.

Table 1 shows the WM instruction list while Table 2 includes the related OS instructions for work involving the combined lathe. These tables are specified by the occupational safety officer the technology officer, respectively.

4. Functionalities of the AR-based system for occupational safety

Functionalities of the AR-system are determined based on the current practice as briefly presented above. They are designed to accommodate the real world occupational safety problems during daily routine work as well as periodical maintenance or repairing tasks by using augmented reality technologies.

4.1. Rationalities of the system

The rationale is that the AR-based system for occupational safety (AROS-system) is supposed to support and improve the present practice, but without any negative influence to the technological process as such. In that respect, the supposed scenario is the following.

The corresponding officers specified the safety models and daily routine work, maintenance, and repairing models as they are already defined by the book of regulations and instructions from which Tables 1 and 2 are derived. These models are used as a basis to define a database structure of the AROS-system. The models assume that each task consists of a set of instructions that should be performed in a precisely specified order. Naturally, the occupational safety instructions precede the corresponding work instructions in order to prevent injuries.

The flexibility of AR-based systems in presenting the information content with the amount of details adapted to workers with different levels of professional skills, enables a new feature compared to the present practice where all the workers are supplied by the same set of instructions as written in the manual.

In reality, the daily tasks that should be performed as dictated by the technological process depend on many factors and requirements are not identical for every day. Since the available human resources are unavoidably limited, a complex planning of task assignments and time schedule is usually necessary. The AR-based system can be useful in facilitating this job and in ensuring the quality of execution of tasks, since enables to take into account personal characteristics of its users and adapt the information content to be presented according to that.

The main background idea is that in an industry unit there is a finite number of employees. Among those that are available at a time there are workers with different level of education, professional training, and work experience. In the current practice, the complexity of tasks that should be assigned to them is not the same. Most complex tasks are usually assigned to well-trained and well-experienced workers. At the same time, it is expected that they will perform the tasks faster due to their better skills. It often happens that the number of adequate workers is insufficient at a given situation and time, which cause the delay in the technological process and increases the possibilities for accidents including injuring of workers when complex tasks have to be assigned to less skilled workers. The AR-based system can be helpful in overcoming such situations.

With this consideration as a motivation, and by following the organizational structure of the Thermal Power Plant Ugljevik, we decided to distinguish three types of workers: less skilled (LS), qualified (QW), and highly qualified workers (HQ). Based on this, we specified the amount of the information content that should be presented to a worker.

Each worker gets the complete set of safety instructions since protection of workers is the main goal.

Detailed maintenance instructions are given to the LS and QW workers, while a HQ worker gets only a subset of maintenance instructions that is sufficient to ensure a proper record of the implementation of the task steps for the work history. In this way, the number of security checks is reduced for the HQ workers, which is in the line with the assumption that they are supposed to perform the task faster due to their better skills.

For the implementation and personalization of the AR-system, to each worker an identification number (ID) is assigned, a part of which is the code for his professional skills as specified above (LS, QW, HQ). The sets of instructions aimed at displaying to workers with different skills are also correspondingly encoded. Further, each task has a unique code. A manager assigns tasks to workers by matching the code for a particular task with the ID of the worker. Then, when the worker login to the AR-system, based on his ID, the system automatically determines which sets of instructions will be displayed. In this way, by providing a rather detailed set of work instructions, a QW or even an LS worker will be able of performing complex tasks which without a strict AR-based guidance will hardly be possible.

4.2. Functionality units

The described functionality of the AROS-system is achieved through four units as illustrated in Fig. 1:

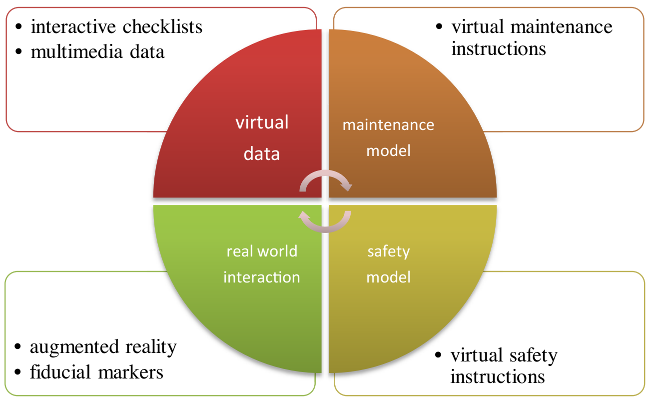


Fig. 1. Functionalities of the AROS-system.

1. Virtual data
2. Real world interaction
3. The safety model
4. The maintenance model.

Virtual Data contains necessary data to project the virtual content consisting of OS and WM instructions and other virtual objects.

Real World Interaction enables real-time projection of virtual instructions inserted into picture of real world capture by the camera of a mobile device. These instructions guide the user how to solve a given task in the work place.

Different work scenarios can be attached to the Virtual Data and Real Word Interaction unit due to which the proposed AROS-system can be applied in different situations. By using augmented reality technologies, the instructions are issued on the mobile device in the industry environment during the working process. Simultaneously, while accessing virtual information, tasks in the real world can be performed by interacting with the real industry objects. Also, through the interaction with virtual objects, a worker can get additional instructions without the necessity of consulting the printed manual book usually attached to the device.

The contents of next two units, the ***Safety Model*** and ***Maintenance Model***, are tailored for specific particular tasks and the corresponding models of occupational safety and maintenance and repair tasks.

The ***Safety model*** enables access to safety instructions defined by the occupational safety experts for various concrete tasks. Instructions are read from a database and visualized on the screen of the mobile device through the augmented reality module (Fig. 2). Since the occupational safety procedures are usually complex in the number and the order of steps, an interactive checklist has been developed to secure the implementation of each step of the safety protection procedures. These procedures are presented to the user as lists of questions to be answered in order to prevent potential risks. The system enables the storage of answers provided by the user in a dedicated database.

The ***Maintenance Model*** provides precise instructions on how to help operators realize the task with less effort. This model is defined by technology officer as specified in the book of regulations and instructions. By issuing detailed instructions in a proper order, this model should drastically reduce the possibility for failures or the error rate since implementation of each instruction is confirmed in the interactive checklist. As discussed above, the level and amount of information that is presented to the workers depends on their skills. Therefore, the system can be adjusted to less or well-trained workers. The selection of the detailed information option allows less skilled workers to engage in completing complex tasks. For concrete tasks, the instructions issued by the maintenance model are read from the database, visualized by the augmented reality module, and connected to the interactive checklist for confirmation (Fig. 2). After confirmation, the next safety model instruction is issued before the next maintenance model instruction. This alternate addressing of the Safety Model and Maintenance Model units is continued until the task is completed.

4.3. Structure of the system

The AROS-system has a twofold goal, to ensure implementation of the OS instructions while performing WM instructions correctly. This feature determines the structure of the system depicted in Fig. 2.

The system consists of two main parts devoted to handling the OS and WM instructions, respectively. Separation OS and WM instruction is done to consider workers with different level of training and work experience. As noticed above, for safety reasons, the same set of OS instructions is projected to all the workers, while the amount of WM instructions is determined depending on the skills of each particular worker. A common database is used to store sets of instructions. Each WM instruction is preceded by the related OS instruction. Therefore, instructions are interconnected through a kind of feedback loop with a common AR module performing visualization of the instructions. The output of this module goes to two checklists to control implementation of the OS and WM instructions, respectively. The first checklist has an inhibitor functionality ensuring that any WM instruction can be performed only if the corresponding OS instruction is implemented and verified in the checklist.

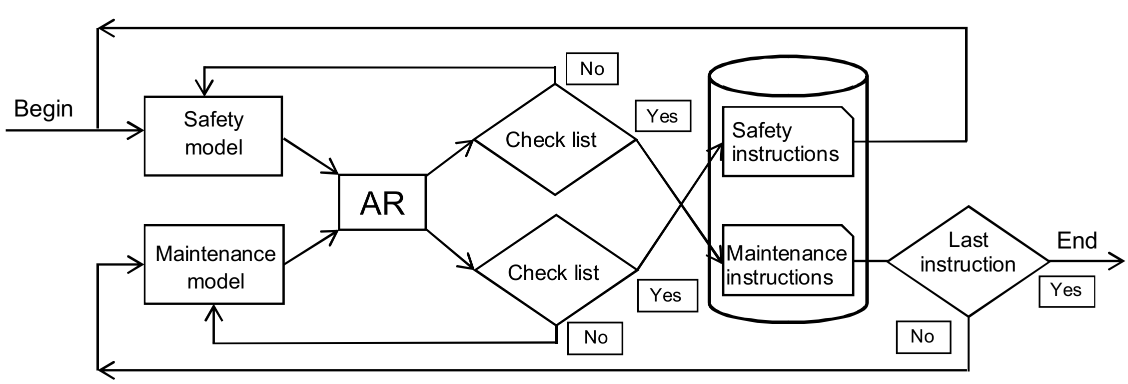


Fig. 2. Structure of the AROS-system.

5. Augmented reality module

The augmented reality module is a central part of the AROS-system. It represents a new way of interaction, making a bridge between the real work environment and the virtual OS and WM instructions in an intuitive way.

When the AROS system is started, the OS and WM instructions are gathered respectively from the database. Every instruction consists of a description, virtual material, and fiducial marker parameters for recognition.

AR module (Fig. 3) activates the camera on the mobile device and the worker is able to see the industrial environment on it. Along with that, the *arDescription* function is activated to process the description data. The description consists of text and images that help the user to find the markers that should be recognized. The processed data are displayed above the image captured by the camera of the mobile device. Furthermore, the AR module runs the *arSearching* function which processes the fiducial marker parameters and virtual content. This also enables tracking one marker at a time, preventing multiple markers from being processed simultaneously. While tracking the marker, virtual material in the form of a video or 3D model is inserted into the real world image on the worker's mobile device. After recognition of the marker, the *arChecking* function is activated. This function draws above the user screen check boxes requiring a confirmation that the assigned task is performed. Until the confirmation is missing, the system remains in tracking mode and waits for confirmation. The confirmation is implemented in two levels to ensure the avoidance of accidental disconfirmation.

6. Architecture of the AROS-system

The architecture of the system is determined by the feature that every task consists of a series of occupational safety and maintenance instructions that have to be performed in a strictly defined order. Table 1 and Table 2 illustrate the tasks and OS and WM instructions on the example of handling a combined lathe.

This organization of instructions and the requirements for their visualization determine the architecture of the proposed AROS-system. The system is organized into two main parts, the database and the application.

The application is installed on a mobile device that is used as the input and output of the system. All the necessary data are stored in a database that is accessed by the application whenever required. When the system is started, the login subsystem is activated on the interface of a mobile device. The worker's ID is used as a database query in the Task list table which assigns concrete tasks to the user. Upon one task is chosen, the first instruction is read from the Instruction list with all the necessary parameters for tracking, and the augmented reality module is activated. Now, the system is able to recognize one marker which is placed somewhere in the industry space. Virtual material shows the OS and WM instructions while tracking the marker. After tracking, the checklist is activated for the confirmation of the implementation of the given instruction. A positive confirmation allows the storage of data in the Finished task list.

In what follows, we will provide a brief description of the main characteristic of the application and the database upon which it is based.

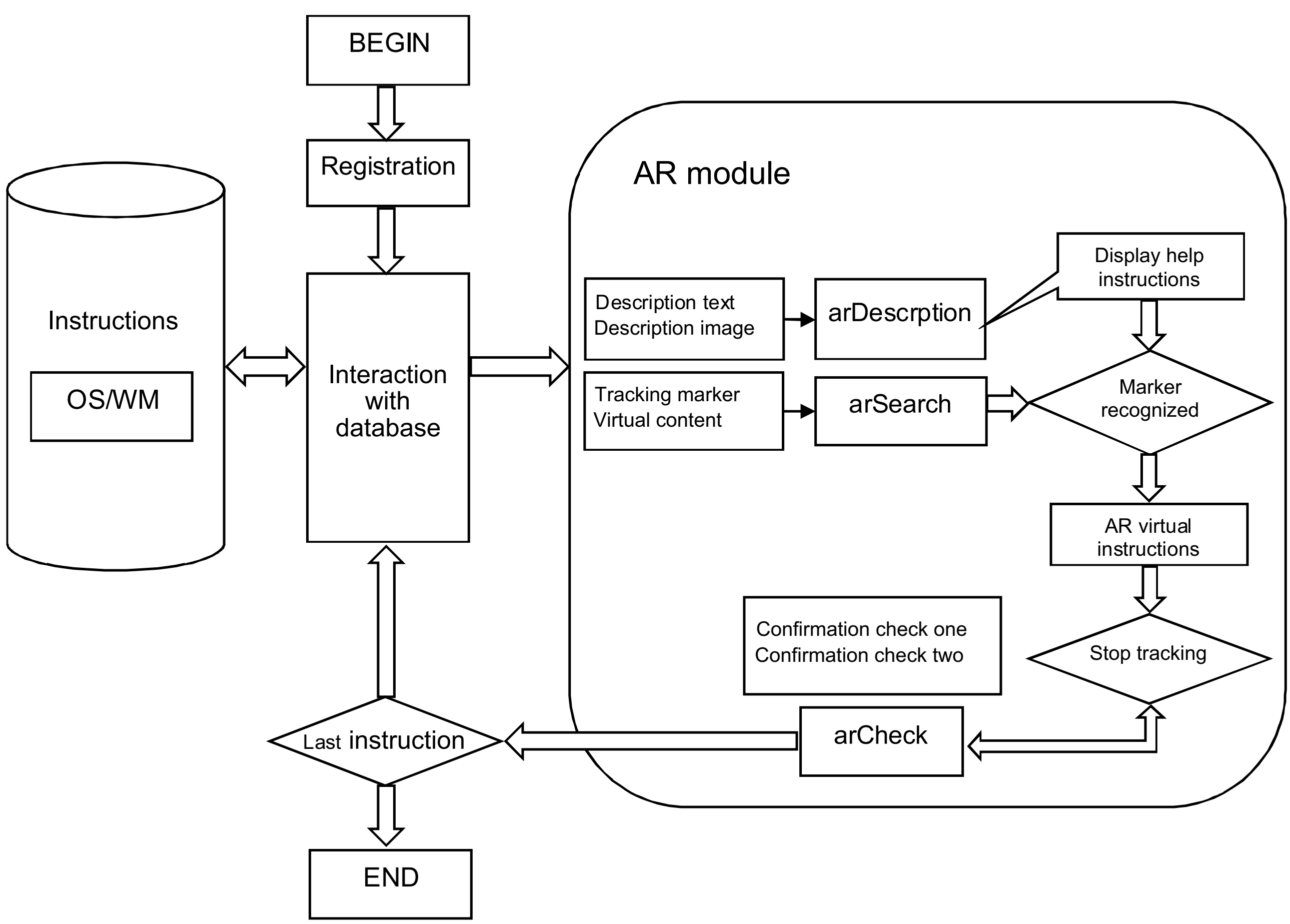


Fig. 3. AR module.

6.1. Database

The database is located on an external server and contains the Task list, Instruction list, and Completed task list.

6.1.1. Task list

The *Task list* is an organizational structure that is used to show how a concrete job has to be realized. Every task has a unique code and an associated set of instructions that are read from the Instruction list. For preforming a task, the unique ID number of a worker is read and assigned to the task that should be performed. Since the ID of the worker provides information about his professional skills (LS, QW, HQ), the amount of information to be displayed to the worker is automatically determined by referring to the code assigned to the sets of instructions.

A task is executed by sequentially performing all the instructions related to the tasks in the order they are stored in the Instruction list. The next task is enabled when all the instructions from the previous task are executed and confirmed. When the task is complete, the information about the finished task is stored in the Completed task list.

6.1.2. Instruction list

The Instruction list is divided into two parts dedicated to the safety and the maintenance instructions. The safety instruction list is defined by the safety model, specified by an occupational safety expert. It stores instructions in the proper order and expresses how to implement occupational safety measures. Maintenance instructions follow the maintenance model as determined in the instruction manual and related instruction data books. The instructions are linked with the corresponding virtual content to be displayed.

Maintenance instructions are displayed after confirmation of safety instructions.

6.1.3. Completed task list

This list stores the information about all the tasks done by a worker. In addition to the information about the instructions performed and task completed, it stores the date, time, and duration of the task. Besides monitoring the activity of a worker, this information is also useful when a particular task is for whatever reason stopped at some point and has to be continued.

6.2. Application

The application consists of three subsystems: login, visualization, and interaction with the database.

6.2.1. Login

The login part handles assignment of tasks to workers and determines which type of data should be provided. A part of this procedure involves the input of an ID assigned to the worker which contains the information about the level of his professional qualification. Depending on that the system decides the amount of information that will be provided to the worker for each particular task as discussed above. Upon login on the mobile device, the worker sees the task assigned to him.

6.2.2. Visualization

It comprises of the augmented reality part and a checklist, which together help the worker to see how to do the assigned job safely. Upon login, the worker sees the task and then the augmented reality module is activated. Parameters for beginning the AR scanning have to be prepared as a dataset. The dataset for a certain job is loaded from the database. This dataset defines the frame markers where each marker represents one instruction. Each instruction has an assigned multimedia content in 3D, video format or text and images which is displayed when the camera of the mobile device scans the marker. Only one marker is active at the time. Therefore, scanning the wrong marker will not give any result.

To facilitate finding of the active marker we show on the screen the picture how the marker looks like with a characteristic symbol inside the frame. We assume that worker knows the position of his working place. Therefore, we provide a map of the machine and display arrows that navigate the worker towards the currently active marker.

After scanning the marker, the checklist is activated. Upon confirmation, information such as time, date, and job duration, are stored in the database.

6.2.3. Interaction with the database

This subsystem enables retrieving data from the database and forwards them to other subsystems for processing. This enables the system to show for each worker the list of tasks and the list of corresponding instructions depending on their qualifications and responsibilities. The visual subsystem uses data about tasks to generate and display instructions on the mobile device. When the instructions are performed and confirmed, this subsystem sends to the database parameters for the completed task such as the start time, completed time, and duration. Also the same parameters for the entire task flow are recorded.

7. Realization of the system

The proposed AR-based system is implemented on handheld devices as an autonomous occupational safety mobile system. The AROC-system is realized in the Unity 3D software tool using Vuforia SDK. It was implemented and tested on the Android software platform.

The main idea is that the worker uses the system on the Tablet PC in order to have a wider screen for the task realizations. This is advisable because the information given on the screen should be clear and enough visible. Accordingly, the worker can hold the device with both hands during the AR-session. On the other side, during the checking process it is advisable that the worker holds the device with one hand. Filling the checklist will be done by using the finger or a stylus for the mobile device. It is envisaged that the working suit has a pocket dedicated to carry or dispose the device during the work.

When the application is launched, the worker sees on the home screen the image of the real world captured by the camera on the mobile device. This image is projected in the background while the navigation layer is displayed above it. Instruction what to do first is provided in the form of a text message with a picture of the frame marker. Also, the navigation map is displayed in the corner of the screen. A special attention is paid to the visibility of instructions, in particular to text drawing styles. In this respect, we followed recommendation initially prosed in [12] and further elaborated and refined in [13,14]. According to these recommendations, white characters and pictures are displayed over a semi-transparent darker background (negative polarity) [13,14]. Transparency gives ability to see the real world image on the billboard, while the text in withe color expresses the navigation sentence. The text is split into reasonably small portions and written in the form of concise and short sentences. The size of the text is defined as suggested in [12] so that the sentence could be read in one look. Visualization of the check lists is realized by appreciating recommendations in [12], [13], [14] in the same way.

It is important to notice that the system allows repetition of the multimedia content if this is required by the user for a better

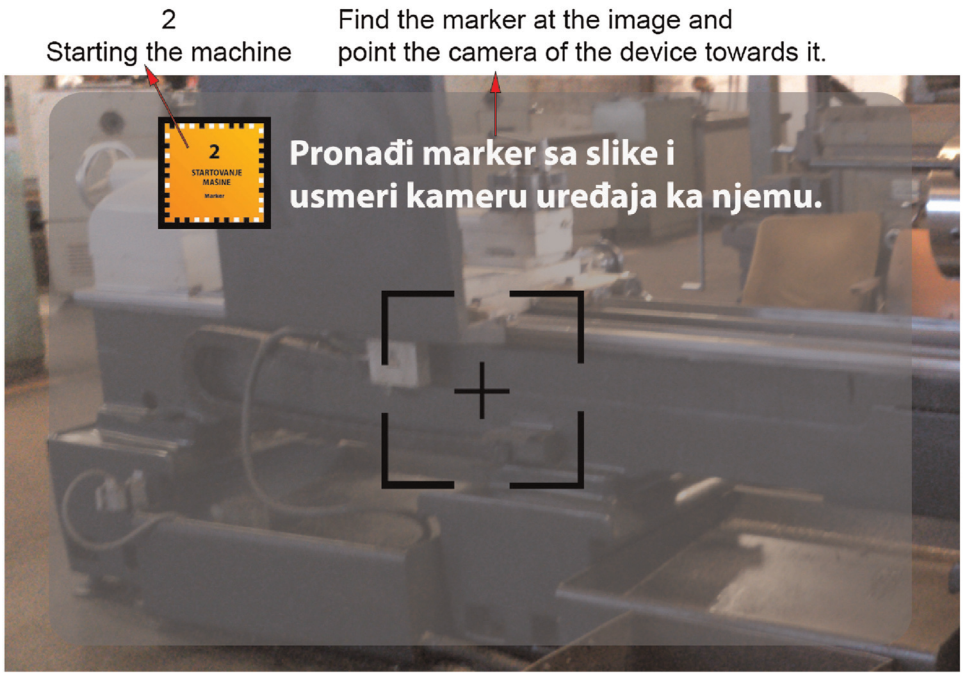


Fig. 4. Initial screen with instructions for marker tracking (in Serbian). (English translation of the text message 2. Startovanje mašine = Start the machine Pronađi marker sa slike i usmeri kameru uređaja ka njemu. = Find the marker at the image and point the camera of the device towards it).

understanding and consequently successful execution of the current instruction related to the particular spot.

8. Application of the system

The proposed scenario for the usage of the system assumes that the worker gets a Tablet PC with the application installed at a purposely dedicated office in the factory. Issuing the Tablet PC to a worker is recorded and the database of available workers for a day or the work shift is updated.

For the case that a worker is not able to reach the office, since for example being transferred directly from a working area to another, the worker can be allowed to download the application to his mobile device. This is done either by sending the installation link or by scanning the QR code for the application download that can be put on an appropriate place in the work area or even simpler directly on the machine. Clearly, the wireless internet connection in the working environment should be provided.

In this section, we describe the application of the proposed AROS-system on the example of work on the combination lathe. The database is configured based on instructions provided by the

Fig. 5. Marker tracking.

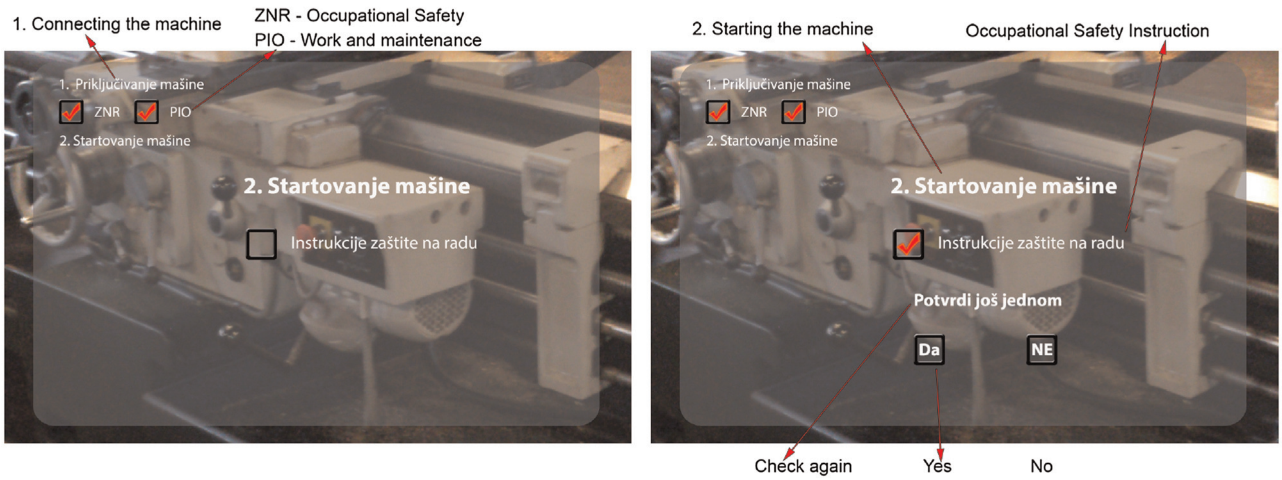


Fig. 6. An illustration of the interactive checklist (confirmation screens are in Serbian) (a) Left upper corner—History of previous activities. Central part – current instruction in the checklist. (b) Reconfirmation of the implementation of current instruction English translation of the text message: 1. Priključivanje mašine = Connect the machine ZNR (zaštita na radu) = Occupational safety PIO (popravka i održavanje) = Repair and maintenance 2. Startovanje mašine = Start the machine Instrukcije zaštite na radu = Occupational safety instruction Potvrdi još jednom = Check again Da ili Ne = Yes or No.

occupational safety and technology officers like these in the example illustrated by Table 1 and Table 2.

According to that, the OS and WM instruction are implemented in the database. Upon login,

the AR module presents to the worker the currently assigned task to him (Fig. 4) after which follow the corresponding instructions (Fig. 5).

In the example below we show some steps of the application of the proposed AROS-system by a less skilled worker. Note that the screen images were captured in the real work environment at the Thermal Plant Ugljevik and, therefore, the instructions are in Serbian. The translations into English are provided in captions of the figures.

When the worker scans the marker that can be found at a specific location on the machine, he receives instructions in the form of video content, a 3D model, or in any other appropriate way (Fig. 5). After seeing the video, the worker performs the task and then confirms the executed instructions (Fig. 6a).

Proceeding with the next instruction is possible only after additional confirmation that the instruction is completed (Fig. 6b).

9. Conclusion and future work

Technology of augmented reality was recognized as a tool that can be used to decrease the error rate which causes injures at work in the industry environment. By following this idea, we developed an augmented reality system for control of the implementation of different tasks on industrial equipment. It is assumed that the tasks can be realized through a series of sequential instructions. Therefore, we implemented functionalities that follow the orders of the instructions. Augmented reality is used to handle occupational safety and working and maintenance instructions respectively, in order to issue exact guidelines at the exact place in industry space. The security of properly performed instructions is ensured by the implemented checklist connected with the subsystems that interact with the database. Doing this we have shown that the implemented strategy has a twofold goal: to ensure secure handling and complete performing of procedures in the correct order. The interaction with the database through checklists ensures that all instructions are performed completely and in the correct order. An important feature is a possibility to differentiate the amount of information to be provided to a worker depending on the level of his professional skills and expertise. Classification of workers by their expertise is a part of the login of the system process. Depending on that, the information sent to experienced workers is reduced and unnecessary parts removed, which accelerates the communication with database and the overall procedure. At the same time, since sufficiently detailed instructions are included and issued when required, the system enables the tasks to be performed by the staff with no highly specialized professional knowledge. In this way, the usage of the system brings a larger flexibility in the management of available human resources.

The proposed system is experimentally implemented in the *Thermal Power Plant Ugljevik, Republika Srpska*. Due to the short experimental period, a proper evaluation of the effects of the system cannot be performed. The preliminary results, according to the safety and technology officer's reports, confirm usefulness of AR system because no injuries were recorded. An observation during the testing was that some workers needed few days of adaptation to the new technology due to initial small experience of dealing with mobile devices. After a short adaptation, the system was accepted by all workers, and their main recommendation was to use mobile devices with large screen. Both technology and occupational safety officers were satisfied with amount of data that was recorded and found it useful for monitoring of current and planning of future work with respect to available human resources and tasks to be performed. Therefore, it may be expected that the system will fulfill its purpose.

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