Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 11 (2017) 1296 – 1302

Procedia MANUFACTURING

27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, 27-30 June 2017, Modena, Italy

Supporting remote maintenance in industry 4.0 through augmented reality

Riccardo Masoni[a], Francesco Ferrise[b]*, Monica Bordegoni[b], Michele Gattullo[c], Antonio E. Uva[c], Michele Fiorentino[c], Ernesto Carrabba[d], Michele Di Donato[e]

[a]*Politecnico di Milano, School of Industrial and Information Engineering, Piazza Leonardo da Vinci, 32, 20133, Milano, Italy*
[b]*Politecnico di Milano, Department of Mechanical Engineering, Via La Masa 1, 20156, Milano, Italy*
[c]*Politecnico di Bari, Department of Mechanics, Mathematics and Management, Viale Japigia 182, 70126, Bari, Italy*
[d]*SITAEL S.p.A, Via San Sabino 21, 70042, Mola di Bari (BA), Italy*
[e]*Amec Foster Wheeler, Via S. Caboto 15, 20094, Corsico (MI), Italy*

Abstract

Due to the Industry 4.0 initiative, Augmented Reality (AR) has started to be considered one of the most interesting technologies companies should invest in, especially to improve their maintenance services. Several technological limitations have prevented AR to become an effective industrial tool in the past. Now some of them have been overcome, some others not yet by off-the-shelf technologies. In this paper, we present a solution for remote maintenance based on off-the-shelf mobile and AR technologies. The architecture of the application allows us to remotely connect a skilled operator in a control room with an unskilled one located where the maintenance task has to be performed. This application, which has been initially described in a previous work, has been improved on the basis of feedback received by industrial partners. We describe the important features we have added and the rationale behind them to make the remote communication more effective.

Peer-review under responsibility of the scientific committee of the 27th International Conference on Flexible Automation and Intelligent Manufacturing

Keywords: Augmented Reality; Remote Maintenance; Industry 4.0.

* Corresponding author. Tel.: +39 02 2399 8232; fax: +39 02 2399 8282.
E-mail address: francesco.ferrise@polimi.it

Peer-review under responsibility of the scientific committee of the 27th International Conference on Flexible Automation and Intelligent Manufacturing
doi:10.1016/j.promfg.2017.07.257

1. Introduction

Industry 4.0 is a current trend in the manufacturing domain, based on the concept of "smart factory". Among other organizational services, Industry 4.0 requires a quick and efficient maintenance service in order to guarantee that companies implement an efficient production system. The use of Augmented Reality (AR) as a support for maintenance operations is not a new idea, as Azuma points out in a recent paper [1]. Since the beginning, it was clear to the research community that one of the most interesting applications for AR could have been the support of industrial application, including maintenance [2]. By that time, AR enabling technology was expensive and thus developing applications required high investments [1]. After decades, and big advancements in AR enabling technologies, e.g. cameras, sensors, tracking algorithms and visualization technologies, and thanks to the evolution of information and communication technologies in general, AR now has entered the consumer market. At the same time, AR has been recognized one of the leading technology in the 4th industrial revolution, the so-called Industry 4.0.

Among the reasons why AR has not been introduced yet in the industrial practice, as probably the research community expected it some years ago, many are related to the low performance/cost ratio of both the software and hardware technologies available on the market. Tracking technology always seems not precise enough as required in industrial applications. It often suffers from lighting conditions. Furthermore, despite several affordable goggles have been made available on the market they still cannot be used for a long period. Batteries, for example, do not permit a long usage period, ergonomics has been improved, compared to the cumbersome wearable displays of a few years ago, but there are still many open issues mainly related to the visual perception of the mixed information (real plus virtual). Anyway, the industrial interest for such a technology is high, and in recent years, many attempts to use AR as a support for maintenance have been made by both longstanding and emerging research groups, consultancy groups, new startups and so on. Big companies are investing in this direction, too.

Augmented Reality as a support for maintenance, is only one example of what can be done by introducing AR in industry. AR can help to reduce time and errors of maintenance tasks [3]. Maintenance can be of different types: as long as machines failure can be predicted with accuracy, predictive maintenance allows the maintenance frequency to be as low as possible to prevent unplanned reactive maintenance, without incurring costs associated with doing too much preventative maintenance, ideally.

Unfortunately, some failures cannot be easily predicted and in these cases maintenance requires an in-depth analysis of the problem and then expert maintenance operators to perform the repair task. This kind of intervention can be expensive, both for the machine owner and for the company selling the maintenance service, and sometimes takes time for the expert to reach the place where the maintenance task must be performed. Local operators may try to fix the machine by communicating with remote experts using any multimedia support, i.e. by sending pictures, videos, by chatting, talking.

In this view, in a previous work, we proposed an application combining AR technologies with mobile technology to help machine producers to improve their maintenance services [4]. An expert operator instructed local operator by exchanging maintenance instructions through symbols and text projected onto the real environment. The application, as well as its features, had been developed considering that a high network bandwidth could not be guaranteed in many real maintenance scenarios. After the first release the application has been tested in several situations, and some new features have been added. In this paper, we first describe what we learnt in the field and then we describe the evolution of the application.

2. Augmented Reality to support maintenance operations

Since the first research works, AR has been recognized as being an interesting support in the industry for maintenance applications, assembly, and repair of machinery [1, 2]. For example, Feiner et al. in [5] describe KARMA, a prototype of an Augmented Reality system that presents a simple end-user laser printer maintenance application based on a see-through Head-Mounted Display. One of the main advantages of using an AR application compared to traditional documentation is that the operator can access the information necessary for performing the activities directly in the working area, without the need to refer to the printed traditional manual. The kind of information to be displayed in AR in order to permit an efficient maintenance task is still an open issue, as also demonstrated by a recent work of Radkowski et al. [6].

AR, as described in [7], also allows an efficient training modality for maintenance and assembly that accelerates the technicians' acquisition of new skill on maintenance procedures. Haritos et al. [8] describe a mobile AR application for training in the field of aircraft maintenance, to replace the traditional modality of training, i.e. on-the-job training. The AR training system can be useful for both job task training and guidance for job tasks for novice technicians in a real working environment.

Regenbrecht et al. in [9] present some application examples, where AR is used in automotive and aerospace industry. This article presents potential industrial applications that show the possible fields of industrial application of AR, particularly the use of this technology for product maintenance and assembly.

In [10] is described a collaborative application where a haptic assembly simulation is connected remotely with an AR application to allow a training from a skilled operator to an unskilled one. The main drawback of this application is that it requires a long authoring time. This is one of the main drawbacks of several existing applications of AR maintenance, and, in particular, of those based on the use of three-dimensional geometries of the product. Generally, each application is specifically developed for a specific product using the three-dimensional CAD geometries. While this approach can be successful from a marketing perspective, geometries during maintenance operations can create occlusions, even when rendered slightly transparent. Also, depending on the quality of the tracking algorithm, the geometries might not be superimposed perfectly onto real geometries, thus creating a bad user experience. The latter problem, which is quite common in the very first examples of AR applications, has not been solved yet. Other applications, instead of representing moving geometries make use of some three-dimensional symbols, indicating the operations to accomplish, i.e. turning clockwise or counterclockwise a screw and so on. By analyzing literature, it comes out that one of the most interesting problems the scientific community has to face with is the kind of information to add to reality in order to perform maintenance operations.

In a previous work [4] we described the development of an application to support remote maintenance based on the combination of mobile tools with AR technologies. The aim was to allow companies to perform remote maintenance activities of various industrial products, with no need of structured environments or high-speed connections. The application was not based on three-dimensional models and/or animations, but on two-dimensional instruction symbols that could be placed onto existing products. The application was designed to reduce as much as possible the authoring time and was based on classic I/O interfaces that the skilled operator could use for instructing the unskilled one. The application has been tested with several companies for years, and new functionalities have been introduced to improve the effectiveness of remote collaborative maintenance. In the following, we will first describe the specifications an application such this should include, based on our experience, and we will describe also how the original application has been improved to take into account the feedback we received from industry. The application is still under development.

3. A tool to support remote maintenance

3.1. Analysis of the requirements

Based on the analysis of industrial needs to enable remote maintenance we performed in years, after the release of the application described in [4], we found out that a tool should include the following features to support remote maintenance effectively:

- An inspection module: the maintenance expert should be able to see why and where the failure occurred, to understand how to perform the maintenance activity. Usually, the diagnosis is performed by visually or aurally inspecting the machine. Thus, the remote maintenance system should include a module with a video and audio streaming. Usually, companies describe this requirement such as "the maintenance expert should be able to see and hear through the operator's eye and ears and then operate through his hands". While this specification seems to be easily reachable thanks to the high availability of cameras and microphones on off-the-shelf mobile technology, goggles and so on, it is important to analyze their specifications to understand that they might not be able to support the diagnosis task. Most of the available mobile technology today might not allow an effective visual inspection of the failed machine parts. Sometimes the failure makes the machine stop working, but sometimes the failure causes unwanted movements into the machine and to detect the failure is necessary to see the machine while is running. The movements might be at high speeds, and this is not compatible with the limitations of the available mobile cameras which work at very limited frame rates. Usually mobile device cameras of the consumer market work at a frame rate of 30 Hz.

- The use of universal language to allow people of different languages and cultures to exchange information without misunderstandings. In this view, the system could make use of graphic symbols, together with text and audio messages. Indeed, it might happen that the maintenance expert is asked to communicate to local operators, who do not necessarily speak the same language. This is a quite common problem we found in industries. To our knowledge, there are few attempts to find a solution to this problem.
- A Remote-Person View (RPV): the expert remote operator should follow step by step what the local operator is doing.
- A maintenance recorder module: the maintenance operation should be recorded, in order to become a potential manual if the same failure occurs on another machine, or to register the maintenance operation for legal issues.

These considerations are based on the experience we made in years with companies on the first release of the application described in [4].

Furthermore, we should also consider the following constraints, we considered during the development and the update of our application:

- Maintenance ideally can be performed in an environment equipped with high-speed internet connections but also can be performed in a place where the connection is not as good as required to exchange information such as high-speed video streaming, high definition pictures, three-dimensional geometries and so on. It is important to design the application to work in the worst condition. To take into account this limitation, in our solution, we decided to keep separate the application to guide operators through the maintenance task from the application to perform the diagnosis thanks to an audio/video streaming. The video streaming, as well as the audio communication, can be performed with an external application, e.g. Microsoft Skype (https://www.skype.com) or other video streaming tools with other specifications.
- Maintenance can be performed on known machinery where three-dimensional CAD models are available because they are used during the design activity, but also old machines where the three-dimensional geometries are not available or even new machines that were designed using two-dimensional modeling tools. Also, maintenance operations can be performed in environments with a high level of visual information available. In this situation, the information must be provided sparingly in order not to overload the visual channel. For these reasons, in our solution, we decided not to display geometrical information, such as moving parts. We decided to communicate only the needed information to perform the task. This kind of information, which can be a symbol, a sketch or some words, in our view, should complement the information already available in the environment.
- Tracking algorithms for AR have been improved significantly in years, but tracking, in general, is still an open issue. Usually, in applications that make use of symbols, instead of geometries, they are animated. While they are nicer to see compared to still symbols, because of the tracking limitations we still face, they might not be represented in the right location. Their movement might confuse the user, and finally, it might affect the correctness of the information communicated. Based on this limitation, we decided to use two-dimensional symbols, to indicate tasks, instead of animated three-dimensional symbols.
- In order to be able to communicate all the possible maintenance tasks, the number of symbols can be high. In order not to reduce the usability of the application, we decided to represent the most common maintenance tasks through symbols and to allow the maintenance expert to add some sketches or text. The idea of using sketches, which was not included in the work described in [4] has been added to allow

a quicker communication among the users. Through sketches, they can exchange operations which are not represented by the symbols, or they can also add notes.

3.2. Implementation novelties

Figure 1 illustrates the architecture of the application, which has not been modified since the first release described in [4], while some features have been added, some removed or changed. The architecture of the application is of type Client-Server, which well supports the connection of a skilled operator with an unskilled one, or with several unskilled operators working on the same machine, remotely located.

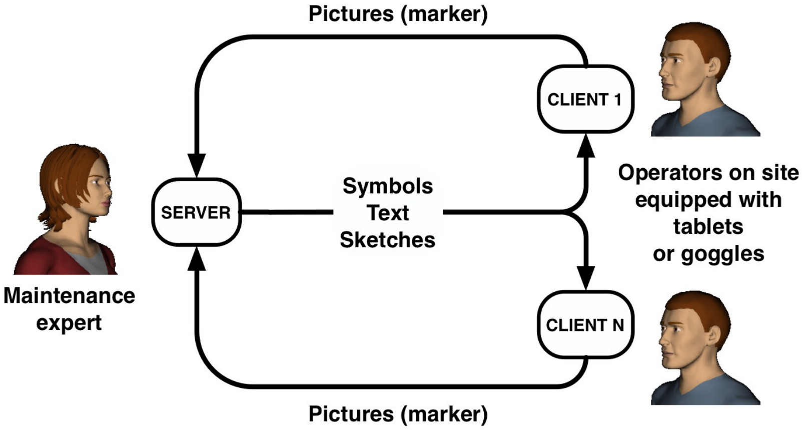

Fig. 1. System architecture: the expert and the operators can communicate thanks to a server/client system. On-site operators send pictures of the real environment to the expert, who uses them to locate instructions that will be sent back through symbols, sketches or text.

The application works in the following way: the unskilled operator/operators (client) take some pictures of the real environments and send them to the skilled one (server) automatically through the application. These pictures are used for the client as a marker to visualize the instructions on the real environment, and for the server to indicate the maintenance tasks to perform.

The skilled operator makes use of some symbols to indicate where to act, and what to do, basically displaying the most common operation (turn clockwise and counterclockwise, assemble and disassemble, locate and warning). A more accurate study of the symbols is still in progress. However, also, he/she can sketch on the picture, or add a text message and send the information to the client. The sketching feature was not included in the application described in [4]. In the previous version of the application, a chat system was included, and we decided to remove it because it was not usable when the local operator was wearing goggles, and thus had to be deactivated. We decided to substitute the cat system with the possibility to send text messages directly displayed in AR. The maintenance expert can write a text message and also decide where to display it. Indeed, the sketch and the text will be displayed in augmented reality to the client. The server can simultaneously communicate with one or more clients acting on the same system.

The new release of the application is still based on the Unity3D 4.3.4 environment (http://unity3d.com), integrated with the Qualcomm Vuforia 2.8.9 tool (https://www.vuforia.com) used for tracking the real scene, and allowing to superimpose digital information onto the real environment. Vuforia is the tracking technology used to recognize the images that will be used as a marker for augmented reality applications. In particular, Vuforia allows us to use image scenes as markers. This is particularly important since no structured environment is required for the AR components.

The application has been developed and used with various hardware devices. Currently, the experienced operator can indicate the operations to perform using a personal computer, equipped with the traditional input and output devices (keyboard, mouse, and monitor), or a tablet or a mobile device equipped with the Android operating system.

The unskilled operator can use a tablet (which is also equipped with the Android operating system) through which he watches a series of statements projected directly on the serviced objects. Alternatively, the maintainer can wear helmets or any AR goggles, which allow him to view the maintenance instructions simultaneously with the execution of the operation. While most of the companies are fascinated by the use of goggles, which might allow the local operator to work while seeing the AR information displayed onto the real scene (thus seeing the AR environment with free hands), we found that AR goggles are not yet ready for this for the reasons already discussed in the introduction. Thus, while for years we tried this application on several wearable technologies, we are convinced that the best solution is still the use of a tablet.

3.3. Description of the use of the tool

The application allows the user, in the first screen, to decide whether to be server or client, which means choosing to start the session as the skilled or unskilled operator. It has to be underlined that, because of the use of Vuforia tracking algorithms, the client version does not run on a personal computer (Vuforia algorithms have been specifically developed for mobile technologies).

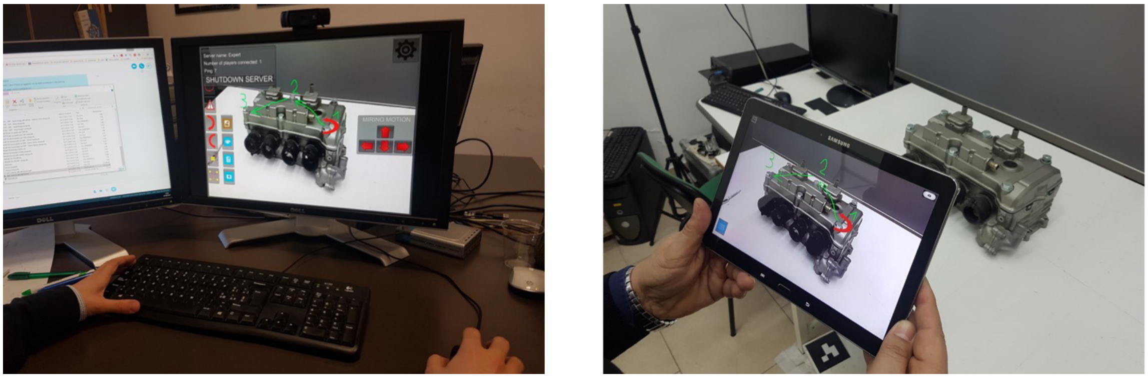

Fig. 2. An example of the use of the application. On the left side the maintenance expert, on the right side the local operator.

First, the client frames the scene where the user must operate, and takes a picture that is automatically sent to the server. These pictures are used as markers for the AR application. In the top right part of the client screen, there is the button to take a picture of the real environment. The button only appears if the program recognizes the picture as a potentially good marker while it is analyzing the scene. Usually, industrial machines are well suited to be used as markers, and if this is not true, a simple solution is to add visual information to the real environment.

Once the skilled operator receives the picture, he/she can annotate it on his/her screen (left side of Figure 2), choosing what kind of message to send to the local operator among symbols, free-hand sketches, and text. For the symbols, we decided to represent a set of common operations in maintenance: unscrew, screw, location indication, warning, disassemble and assemble. To move the symbols, the operator can use some arrows, which are represented on the right side of the screen. For the sketches, the skilled operator can choose among three colors (white, red and green). Once the sketch is finished, this is transformed into a picture and sent to the client. Finally, he can also send text messages. Some functions of the Graphical User Interface (GUI) elements of the server application can be selectively displayed or hidden.

In the client part of the application (right side of Figure 2) the unskilled operator through the AR window sees the symbol or the sketches the skilled operators sent, superimposed onto the real environment in the correct location. The GUI here is clean in order not to overload the visual channel of the operator and to be used with different devices (goggles, smartphones, tablets).

4. Conclusion

In the recent Industry 4.0 initiative, AR has started to be considered one of the most interesting technologies companies should invest on, especially to improve their maintenance services, although this kind of use of AR is not a new idea [1,2]. In the past, several limitations have prevented augmented reality to become an industrial tool. In this paper, we analyzed these limitations which are technological (software/hardware) and also due to an incorrect use of the technology. Now that some of the technological limitations have been overcome and AR seems to be ready to become a tool for industry, we believe that the scientific community can focus on trying to solve the real industrial problems.

In an ongoing research activity, we analyzed a set of needs of some companies interested to improve their maintenance service using today available technologies and in particular AR technologies. We designed and implemented a remote maintenance tool based on off-the-shelf mobile and AR technologies, initially described in [4]. We tested the first release with some end users and, based on the feedback we received, we have introduced new features. In this paper, we described the new version of the remote maintenance system and, most important, the rationale behind it, which is the most important result we obtained from the interaction with end users. The research and the development are still in progress to let this application become an industrial tool from a laboratory prototype.

References

[1] R. T. Azuma. The Most Important Challenge Facing Augmented Reality. PRESENCE: Teleoperators and Virtual Environments, 25(3), pp. 234-238 (2016).
[2] R. T. Azuma. A survey of augmented reality. PRESENCE: Teleoperators and Virtual Environments, 6(4), pp.355–385 (1997).
[3] M. Fiorentino, A. E. Uva, M. Gattullo, S. Debernardis, G. Monno. Augmented reality on large screen for interactive maintenance instructions. Computers in Industry, 65(2), 270-278 (2014).
[4] M. Bordegoni, F. Ferrise, E. Carrabba, M. Di Donato, M. Fiorentino, A.E. Uva. An application based on Augmented Reality and mobile technology to support remote maintenance. In Conference and Exhibition of the European Association of Virtual and Augmented Reality, pp. 131-135. (2014).
[5] S. Feiner, B. Macintyre, D. Seligmann. Knowledge-based augmented reality. Communications of the ACM 36, 7 (1993), pp.53–62.
[6] R. Radkowski, J. Herrema, and J. Oliver, Augmented reality-based manual assembly support with visual features for different degrees of difficulty, *International Journal of Human-Computer Interaction*, vol. 31, no. 5, pp. 337–349, (2015).
[7] S. Webel, U. Bockholt, T. Engelke, N. Gavish, M. Olbrich, C. Preusche. An augmented reality training platform for assembly and maintenance skills. Robotics and Autonomous Systems, 61(4), pp.398-403 (2013).
[8] T. Haritos, N. Macchiarella. A mobile application of augmented reality for aerospace maintenance training. In Digital Avionics Systems Conference, 2005. DASC 2005. The 24th (2005), vol. 1. 2.
[9] H. Regenbrecht, G. Baratoff, W. Wilke. Augmented reality projects in the automotive and aerospace industries. Computer Graphics and Applications, IEEE 25, 6 (2005), pp. 48-56.
[10] F. Ferrise, G. Caruso, M. Bordegoni. Multimodal training and tele-assistance systems for the maintenance of industrial products. Virtual and Physical Prototyping 8, 2 (2013), pp.113-126.