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A Human Centered View on E-Maintenance

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In general the objective of E-Maintenance is to organize, structure and link the Information and Communication Technologies (ICT) to develop a maintenance support system that is effective and efficient during the whole life cycle of the product. Among the many challenges of E-Maintenance, human centered solutions that can better assist technicians and engineers are emerging, using ICT resources integrated with visualization technologies, such as Augmented Reality (AR). Supported by a human centered infrastructure, AR can bring knowledge to the real physical world, to assist the technician perform his/her work without needing to interrupt to consult manuals or electronic systems for information, real time data and safety issues. This work reviews solutions to create a human centered E-Maintenance and discusses the steps to implement this vision.

1. Introduction

Over the years the amount of data available in the industry has grown to a state that ICT (Information and Communication Technologies) has become vital for the industry. Now, with all the data in digital form and a large part also online (accessible through the Internet), many types of systems can be developed to assist industry to manage and improve their services and products.

Manufacturers of complex products, such as airplanes, have an increasing demand from customers to improve availability, safety, sustainability, decrease Life Support Cost (LSC) and provide worldwide support at anytime (Candell et al., 2009).

Although ICT is advancing and online information can be used during the maintenance process, these information need to be integrated to form a powerful maintenance system with all the information about the product, such as technical information, maintenance plans, fault diagnosis, real time inspection, etc. The integration of these data in a system is the objective of E-Maintenance (Kajko-Mattsson et al., 2011).

There are many definitions for E-Maintenance, the most used is of a technology that matches ICT with the necessity to keep machines running properly, efficiently and safely (Marquez and Iung, 2008), dealing with the ever increasing information flow and complexity of actual technical systems (Candell et al., 2009). There are many challenges to be overcome in E-Maintenance, such as the restructuring of human resources to pace with the new information flow and cross-platform information integrations. To deal with the increasing amount of information and product complexity, new technologies have been considered to support professionals, such as advanced interactive visualization interfaces. However, huge amounts of data are coming from several heterogeneous sources and they need to be structured and organized in a knowledge representation model, so that a methodology to guide designers to use this knowledge to create human centered interfaces is devised. In this paper we explore the challenge of using this knowledge to develop visualization solutions as tools to facilitate maintenance tasks.

One visualization paradigm that has been used to support maintenance is Augmented Reality (AR). AR is defined as the research area in which computer-generated objects supplement or compose real environments, providing users with a more resourceful tool to visualize their surroundings and related information without space or mobility constraints (Oliveira and Araujo, 2012).

AR can be a potential technology for E-Maintenance visualization, since it can bring knowledge to the real physical world, to assist the technician perform his/her work without the need to interrupt to consult manuals for information. Several AR solutions have already emerged, as explained in section 3.1.

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Using AR interfaces in the maintenance process, users can become aware of their surroundings and tasks in real time. This means that not only this interface can enhance and facilitate the users´ job, but it has also the potential to improve users´ and machines´ safety, notifying the possible dangers of executing current operations (e.g. power is on). It is also possible to support several levels of user experience depending on users´ profile and expertise on the subject.
In this paper we review some of the technologies that are cornerstones for a human centered e-Maintenance, some of the solutions already created and discuss what is our view on this issue and the initial steps of our solution.

2. New Technology Paradigms for Maintenance

E-Maintenance is the main technology promise to improve maintenance in companies. It organizes and structures the ICT along the whole life cycle of the product, to develop a support system that is effective and efficient. Advantages of E-Maintenance include (Marquez and Iung, 2008):

- New maintenance types and solutions: online (remote) cooperative maintenance makes it possible to quickly learn and share solutions with experts around the globe.
- Improved maintenance tools and support: maintenance documentation and online support can be created, so that adjustments are shared.
- Enriched maintenance activities: “E-diagnosis” enables experts to perform online fault diagnosis and since it is possible to keep contact with the manufacturers of a product, the repair time is reduced.

Although automatic machine diagnosis is the trend (Jantunen et al., 2011) the reality is that it did not turn out to be widespread, even with several researches (Jardine et al., 2006). However, when signal analysis for automatic diagnoses are widespread, new forms of data presentation can be used, leading to believe that as data issues are resolved, the importance of the user interface for maintenance grows.
For this to be possible several cross-platform information integrations have to be developed, such as data transformation mechanism, communication protocols and safe network connections. Since data are expect to come from different sources, such as Institutional DBs, Internet of Things, Wireless sensors, WWW, among others, a powerful mechanism for data analytics, data fusion and interpretation is necessary.
Interoperability is an open problem, with each producer having their own solution, even with important standardization initiatives, such as the creation of OSA-CBM (Open System Architecture for Condition Maintenance Based) from MIMOSA (Machinery Information Management Open Systems Alliance). OSA-CBM is a standard architecture for data exchange in a condition based system, that defines a data structure and methods to interface between the six main functionalities of these systems. These functionalities are: data acquisition, data manipulation, state detection, health assessment, prognostics and advisory generation. But according to Jantunen et al. (2011), some challenges, such as setting up and updating a huge maintenance database, are making the breakthrough of OSA-CBM difficult to end users.
Another possible solution for data standardization is domain specific ontologies. Ontologies are high level definition of relations between pairs of concepts, modeling a domain to support reasoning about entities. With data modeled through ontologies it is possible to take advantage of another technology to facilitate interoperability, communication and reasoning of data in E-Maintenance systems, the Semantic Web.
Further on, Semantic Web technologies in maintenance naturally lead to think about Web of Things, which is the implementation of the Internet of Things using the Semantic Web as a mean to exchange and interoperate data (Atzori et al., 2010). Web of Things is a powerful technology to improve maintenance, defined as a novel paradigm to enable “things” (any object with a computational device able of communicating) to communicate, exchanging data with each other.
The advantage of these solutions is that they can be used by shop floor staff to increase their performance in operations (Jantunen et al., 2011). However, these solutions also require powerful and useful user interface to display the right and necessary information. Currently, PDAs or Smartphones are used as a mobile visualization solution. However, Augmented Reality has been regarded as a promising interface for this, allowing a mix of 2D and 3D interfaces coupled with 3D projections in the real environment.

3. AR in the Maintenance Process

According to Jantunen et al. (2011) companies are going towards handheld applications for tasks like work order management, communication with central, guidance to the equipment and reporting work and availability. However, AR is an emerging interface that can be brought to the workplace of nearly every job. When this technology reach its maturity level, contact lenses or high definition optical see through glasses (Azuma, 1997) will be available and they will lessen several burdens other interfaces put on users: to use hands to hold things, lack of mobility, the cognitive load of understanding virtual information and applying it in the real world. Also this interface is not limited to projecting 3D objects in the real world, it will use 2D interfaces together (as a HUD in users' point of view).

3.1. AR in E-Maintenance

There are several works for creation and visualization of AR focused in maintenance and other procedural tasks in industrial processes. Most tend to focus on building an application in a real case scenario and proving their validity. Some focus on the user experience and others in creating new modes for interaction or new paradigms for the maintenance task.

One of the first works to propose the use of an Augmented Reality interface for equipment maintenance is by Lipson et al. (1998). They created the Online Guided Maintenance approach, which uses a web link to obtain the equipment maintenance content and feed an AR application with it.

T.A.C. (Tele-Assistance-Collaborative) (Bottecchia et al., 2010) aims to combine remote collaboration and industrial maintenance, creating systems which implement co presence collaboration between the operator executing the task and an assisting worker (with a higher level of understanding of the equipment).

Henderson and Feiner (2010) made and experiment with users to test the efficiency and comfort of an AR application for maintenance, using a Head Mounted Display. They compared it with a computer manual and a HUD-only application, concluding that not only using the AR application is faster, more intuitive and satisfying, but also it resulted in less overall head movement, causing less physical wear.

Arvika (Weidenhausen et al., 2003) is perhaps the most advanced (or tested) work for AR in maintenance and industrial contexts to date. The project had a vision of providing user centric mobile and stationary AR solutions for industrial applications. Its architecture had three main focuses: tracking (and visualizing AR), information provision from ICT systems for the application and user interaction.

Like Arvika, ARIMA (Benbelkacem et al., 2011) focuses on using the ICT structure already existent in the industry to improve their AR solutions. They created a platform for AR maintenance based on collaboration between technicians and experts, similar to T.A.C., but with a greater focus in integrating AR in an existing E-Maintenance system.

Lastly there is an interesting work from BMW (Stock et al., 2005) that demonstrates a view of how in the future technical documentation will be prepared for AR using metadata based authoring. The core idea is to adapt the already necessary creation of maintenance documentation to AR compatible format, using the metadata of the dis-/assembly process, the tools, the part and its geometry and connected peripherals.

In summary, the main strengths of existing solutions are: validating AR in the maintenance process; the use of remote collaboration for improvement; implementation of a web based solution. However there are still limitations that are challenging and provide exciting opportunities for exploration, mainly: adapt the interface to users, adapt the interface to ongoing situations, provide team work awareness in the interface (benefits demonstrated in Nazir et al. 2012), more complex interfaces that go beyond manuals (giving access to all maintenance data), structuring the data in ontologies to generate knowledge and easier and faster ways to author applications. These challenges are the key to evolving from AR based maintenance interfaces that exist nowadays to a human centered anytime and anywhere solution for maintenance.

3.2. Requirements for AR Interfaces

The goal of using AR is to achieve an interface to improve human work in the maintenance process and to reduce cognitive load through real time data visualization. But carefulness is important, since AR can go from helpful to cumbersome easily if the interface is not well designed.

A human centred solution goes beyond usability requirements, it considers users, environment and task to construct an adaptive and situational aware user interface, to provide efficiency and safety for users. Efficiency, error consequences and subjective satisfaction are the main concerns in maintenance systems.

Efficiency is how fast users can accomplish their task. Visual Design is an important aspect of efficiency, being the study of how to represent information in the user interface, for instance what is the correct media choice for representing information (AR, 3DUI, video, image, graphics) and also how to organize the interface to avoid cluttering. Information filtering, another aspect of efficiency, is the selection of the information to be displayed for the users from all the available data, considering that only the essential information to assist users reach their goal should be displayed. The visualization device influences both listed aspects, with their key characteristics: 1) size of the display, which impacts on the amount of information that can fits the screen; 2) type of device, since Smartphones forces users to use one hand to hold them, while HMDs can be expensive and cumbersome; 3) processing and memory capacity, which may determine the medias used to represent information and their quality.

Considering the maintenance field, error consequences are crucial and can even lead to deadly injuries. Errors induced by the interface can put users in danger due to the nature of industrial plants (high

temperatures, electricity, radioactivity, chemicals, etc.) and others mistakes can be irreversible and compromise the maintenance (like cutting the wrong wire).
The last concern, subjective satisfaction, is the hardest to achieve and involves a lot of user testing and experimentation to regulate. Examples include: 1) device lightning, as some devices or interfaces that uses too much flashes or lights may cause malaise in some persons; 2) video based HMDs with eye offset, which is the difference between the camera position and the users eye position; among others.
The application should improve efficiency and reduce mistakes with the following guidelines:

- Use up-to-date documentation: documentation can be altered or enhanced to reflect difficulties in interpretation or utilization of certain parts.
- Use check list so that users don't get lost during the process and don't skip steps.
- Reduce the time spent to consult or locate resources and materials.
- Reduce time to report problems: the application has an option to mark that task as problematic. Normal problems could be: incorrect documentation (inconsistent 3D models, tasks missing steps, lacking data, danger not alerted), inaccurate tracking, polluted and clustered interface, insufficient time for system response (may be due to problems in networking, tracking, voice and gesture interpretation).

Continuing the requirements for AR interfaces, there is interaction in AR, a wide field with many solutions, with the same base as 3DUI interaction. The main interactions modes identified for AR are:

- 3D interaction: mainly gestures interpreted through a camera and a pattern recognition algorithm, or a 3D device (3D mouse), but can also be gaze based. Gestures have a limited defined set for each application and need great processing capacity, while 3D devices are simple but occupies one hand of the user (to hold the device) which may be unviable.
- 2D interaction: this is mainly interaction in the visualization device, which works well with Smartphones, but it is hard to achieve in a HMD.
- Tangible interaction: interaction using physical objects that affect the digital world.
- Speech recognition: interaction using voice commands.

The four fundamentals forms of 3D interaction (Bowman et al., 2001), selection, manipulation, scaling and virtual menus, could be performed by a single interaction mode or by a combination of them (navigating the environment is not an important form of interaction in AR considering the UI is registered with the environment, therefore navigation can be accomplished by the user himself moving). However, navigation (browsing) is a form of interaction usually ignored by AR applications but very important to be considered. Navigating (browsing) an application means going to the desired function without getting “lost” (normally through menus), which considering a Human Centered AR Maintenance System, is a critical feature for users be able to select the maintenance target, ask for help, report the results of the job, etc.
Overall, in industrial environments, safety (for both users and equipments) is the most important requirement. Ward et al. (2008) introduces the following guidelines to ensure safety:

- Provide the right information in the right time.
- Easy access to information, obtaining during the task, more data about the maintenance of the product or about the failure and heeds of how to handle the product.
- Improved visualization of warnings in the documentation.
- Update to the AR application when there is an update in the E-maintenance system.

Finally it may be interesting for users to be able to locate pieces or tools in an industrial scenario when necessary. An interface like Pick-by-vision (Schwerdtfeger et al., 2011) could be used if some form of tracking for the objects is available (Internet of Things or WSN could support this).
Moreover, the objective is that not only maintenance tasks can be facilitated by the AR applications, but also any procedural task dealing with complex industrial equipment. Some of the activities that could be supported, as appointed by Henderson and Feiner (2010) are: inspection, testing, servicing, alignment, installation, removal, assembly, repair, overhaul and rebuilding.

3.3. Different implementation perspectives to AR

An important consideration regarding implementation of AR applications is the ease of updating them. If the application is compiled and static, with every update of the documentation a new application has to be created, but then applications are less prone to bugs and inaccuracies.
If the AR application runs as a “browser”, similar to Hill et al. (2010), and for each equipment there is an AR application description format, then any update in the documentation is reflected immediately in the application. However, for this to be possible, documentation has to be extremely complete, because it will describe the entire application, and it also needs default 3D models or primitives to create then during execution, and this can lead to inaccurate applications.

A third option considered is the combination of these two, using the current documentation as a raw input, and creating a model upon it that describes how this documentation becomes AR. This way updates in the documentation would still be reflected in the application immediately, through a generic interface, and they can be improved at any time.
The feature of adapting to different visualization devices, specifically regarding display size, should also be considered. If a company owns different devices and they will be used for the same tasks, the second update strategy (AR runs as a browser) should be the best solution to create adaptable interfaces for heterogeneous devices.
Concerning interoperability, it is essential to define an open architecture to support and connect the AR application with other systems (E-maintenance, Internet of Things), and a specification to what will be the format of data used, preferably in the form of an ontology.

3.4. Sub-Products: Training and Reporting

Learning, training and mastering the system is important to elevate users' proficiency with it, and usually involves simulating a problem so that users practice solving it. Since AR can display virtual information in the real world, training could be designed as assemblies' tasks simulated with virtual problems in real equipments. Also virtual immersive trainings could be done, using the same system design results to create a Virtual Reality environment for a virtual training, and simulating the "Augmented Reality" interface in it.
Finishing this discussion, what happens after the maintenance is accomplished? In case of any problem found during the maintenance, users could respond to a more complete form in the end to elaborate what were the problems and even give suggestions of how to solve then.
Ward et al. (2008) defined an interesting questionnaire template to specify blocker situations. This would help keeping the organizational memory of the company up-to-date, but companies usually don't make this effort and lose specialized knowledge when they fire an employee. This type of knowledge, know as informal, is normally underused and not even adequately captured and stored in the corporative knowledge base, even though they may be necessary in future problem solving.
With the maintenance finished, the AR system should send data back to the E-maintenance system about the process, so that these data can improve the process the next time. These data could be: (1) data to notify other teams or team members, and release them to do their job in case their task were being blocked by this one; (2) data about the user (name, level of expertise) or the team (integrants), time spent to fulfil the task, any additional information accessed during the task besides the basic provided (virtual help, information from the equipment, from the environment) and situations that occurred during the task.

3.5. Considerations to a Methodology for Human Centered E-Maintenance

An AR solution that aims to be a part of the industrial workflow must be integrated with the E-Maintenance system, considering new sources of data, and provide an intelligent AR-oriented information system (Friedrich, 2002). In this solution, the different data sources that are input to the E-Maintenance system have to be merged, filtered, aggregated, submitted to data quality treatment and then interpreted, through different layers of inference and applied to create an interface in the real world that enhances the user ability and experience in the maintenance task.
Considering the aspects discussed above, we are establishing a methodology for the process of interface design, to be inserted in the System Development Life Cycle. It will assist in the creation of human centered interfaces for maintenance systems, by using the organizational memory and knowledge management of the enterprise, focusing on formal/informal information and real time data. By doing an analysis of user, environment, function, task and representation, designers will specify the UI (with the support of our data model), creating a document that describes it and can be used to guide implementation.
Therefore, the challenge of creating visualization solutions for E-Maintenance systems (a complex and heterogeneous systems), can be overcome with careful analysis of all the data involved in the maintenance process (formal/informal information and real time data) with a focus on user, environment, function, task and representation, to create a human centered interface.
The general idea is to list the data that is important for the user to do his/her job, organize it to represent every actions possible in the application, and then devise an interface (or an input and output mode) to each of these actions.
As a result, designers would obtain a data model that describes the user interface (and indirectly also the application), and it could be used as a guide in the development phase of the System Development Life Cycle, or even together with a tool to generate code automatically.

4. Conclusion

A human centered solution for maintenance has to consider all the future technologies that will be involved in the maintenance process. E-maintenance is the base technology, but we also have IoT, with RFIDs and WSNs, Semantic Web, and visualization technologies, such as AR.

Therefore, structuring maintenance related data is essential for developing new systems, and also for the creation of interface's authoring solutions. Current user interfaces must evolve in a human centered direction, to understand the human role in the maintenance process, and assist beyond the basic procedural manual, e.g. displaying information for safety, information about the environment, about the broken machine (for better comprehension of the equipment state), about the task progress of the user and his/her team, always according to each individual cognitive process. The final goal is to provide the user full understanding of his/her situation while the job is being executed, ensuring Situation Awareness and enhancing the decision making process.

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