An Augmented Reality Framework for Supporting and Monitoring Operators during Maintenance Tasks

Guido Maria Re and Monica Bordegoni

Politecnico di Milano, Dipartimento di Meccanica,
Via La Masa, 1, 20156 Milano, Italy
{guidomaria.re,monica.bordegoni}@polimi.it

Abstract. The paper proposes a framework for supporting maintenance services in industrial environments through the use of a mobile device and Augmented Reality (AR) technologies. 3D visual instructions about the task to carry out are represented in the real world by means of AR and they are visible through the mobile device. In addition to the solutions proposed so far, the framework introduces the possibility to monitor the operator's work from a remote location. The mobile device stores information for each maintenance step that has been completed and it makes them available on a remote database. Supervisors can consequently check the maintenance activity from a remote PC at any time. The paper presents also a prototype system, developed according to the framework, and an initial case study in the field of food industry.

Keywords: Augmented Reality, Framework, Maintenance tasks, Remote Supervision.

1 Introduction

Maintenance operations in a factory are necessary duties in order to provide a continuous functioning of the machineries and of the production. In several cases, operators are trained in order to acquire skills necessary to intervene on the machines on a scheduled time and to operate by following proper procedures. However, the outcome and the time planned to achieve these maintenance operations are always uncertain. The uncertainties are due to difficulties that the operator must face to complete the maintenance task, such as the functional and mechanical complexity of the machine.

The level of uncertainty increases when the maintenance operation is not a routine work because it is a fortuitous or compelling event that the operator is not used to carry out. In other cases, instead, an operator carries out a maintenance task even though his background is not sufficient to accomplish it autonomously or accurately, such as when the operator gets confused because he deals with several similar machines or when an unskilled operator performs the task. This case usually happens to avoid the intervention of an expert operator, which could be costly and require a long waiting. Thus, an instruction manual traditionally supports the operator to accomplish the maintenance activity.

However, maintenance operations accomplished with lack of depth or without complying with the protocols could lead to functioning problems of the machine.

R. Shumaker and S. Lackey (Eds.): VAMR 2014, Part II, LNCS 8526, pp. 443–454, 2014.

A malfunctioning can be dangerous to the people working in the factory or it can lead up to additional maintenance, due to unexpected machine fails. From these considerations it turns out that the complexity of the machine, inexperience, negligence and the human predisposition to errors affect the maintenance effectiveness. Consequently, these issues negatively influence a machine, by affecting its production in a plant, its working life and, in a long-term perspective, it leads to the increase of the industrial costs.

According to the above-mentioned considerations, current research trends are oriented to reduce maintenance costs by improving the operator's performances at work. In particular, one of the main trends aims at reducing time and money for the training, by providing supports for instructions that are more accessible and easy to understand also for unskilled operator.

A great advantage in the field of maintenance is offered by Augmented Reality (AR), which is an emerging technology coming from Computer Science. AR enables the user to see and interact with virtual contents seamlessly integrated in the real environment [1, 2]. In case of maintenance operations, the virtual contents are the instructions to perform, which can be represented as text or as three-dimensional objects. Hence, the instructions are provided in a way that it is more direct, accessible and easy to understand than the approach based on a traditional paper manual.

In this research work, the authors describe a framework that aims at extending the AR solutions for supporting maintenance tasks so far proposed. The framework combines a method to provide maintenance instructions to the operator by means of a mobile device and a solution to record and monitor the performed tasks in a remote location. The mobile device shows the instructions to the operator by using AR and, at the same time, sends data and pictures regarding the on-going maintenance task to a remote PC through a wireless network. The advantage of this framework is twofold. Operators have an intuitive support to achieve maintenance at their disposal, while supervisors can visualize the maintenance history of a machine and check the operators' work from remote. In particular, the remote PC can be used to evaluate if the tasks have been carried out in accordance with the protocols, if the operator did a mistake and if the maintenance has been accomplished on schedule.

The paper is divided as follows. The most relevant research works carried out in the field of AR for maintenance are reported in Section 2. Then, the developed framework is described in Section 3, while an initial case study is presented in Section 4. The paper ends with a discussion and an outlook on future developments.

2 Background

AR technology has been successfully experimented in the field of maintenance [3] and nowadays first industrial cases and applications are coming out [4]. The advantage of applying AR in this field is the reduction of the operator's abstraction process to understand the instructions. In fact, the instructions are represented by means of virtual objects directly within the real world so that paper manuals are no longer required. Comparative tests demonstrated the improvement of operator's work in some manual activities by using AR in comparison with other supports to provide instructions. Tang et Al. demonstrated how AR reduces the user errors during manual operations and the mental workload to understand a given task [5]. Henderson and Feiner showed that AR reduces the time to understand, localize and focus on a task during a maintenance phase [6]. In summary, AR increases the effectiveness of the operator activity and it consequently speeds up the whole workflow.

Many AR applications conceived for conducting maintenance operations are based on immersive visualization devices, as for instance the Head Mounted Displays (HMD). The first research focused on maintenance using AR was carried out within the context of the KARMA project [7], in which they provided maintenance instructions on a laser printer through an HMD tracked by an ultrasonic system. A case study in the automotive domain has been described in [8] for the doorlock assembly into a car door, while an immersive AR support is proposed for a military vehicle in [9]. Lastly, the immersive AR solution presented in [10] enables the operator to manipulate maintenance information by means of an on-site authoring interface. In this way, it is possible to record and share knowledge and experience on equipment maintenance with other operators and technicians.

However, HMDs have ergonomic and economic issues that impede their wide deployment in industry, even though they are an effective means to give AR instructions. It is a relatively expensive technology that does not provide a good compromise between graphic quality and comfort for the user [11]. Moreover, its use is unsuitable for a long period, as for an entire working day [12].

Mobile devices are currently the most interesting support for AR applications. Billinghurst et Al. evaluated the use of mobiles as AR support for assembly purposes [13]. Klinger et Al. created a versatile Mobile AR solution for maintenance in various scenarios and they tested it in a nuclear power plant [14]. Also Ishii et Al. tackled maintenance and inspection tasks in this very delicate environment in [15]. As negative aspect, mobile AR has the disadvantage of reducing the manual ability of the operator during its use, if compared with the HMD case. In the first case, in fact, he has to hold the device. For this reason, Goose et Al. proposed the use of vocal commands in order to obtain location-based AR information during the maintenance of a plant [16]. Nevertheless, from an industrial point of view, mobile devices are currently the most attractive and promising solution for supporting maintenance tasks by means of AR. They are powerful enough to provide augmentation and they are cheap and highly available on the market, due to their high volume production for the mass market. In addition, since these devices are easy to handle, to carry and they are currently present in the everyday life, they are considered more socially acceptable than the HMDs.

This work aims at extending the use of AR in maintenance by monitoring the operator's activity from a remote location. Some research works partially dealt with this idea by integrating AR in tele-assistance. Boulanger demonstrated it by developing an immersive system for collaborative tele-training on how to repair an ATM machine [17]. Reitmayr et Al., instead, integrated a simultaneous localization and mapping system (SLAM) in an online solution of annotations in unknown environment [18]. The integration of mobile devices into maintenance activities increases the effectiveness of remote assistance by experts because it makes as if the expert was collaborating on-site.

The research described in this paper distinguishes itself from the others because it presents a framework to record the work done for future monitoring. Actually, the cited works focus only on the support and supervision of the operator in real-time and they do not allow recording his work in order to check it afterwards. By the time this paper has been written, only Fite-Georgel et Al. have proposed a research with a similar approach to monitor the accomplished work [19]. Their solution is a system to check undocumented discrepancies between the designed model of a plant and the final object. However, it works only offline and it has not been conceived for maintenance purposes.

3 Framework Description

The developed framework enables the visualization of maintenance instructions through a mobile device and the remote monitoring of the accomplished work. In this section, an overview of the framework is firstly depicted and subsequently the two main modules, of which the system is made up, are described in detail.

3.1 Overview

Figure 1 provides a schematic representation of the framework and shows its two modules. The first one is the Maintenance Module and it is based on an AR solution to display instructions to accomplish on a mobile device. Thus, the instructions, which are traditionally provided by a paper manual, are stored in a database as digital information and loaded automatically by the AR solution when they are required. For each maintenance step, the module saves data about how the maintenance operation is going and, if the device is connected to a Wi-Fi network, it sends them to a remote storage server.

The data stored into the server are visible at any time by means of the Monitoring module. In this way, a supervisor can check the entire maintenance history carried out on a specific machine.

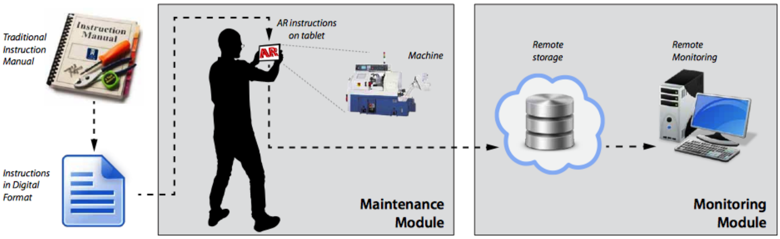

Fig. 1. Schematic representation of the framework

3.2 Maintenance

The Maintenance module is basically an application that provides a mobile AR visualization of the instructions. Besides this, a Wi-Fi client is integrated in the application and it sends the data about the accomplished step to the remote server.

Figure 2 shows the tasks of Maintenance Module. The camera, embedded in the mobile device, frames the machine that requires maintenance service and provides video stream to the AR application. Specific algorithms estimate the position of the camera with respect to the mechanical component by the video stream. This task, also referred to as tracking, allows the module to represent precisely the virtual contents in the real world, with a proper perspective and spatial coherency.

The instructions of the tasks to carry out are stored in configurations files and they are loaded during the initialization of the AR application. They are textual information about how to perform the task and the spatial position of the machine components on which the operator should intervene. The instructions are rendered in a graphic manner, by using also the tracking data. The graphic result is superimposed onto the video stream and shown through the video display of the device.

Once a step is finished, the module automatically saves the maintenance information and makes them available to the remote PC through the Wi-Fi client.

Data Communication. Every time the operator presses the button to move to the next maintenance task, the application saves the data of the last operation concluded and sends them to the remote server. This approach, if scaled with several AR mobile maintenance devices, is a cloud-computing network, which is referred to as *cloud* in

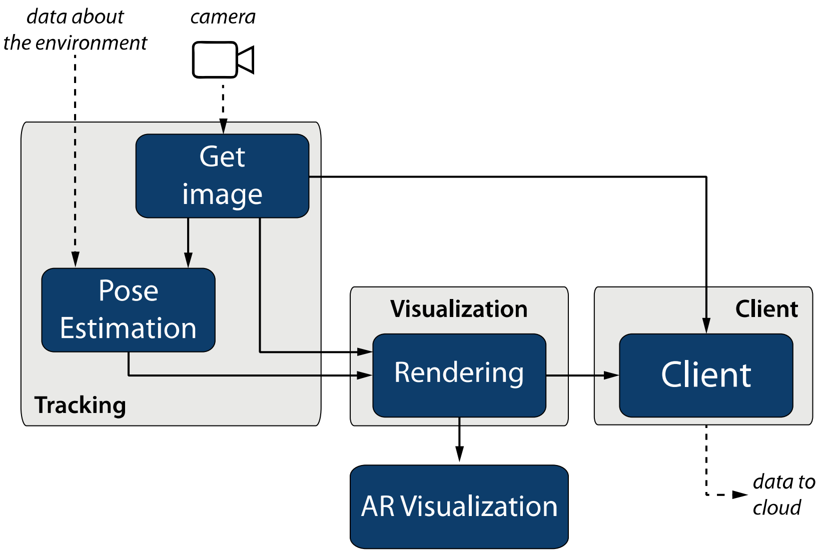

Fig. 2. The tasks that the Maintenance Module performs in order to provide an AR visualization and the data to the remote database

this work. These data are two pictures of the machine at the end of the task and additional textual information. The pictures are the same one and they distinguished between each other because one shows also the augmented content. In this way, the supervisor can check the correctness of the operation by comparing it also by the AR instructions.

The other pieces of information are complementary data to complete the description of the operation and they are the following:

- Operator's name
- Data
- Time
- Machine ID number
- Typology of maintenance (ordinary, extraordinary, intervention for breakdown/error)
- Name of the maintenance operation
- Step Number
- Step description
- Time taken to execute the task

These data are saved in a file and organized according to a simple XML-like structure so as to have an effective communication protocol to exchange information between Maintenance and Monitoring Modules.

3.3 Monitoring

Monitoring Module is constituted by a software application that allows the supervisor to check the maintenance data stored in the Cloud. A parser retrieves the maintenance data saved in the XML files and makes them available to the module. Then, a GUI collects all the data and enables the supervisor to visualize and navigate through the pictures and the maintenance information of each task.

4 Case Study

The case study, which will be presented in this section, describes an initial test of the framework within the context of food industry. In particular, the machine used for the study is addressed to food packaging and it requires particular attentions and a periodic maintenance service in order to provide a safe packaging process of the product.

Several maintenance operations on this kind of machine must be carried out daily, due to hygienic reasons. Food Companies usually involves normal operators without any particular skills or knowledge about the machine to take care of it. The reason lies in the necessity to avoid the constant need of a skilled operator, but it involves a higher risk of uncertainty on the outcome of the operation.

The system developed according to the framework is described in the following. Then, the case study is presented.

4.1 System Description

The system used for the case study is here described according to the two modules of the framework. This section takes into account both hardware and software components.

Maintenance. The Maintenance Module used by the operator is an AR application, constituted by a GUI designed for maintenance purposes, which runs on a mobile device. The mobile device used for this case study is a Windows-based tablet PC. The tablet is equipped with a 1.80 GHz processor, 2 GB RAM, 10.1in color touch screen display and a 640x480 camera working at 30Hz.

Once the operator has selected the right maintenance service to perform on the machine through the GUI, the application provides him with the AR instructions. All the tasks have been taken directly from the paper manual, while the machine components, which are visible as augmented contents in the scene, have been exported from the CAD model of the machine. Each set of instruction for a specific maintenance service is saved in a separated file.

A very stable marker-based tracking solution has been chosen to detect the camera pose and subsequently to properly represent the virtual content in the real environment. Thus, tracking is performed by placing squared, black and white markers on the machine. The tracking algorithms are from the library called ARToolkit Plus [20]. These algorithms detect the markers placed in the environment and they retrieve the camera pose by means of mathematical considerations on the four corners of each marker in the scene.

The visualization of the AR contents in the real world is a merging process between the video stream of the camera on the tablet and the virtual objects, which are rendered with the right perspective according to the tracking data. OpenSceneGraph[1] is the Computer Graphics library used for this purpose and it updates the visualization at every new camera frame.

The interface has been specifically designed for the AR use on a mobile device. Thus, some considerations regarding how to represent and manage the AR content for the operator in the best manner have been taken into account. Actually, the instructions to execute a task have to be provided by the system in a way that is simple to understand and interact. The guidelines presented in [21] have been used as starting point. Figure 3 shows the achieved result of the following considerations.

The first consideration regards the visibility of the virtual objects in the working environment. The objects are 3D or 2D elements and each of them has a precise purpose, such as indicating the point on which the user has to work or showing the action to perform. For this reason, animations applied to them in order to show how to deal with a component can increase the understanding of the user. In addition, these virtual elements must be easy to be recognized into the scene by the operator.

---

[1] OpenSceneGraph library: `http://www.openscenegraph.org/`

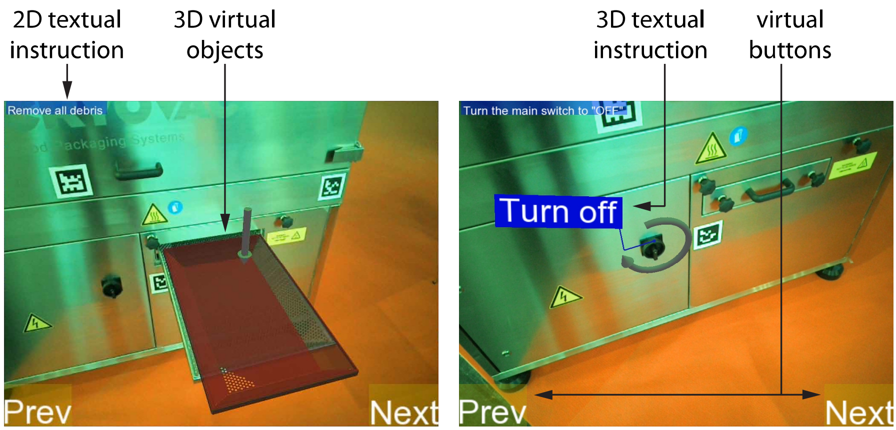

Fig. 3. The virtual objects present in the augmented visualization

Second, the instruction has to be also complemented by some textual information. The purpose of the text is to give additional information, which cannot be provided by other graphical representations. The text is represented as a 2D element on the Graphic User Interface (GUI) and also as a 3D element, which is in a fixed position on the machine. The text should be short, clear and direct, so as to enlighten the operator about the task to accomplish.

Finally, a way to manage the instructions has to be taken into account, since they are represented as a sequence of tasks. By means of a step-by-step instruction approach, the user focuses only on one operation at a time. Therefore, two virtual buttons are present on the GUI and they enable the operator to switch from one instruction to the next one.

Fig. 4. The Graphic User Interface for the remote monitoring

Monitoring. The Monitoring Module is a Windows application that runs on a desktop PC. As shown in Figure 4, the application provides a GUI to visualize the pictures, which were automatically taken by the Maintenance Module, and to show all the complementary maintenance data in a textbox. Finally, a button enables the supervisor to switch from the normal to the AR visualization of the picture.

Fig. 5. Maintenance of the machine. The user frames the machine with the tablet (left) and looks at the instruction by means of the tablet (center and right).

4.2 Maintenance Service on a Machine

The case study is a simulation of maintenance service on a machine from food industry. For safety reason, the machine was not installed and operative; all the required utilities (water and electricity) were not plugged. The study regards an ordinary and extra-ordinary maintenance service. As depicted in Figure 5, the user was asked to select the proper operation through the GUI on the tablet and to accomplish it by following the AR instructions. The user involved did not have any experience with the machine.

Figure 6 shows some screenshots during the maintenance simulation. The markers placed on the machine allow the user to move in the environment and to experience

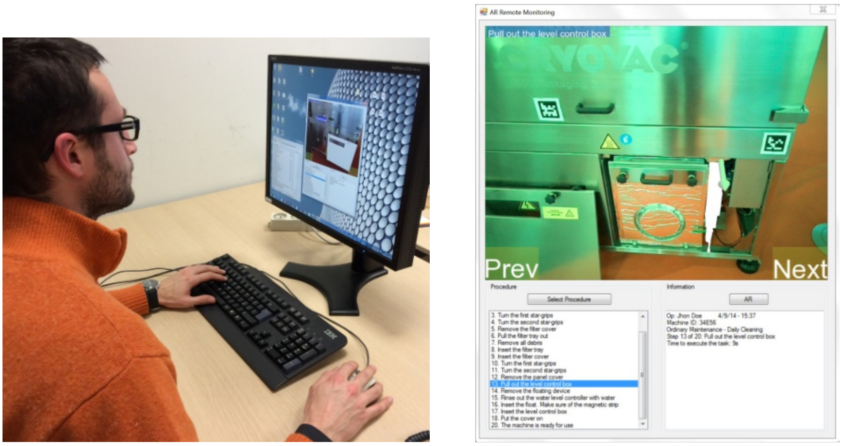

Fig. 6. On the left, the remote user checks the work of the operator. On the right, a screenshot of the interface.

the AR visualization from both a close and a far distance. At the same time, a supervisor, who knows the maintenance tasks of the machine, sits in front of the remote PC and visualizes the user's work. This interface turns out to be a very effective means to check the work and find possible mistakes.

5 Discussion

The case study shows the benefit of the framework to support and monitor maintenance operations. Actually, AR allows avoiding the use of traditional instruction manual and the training of operator on how to perform a correct maintenance. The visualization of the instructions contextualized on the machine makes the operator's work easy, potentially faster and more precise than the one carried out with traditional means. Thus, experts are less required. In addition, the use of AR in maintenance tasks introduces the mobile devices in industrial fields, which can be used also for other purposes. In this case, the mobile device has been used to send information to a remote PC about how the maintenance process is going. Therefore, a company can increase its control on the operator's work and collect the maintenance history of its machines in the factory. For these reasons, the proposed framework meets the expectations about the increase of the effectiveness of maintenance tasks through AR and remote supervision.

The only drawback noticed during the case study is related to the tracking technology used in the AR application. Markers allow having a very stable and precise tracking, but they have to be placed onto the machine and its components. Thus, a time-consuming procedure for fixing and calibrating the markers is required. In addition, the camera must always frame at least one marker to estimate the camera pose. The use of different camera tracking methods, which are not based on markers, can be used in order to overcome the problem. Currently, some methods are able to estimate the pose by means of distinguishable geometrical features that are already present on the mechanical component and the environment without placing any marker. These methods are usually called marker-less or natural features tracking. Examples of the use of these tracking technologies can be found in the automotive field [22] and in the aeronautic maintenance [23].

6 Conclusion

This paper presents a framework for supporting maintenance tasks in industrial environments. The framework provides a method to represent instructions through mobile AR that eases the operator's work. In addition, the framework introduces a new way to monitor the worker. The mobile device, which provides the AR instructions, records information about the performed maintenance steps and it makes them available on a remote PC. Thus, a supervisor can check the maintenance activity from the remote PC.

In the future, new technologies will be integrated in order to provide more advanced tracking and interaction systems. Moreover, the power offered by the cloud computing will be investigated by making the data exchange between the mobile device and the remote PC in both ways. Therefore, the supervisor will be able to collaborate with the operator by sending notes or alerts that will be automatically visible by the operator in the augmented environment.

Acknowledgments. The Authors thank Sealed Air, the Company that kindly provided the industrial machine to perform the case study. The Authors are also grateful to Serena Graziosi, Francesco Furini and Prof. Giorgio Colombo for their support and collaboration during this project.

References

1. Milgram, P., Kishino, F.: A taxonomy of mixed reality visual displays. IEICE Trans. Inf. Syst. E77-D (1994)
2. Azuma, R.: A survey of augmented reality. Presence 6, 355–385 (1997)
3. Fite-Georgel, P.: Is there a reality in Industrial Augmented Reality? In: 10th IEEE International Symposium on Mixed and Augmented Reality (ISMAR), pp. 201–210. IEEE (2011)
4. Davies, P., Sivich, L.: Augmented Reality and other Visualization Technologies for Manufacturing in Boeing. SAE Int. J. Aerosp. 4(2), 1133–1139 (2011)
5. Tang, A., Owen, C., Biocca, F., Mou, W.: Comparative effectiveness of augmented reality in object assembly. In: Proceedings of the Conference on Human Factors in Computing Systems (CHI), pp. 73–80. ACM Press, New York (2003)
6. Henderson, S.J., Feiner, S.: Exploring the benefits of augmented reality documentation for maintenance and repair. IEEE Trans. Vis. Comput. Graph. 17, 1355–1368 (2011)
7. Feiner, S., Macintyre, B., Seligmann, D.: Knowledge-based augmented reality. Commun. ACM. 36, 53–62 (1993)
8. Reiners, D., Stricker, D., Klinker, G., Stefan, M.: Augmented Reality for Construction Tasks: Doorlock Assembly. In: IEEE and ACM International Workshop on Augmented Reality (IWAR), pp. 31–46 (1998)
9. Henderson, S.J., Feiner, S.: Evaluating the benefits of augmented reality for task localization in maintenance of an armored personnel carrier turret. In: 2009 8th IEEE International Symposium on Mixed and Augmented Reality, pp. 135–144. IEEE (2009)
10. Zhu, J., Ong, S.K., Nee, A.Y.C.: An authorable context-aware augmented reality system to assist the maintenance technicians. Int. J. Adv. Manuf. Technol., 1699–1714 (2012)
11. Ong, S.K., Yuan, M.L., Nee, A.Y.C.: Augmented reality applications in manufacturing: A survey. Int. J. Prod. Res. 46, 2707–2742 (2008)
12. Didier, J.-Y., Roussel, D., Mallem, M., Otmane, S., Naudet, S., Pham, Q.-C., Bourgeois, S., Mégard, C., Leroux, C., Hocquard, A.: AMRA: Augmented Reality assistance in train maintenance tasks. In: 4th ACM/IEEE Int. Symp. Mix. Augment. Real. - Work. Ind. Augment. Real., pp. 1–10 (2005)
13. Billinghurst, M., Hakkarainen, M., Woodward, C.: Augmented assembly using a mobile phone. In: Proceedings of the 7th International Conference on Mobile and Ubiquitous Multimedia (MUM), pp. 84–87. IEEE (2008)
14. Klinker, G., Creighton, O., Dutoit, A.H., Kobylinski, R., Vilsmeier, C., Brugge, B.: Augmented maintenance of powerplants: a prototyping case study of a mobile AR system. In: Proceedings IEEE and ACM International Symposium on Augmented Reality, pp. 124–133. IEEE Comput. Soc. (2001)

15. Ishii, H., Shimoda, H., Nakai, T., Izumi, M., Bian, Z., Morishita, Y.: Proposal and Evaluation of a Supporting Method for NPP Decommissioning Work by Augmented Reality. In: 12th World Multi-Conference on Systemics, Cybernetics, pp. 157–162 (2008)
16. Goose, S., Güven, S., Zhang, X., Sudarsky, S., Navab, N.: Paris: Fusing vision-based location tracking with standards-based 3d visualization and speech interaction on a PDA. In: International Conference on Distributed Multimedia Systems, pp. 75–80 (2004)
17. Boulanger, P.: Application of augmented reality to industrial tele-training. In: Proceedings of First Canadian Conference on Computer and Robot Vision, pp. 320–328. IEEE (2004)
18. Reitmayr, G., Eade, E., Drummond, T.W.: Semi-automatic Annotations in Unknown Environments. In: 6th IEEE and ACM International Symposium on Mixed and Augmented Reality, pp. 1–4 (2007)
19. Fite-Georgel, P., Schroeder, P., Navab, N.: Navigation Tools for Viewing Augmented CAD Models. IEEE Comput. Graph. Appl. 29, 65–73 (2009)
20. Wagner, D., Schmalstieg, D.: Artoolkitplus for pose tracking on mobile devices. In: Proceedings of 12th Computer Vision Winter Workshop (CVWW), pp. 139–146 (2007)
21. Agrawala, M., Phan, D., Heiser, J., Haymaker, J., Klingner, J., Hanrahan, P., Tversky, B.: Designing effective step-by-step assembly instructions. In: ACM SIGGRAPH 2003 Papers on - SIGGRAPH 2003, p. 828. ACM Press, New York (2003)
22. Platonov, J., Heibel, H., Meier, P., Grollmann, B.: A mobile markerless AR system for maintenance and repair. In: Proceedings of the 5th IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR), pp. 105–108 (2006)
23. De Crescenzio, F., Fantini, M., Persiani, F., Di Stefano, L., Azzari, P., Salti, S.: Augmented Reality for Aircraft Maintenance Training and Operations Support. IEEE Comput. Graph. Appl. 31, 96–101 (2011)