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Shaping the future maintenance operations: reflections on the adoptions of Augmented Reality through problems and opportunities

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Abstract

Maintenance technicians play a fundamental role in ensuring the success of the system reliability, but several fatal accidents occur during the maintenance operations in Europe due to the nature of the job and to human errors. Augmented Reality (AR) technology could ease the execution of complex maintenance operations under specified conditions reducing the probability of failures, guiding through the task the technicians, updating in real-time the operators about the environmental and boundary conditions, reducing costs and time for service and maintenance, reducing documentation of work processes, increasing the level of safety and decreasing the human error probability.
This paper investigates possible applications of AR technologies for assisting the workers during the maintenance operations, identifies challenges for the use of this technology in maintenance applications, and discusses the actual level of feasibility of the technology and the possible improvements in terms of information and communication selection and reduction of human errors.

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Keywords: Augmented Reality; maintenance operations; safety; information and communication selection;

1. Introduction

The rapid changing of new technologies is turning the working rules and the working environment. New potential solutions (e.g. the adoption of systems to empower the workers) are giving the opportunities to better face the existing and well-known maintenance and Occupational Safety and Health (OSH) issues. These new technologies encourage research in a domain of scientific development such as the application of smart and functional equipment in different industrial sectors. The goal is represented by the possible reduction in terms of OSH risks and human errors and by the improvement of the job effectiveness in terms of quality and time. Maintenance tasks are complex operations that require a relevant amount of information, specific procedures and techniques for each machine and equipment to learn. Moreover, new equipment and machines are projected and built every year by industrial companies, requiring new training sessions for technicians. The result is a time-consuming and expensive training process. Therefore, finding ways to more efficiently train and guide technicians to perform their jobs is vital to continue to maintain different types of equipment around the world [1].

Mixing virtual elements with the existing reality AR offers promising technologies to address the mentioned needs, monitoring working conditions as temperature, humidity, spatial position of other workers and providing information and suggestions to the operator in real time empowering the real world. Supplying digital information to the user's real time environment, it is possible to increase the cognitive knowledge [2] of the users and helps them to perceive and interact with the environment.

An AR system augments the real world vision with real-time, interactive, computer-generated objects that coexist in the same space as the real world [3]. For these characteristics AR enables symmetrical communication between two parties and the right information in the right place can be displayed thanks to the embedding of them on the real scene.

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The approach finds its roots in the Digital Twin concept defined as combination of IT applications in the real world using digital and virtual techniques. It was applied during the Apollo missions for the first time in the ‘60s to carefully evaluate and mirror what it would be happened in case of failures on the space vehicles; in the recent years NASA formalized this method [4] defining it as integration of physical phenomena, sensors, objects and simulations.
The transition to the industrial applications was facilitated and supported by the introduction in the industries of the Internet of Things (IoT) paradigm that is giving the access to a relevant amount of essential data necessary to interconnect machines, equipment and operators. But the IT infrastructures have to be able to support and store a lot of data [5].
The achievement of new objectives and better results with AR, it is of paramount importance to ensure a constant support in terms of input processing, storing and data managing with suitable systems technology. As The choice of a software architecture [6] and hardware architecture play a very important role in determining the longevity and re-usability of these products whilst reducing the gratuitous complexity [7].
Therefore, still some big challenges have to be faced in order to effectively get benefits from this opportunity and to prove its feasibility: the digitalization of product information and the management and the way and the technological devices used to provide and supply big data to the operators.

2. Opportunities and challenges of AR in maintenance operations

The actual fields of application of AR show how the maintenance-related sectors are among the most utilized for testing the power and the effectiveness of new technologies. The Fig 1. [8] shows the continuous increasing in wearable AR devices utilization and a forecast the two coming years.

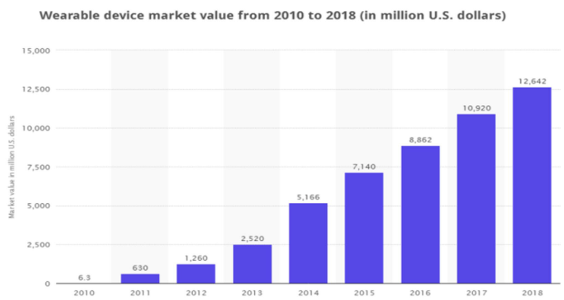

Fig. 1. The evolution trend of the wearable devices [8].

The reason lies on the nature of the maintenance: the involved technicians have always more information to remember on how to perform correctly and on time the tasks due to the introduction in every equipment of electronic components. It needs a relevant amount of time to learn all the required steps increasing the risk of human errors during the operation. Moreover, the increased turnover among the workers requires more training sessions forcing the companies to spend more resources and trying to find new solutions.

2.1. AR opportunities in maintenance operations

Maintenance activities are usually very costly in terms of time and often performed under pressure. Industries with very strict time schedules (e.g. railway and aircraft sectors), are looking for having better time management and reduction in the overall duration of these operations.
A great amount of time is spent searching for instructions, in order to reduce maintenance time, worker stress, and decreases overall job performance.
As suggested by Neumann [9], the 45% of an Aircraft Maintenance Technicians (AMTs) shift is spent on finding and reading instructional procedures for job tasks. Railway technicians are likely under-time pressure due to the fact that railway is a time-critical system and a lot of logistic operations have to be taken into account. Moreover, it is also affected by external variables as construction activities, removal of trucks etc.[10].
According to these issues, AR technologies have been recently tested in order to accelerate the procedures in various maintenance tasks assisting the optimization of the physical movements and helping to save time and energy.
Allowing the transfer of asset information directly to the workers in a real-time mode it is possible to make the management of assets along the networks easier resulting in an increased general efficiency of the system.
It also means a significant improvement and an errors probability reduction in performing several potentially unfamiliar tasks in a complex operation or in an harsh environment. In the study carried out by Henderson & Feiner [11], two kinds of assistances were tested in order to discover the most suitable one to adopt: first an assistance based on a traditional approach of maintenance (a set of baselines to be followed) and a second approach AR-related. The study showed that the technicians performing maintenance sequences under an AR condition were able to address tasks more quickly than when using baseline conditions. Furthermore, the instructions visualized in a AR platform are easier to manipulate than in a traditional baseline.
The support of AR in time saving is also extremely relevant for the knowledge acquisition and transition from skilled experts to new technicians.

2.2. AR challenges in maintenance operations

As discussed in the previous paragraphs due to the nature of the maintenance operations the involved personnel is constantly facing numerous challenges; therefore, an assistance is desirable even for the most experienced technicians for several reasons [12].
The information must be content specific and dynamic. The users should have real time information on request: recognition of objects and patterns in the real world, current location and direction. Moreover the system should track his progress and communicate it, driving the user through the different time steps.
The operation requirements arise several challenges that have to be properly managed to provide helps and not obstacles. The physical and cognitive needed requirements to perform a maintenance task could represent a critical step towards a successful maintenance task. Most of the times, for each task, simultaneous sub-operations are necessary. Only optimizing

the entire process can help the technician in reducing time and energy, allowing the technician to move between the steps, going back to the previous step or forward to the next one more quickly [1].
It is important to note that, in dangerous and often harsh environments, the cognitive part during the learning path in the training session, in terms of interpretation of the results of successful maintenance tasks, is confirmed as an essential part as well [1], [13] in order to contribute to improving spatial ability and mental adaptability of the workers [13].
Several studies have proved [14] that people using wearable devices (glass, helmet with screen etc..) are more prone to blindly follow instructions than people used to learn. This results in a less flexible and resilience approach in case of unexpected event and decision making situations.
This specific reason has been confirmed by a study (in the automotive sector) led by [15] in the form of overreliance where the dependency on this particular technology is very high.

3. Design and communication aspects

As already underlined, one of the most promising aims of the AR systems is to assist the technician in maintenance operations. To enable this capability, a well-defined system architecture is vital. This architecture requires some basic modules needed to interface with user, store the maintenance data, and process it in real time. Therefore, the system basically requires three main modules which are AR, Knowledge-Based-System (KBS) and Unifier module (Um). Here we use the SysteMs engineering Language (SysML) to present different components of this architecture as shown in Fig. 2. This structure has been discussed elsewhere for example in [16] and [17]. The AR module deals with the interface between system and user and addresses the vision-based-tracking and presents information. The Knowledge-Based Module (KBS) module is a mean to identify information relevant to a maintenance task, and the Um which matches information. To architect the content, one should design these modules and their interfaces. Here we elaborate in each one of these modules. Next subsections present summary of main functions. For more details, see e.g. [16, 17]

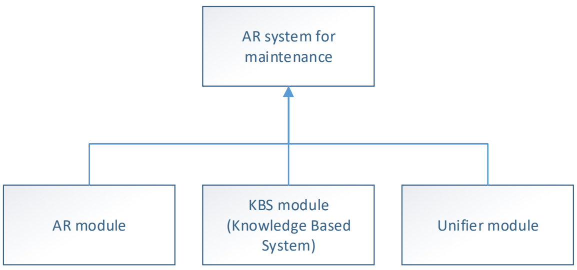

Fig. 2. The main components of the AR system for maintenance.

3.1. AR (interface) module

The AR module takes care of tracking, annotation, recognition, and presentation. The majority of the AR systems contain the following features listed below as also discussed in [11, 9]:

- Text instructions describing the task and accompanying notes and warnings: the user is driven through the operation receiving input coded as visual information;
- Verbal instructions: the information are also provided using verbal messages;
- Registered labels showing the location of the target component and surrounding context: in order to focus the attention of the user to the correct information, labels are assigned to the different target;
- 3D models of tools (e.g. screwdriver): in order to facilitate and to save time during the operations the necessary tools will be displayed and shown to the user;
- Images of correct condition: the user will receive examples describing the correct and failure conditions of the systems.

The importance of the information selection process becomes more evident Too much information, too less information, wrong information, distracting information, distracting sounds can heavily affect the level of attention of the user compromising the results of the operations, the performance and the safety of the system.

3.2. KBS module

KBS takes care of the large amount of information required for maintenance. KBS has to capture the fundamental knowledge for performing maintenance tasks and presents it in a single view without ambiguities. For this process, the V model is used to ensure that the presented information meets the user requirements [18] and [10]. This implies that the practitioners have to be involved in different phases of design including verification and validation. The source information is composed of four different aspects:

- Technical documents: the technical information included in the manuals that will be carefully analysed and evaluated to be selected for the digitalization;
- Videos and clips: multimedia materials used during the technical trainings to transfer messages to the users;
- Pictures and icons: drawings and illustrations useful for clarifying the risks during the task and to highlight the problems;
- Collection of snap-shots: moments of the task that describe particular situations, errors and problems during the operation.

It becomes evident that the KBS module represents a relevant and fundamental decision-making steps that will affect the performance and the safety of the systems in case of AR applications. The knowledge, defined as the set of essential information to provide during the operation to the user, drives the results in terms of OHS; during the preparation phase of AR introductions is important to assess the usability of the device, understanding the "multidimensional" approach and the needs of several evaluation methods to adopt [14]. Therefore, the level of the discussion is attached not only to the technical and technological feasibility, but also to the proper design of human-computer interactions.

3.3. Unifier module

To merge the environment and tools with the organised knowledge is required the last component. The Unifier module integrates the information available in the KBS module with the information comes from the AR module (context). Model Based Systems Engineering (MBSE) is a technical enablers for unifying the AR and KBS modules [19]. The Unifier module receives visual information from AR and technical information from KBS, then it relates this information, and sends the processed information to the AR. This processed information is presented in the form of video view, text view, etc. Um is to also address the integration of human factor concerns into the development of applications as highlighted by Hall [10].

4. Conclusions and future researches

Currently, some prototypes of the AR equipment have been applied in the car repairing operations, airplane inspections off-shore industry and railway maintenance creating a relevant and helpful tool for reducing human errors and for increasing occupational safety. In the next future, it can be applied more extensively in several industries, such as the products assemblies, medical device maintenances, or extremely large-scale complex machines (gas-turbine engine assembly). To be applied intensively in the aforementioned fields, AR system should have higher technical requirements, such as the accuracy and data processing ability, so that they can handle more demanding tasks at the same time.

This technique has also to be integrated in the design phase in order to match the best information to provide, retrieved through an analytic process with technicians and users, with a suitable human-computer interaction avoiding useless and confusing situations and visualization.

As it enables remote collaboration and interaction, the mechanical designers can create models together and modify the model features at the same time [20]. This design approach is especially effective for a multi-disciplinary product, which need different types of inputs from experts in different fields. In the future, since industrial products become more and more complex, implementing this interactive technique in the design phase will be very promising. Moreover, the application of AR technology could overcome complexity barriers and dispersion.

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