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The Development of an Advanced Maintenance training programme utilizing Augmented Reality

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A B S T R A C T

Maintenance engineering represents an area of great opportunity to reduce cost, improve productivity, and increase profitability for manufacturing companies. There are examples of best practice that can be classed as World Class Maintenance which deliver great benefits. Unfortunately very few companies, and especially small and medium sized companies, remotely approach this level. Research has shown that savings of around 10% are achievable by improving asset management techniques through adopting modern maintenance practices, tools, and techniques. One area that is often overlooked is the development of an appropriate training programme in which the skills and knowledge are retained and used to develop the skills of young apprentices or new staff using specific technologies. Augmented Reality (AR) has been identified as a technology offering a promising approach to training which combines a number of disciplines including engineering, computing, and psychology. Augmented Reality (AR) enables users to view, through the use of see-through displays, virtual objects superimposed dynamically, and merged seamlessly, with real world objects in a real environment via a range of devices such as Ipad or Tablet, so that the virtual objects and real world images appear to exist at the same time in the same place providing real-time interaction. Therefore, this approach expands the surrounding real world environment by superimposing computer-generated information. It presents the information more intuitively than legacy interfaces such as paper-based instruction manuals enabling the users to interact directly with the information and use their natural spatial processing ability.

This paper will identify augmented reality tools and techniques with the potential to support efficient training systems for maintenance and assembly skills that accelerate the technicians' acquisition of new maintenance procedures. A platform for multimodal Augmented Reality based training will be proposed which could allow small to medium sized companies to develop and implement appropriate maintenance tasks based upon cost effective and efficient training systems. Such systems would give technicians' the opportunity for practical training, that is, the possibility to "learn by doing" in the workplace; provide information when and where needed, thus reducing the technicians' information search time; and potentially reduce errors due to violations in procedure, misinterpretation of facts, or insufficient training.
A detailed bibliography on these topics is also provided.

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1. Introduction

In the maintenance arena, reliability can be improved by means of a shorter availability (Johansson et al, 2013). In order to achieve this challenge, maintenance actions might be as effective as fast. Over recent years, the importance of maintenance, and therefore maintenance management, within manufacturing organisations has grown. This is a result of increasing pressure upon manufacturing organisations to meet customer and corporate demands, and equipment availability and performance is central to achieving these (Baglee & Knowles, 2010). A field where researching may cause a deep impact is human interaction in maintenance tasks. Maintenance employees usually work under high-pressure conditions. They are under strict time constraints (e.g., the longer the maintenance time is the longer the production is stopped, what has an important economic repercussion for a company) and must adhere to stringent guidelines (for instance, in aviation the maintenance tasks may follow a tight procedure). Because of such constraints, they might be prone to making errors or consume more time in order to do not commit them.

For this purpose, an expert has to apply background knowledge when repairing or maintaining is required. This accumulated expertise extracted from the performing of repetitive routines should be stored and transmitted, otherwise this knowledge will not last. Augmented Reality (AR) plays a crucial role in retaining and utilising explicit knowledge this facet being able to provide the user an instant and interactive knowledge from raw data. Furthermore, this technology allows the users to improve their knowledge instantaneously during the maintenance actions. Such features can help to reduce errors due to procedure violations, misinterpretation of facts, or insufficient training.

Toward that end, AR seems to be a promising technology to build a combination of interfaces using interactive, simple and wearable visualization systems to implement new methods to display documentation as digital data and graphical database (Crescenzio et al, 2011).

Integration of this technology in medium and small sized companies will imply several stages. A first step may be to select the specific product to use, since this market has grown recently and a huge variety of devices are available. Different apparatus can provide better results for different aims. In maintenance two types of issues have to be faced. Identification of the actual condition of a system or component at any point in time is important.. This task is related to preventive maintenance and help to identify the potential failures in a system. On the other hand, once the issue has been identified, a range of repair and assembly actions might be deployed (corrective maintenance) (Johansson et al, 2013). For these two different goals, there are some devices with their associated technologies that fit for each of them.

In order to merge AR within a company´s facility and products a database is required. A catalogue of the different systems and their components is necessary to provide the users interactive information along their facilities.

The third stage is the problem segregation. Once the problems are listed and classified, they should be divided in different procedures and sub-procedures. It is in this stage where the inputs from a maintenance expert are needed.

Finally, all this information has to be sent and shown by means of AR environment to the user/employee/maintainer and form an expert knowledge on the fly when maintaining.

The procedural skill in assembly and maintenance tasks is the foundation of a correct performance. This type of skill reflects the ability of the user/employee/maintainer to obtain a good mental representation of how to follow, in a commanded order, the different steps of a task (Anderson, 1982).

It has been proved that multimodal interfaces can reduce errors and time of action, improving efficiency and effectiveness while executing a certain task. This is largely due to the fact that the operator can freely choose from the different interfaces which are considered more appropriated to execute each one of the tasks (Oviatt & vanGent, 1996). Providing simulation in a real environment partly removes the time-consuming geometric and kinematic modelling of the machine tools and accessories in the real environment, and thus improves the simulation efficiency. The usability of this system must be verified to determine its effectiveness.

2. Identification of Technologies

Computing technologies offer high sophisticated platforms integrating multimodal sensory; on the other hand, information is structured geo-referenced linking information within our environment. One of the most profitable advantages that AR provides in the field of assembly and maintenance is that instructions or rather location-dependent information can be attached and related to physical objects (Webel et al, 2011). Generally, maintaining (corrective) implies to replace and fix a limited number of components, as screws, plugs or bolts. This characteristic of the objects to be maintained entails that the provision of location-dependent information turns extremely important.

AR technology performs a camera based interaction fusing computer vision with computer graphics. For this purpose, the real environment has to be seen through a display that can provide augmented features. This action may be deployed by means of a display device and can be visually presented in three ways: video see-through, optical see-through and projective, and each of these can be incorporated into a visual display. Visual display devices can be categorised based on their position between the viewer and the real environment: head-mounted or head-worn, handheld, and spatial or projective.

Head-mounted display (HMD) or head-worn display (HWD) devices include video see-through or optical see-through HMD, a virtual retinal display (VRD), and a head-mounted projective display (HMPD) (van Krevelen & Poelman, 2010). These type of devices have some disadvantages, for instance, a reduced field of vision (between 16º and 60º while the normal vision is 170º), which may reduce performance is task such as object manipulation and navigation (Real & Marcelino, 2011).Handheld devices include smartphones, tablets PC, video/optical see-through displays as well as handheld projectors (Nee et al, 2012). In this case a lack of freedom in both hands is the biggest constraint.

The infrastructure of an AR system for assembly and maintenance may integrate several types of devices. The structure of the system should include server-client architecture, where the complex model of the data and the database itself resides in a server and the previous devices commented, act as a thin client (Billinghurst et al, 2008). In addition, 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 providing an intelligent and updated AR-oriented information system. The inputs 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 (Oliveira et al, 2013).

Services to be accessed from the client may be presented in two different ways and with two different purposes. On the one hand, an AR browser is able to link virtual content to physical objects of our everyday life, e.g., magazines, posters, advertisements. These browsers belong to the second generation of AR browsers and they use computing vision-based recognition and tracking techniques (Langlotz et al, 2013). These services grouped with the interaction of the user/operator with the system, either recording video and acoustic signals, storing some images, or accessing some commanded extra information of the object under inspection will form the augmented services for preventive maintenance. On the other hand, the possibility to display video streaming on the client side, related to the real environment and augmenting it will provide the basis of the services for corrective maintenance. In this case, this type of service might be a static and compiled programme.

2.1. Interaction in AR

Other authors have explored multimodal interaction within an AR environment. The most expanded and used in the framework of the last years are:

- Speech recognition, interaction using voice commands. Microphones and earphones are easily hidden and allow auditory UIs to deal with speech recognition, speech recording for human-to-human interaction, audio information presentation, and audio dialogue (van Krevelen & Poelman, 2010).
- Gesture recognition, three types of interaction can be found in this recognition mechanism: 3D interaction, mainly gestures interpreted through a camera and a pattern recognition algorithm; 2D interaction, this is mainly in the visualization device, which works better in handheld devices than in HMD; and tangible interaction, where manipulating physical objects affect the digital world (Oliveira et al, 2013).
- Motion, graphical augmentation based on geographic location and point of view information delivered from integrated sensor such as GPS, compass and gyroscopes (Langlotz et al, 2013).
- Images, video and audio recording is a well-known technique that allows the user to communicate with different types of platforms, which can store, analyse and treat this data in order to give back augmented information.

Selection, manipulation, scaling and virtual menus are fundamental aspects that can be performed by a single interaction mode or by a combination of them. These are critical features for users to be able to select the object to be repaired, report some failures found (preventive maintenance); ask for guidance or help, create an entry in the system when an error has been solved (corrective maintenance).

3. AR challenges in maintenance

In maintenance systems the main concerns are efficiency, i.e. how fast a task can be accomplished by the maintainer; error consequences and subjective satisfaction. A human centred solution joins not only usability requirements; but also considers users themselves, environment and task to build an adaptive user interface to provide safety for users and enhance their efficiency.

Improving operator’s efficiency passes through giving him/her the necessary and correct information in the display device. The more amount information does not mean the better operator’s performance. It is essential that the information presented to the user is related to the issue to be solved, in order to allow the user to extract a valuable knowledge from it. For this purpose, information filtering tightly deals with efficiency. This important aspect is the selection of the information to be displayed for the users from all the available data. Easiness accessing information is also a key feature to accomplish. Visual design is the study of how to represent information in the user interface, avoiding the user get lost browsing the information or cluttering. This discipline implies different methods to show information, for instance: graphics, images, sounds, video, 3D objects or AR.

The visualization device influences both listed aspects, with their key characteristics: size of the display, which impacts on the amount of information that can fits the visualization screen; type of device, already commented (handheld or HMD); and memory and processing capacity, which deals with the quality of the information presented (Oliveira et al, 2013).

3.1. 3D modelling and database building and updating

As previously mentioned, a server-client infrastructure is generally used to provide AR services. All of the complex model rendering, handling of model formats and image processing are performed on the server side, and a still image or short animation shows the result in the client side. In this way a complex AR rendering system that already exists on the server can be used, and connect it to the client with relatively little programming effort.

The server creates a simple animation of the current part being placed in the AR scene by a series of sub images placed on the main image. Each sub image contains a bit map defining which pixel actually shows the part and which is transparent (Billinghurst et al, 2008). Digital content targeted by AR systems comprises 3D basic models, such as symbols, arrows, and frames and 3D models of parts and subparts. CAD component models may be a great help for the AR visualization. Otherwise, digital replicas of parts or can be modelled or obtain them through reverse-engineering (Crescenzio et al, 2011).

Setting up and updating a huge maintenance database is also a challenge. A complementary supportive solution to standards is the development of domain-specific ontologies and semantics. Web based computing empowers dispersed communication and information storage and on-demand software creation in the form of web-services, thus becoming a powerful computing paradigm for E-Maintenance. Ontology formally represents knowledge as a hierarchy of concepts within a domain, using a shared vocabulary to denote the types, properties and interrelationships of those concepts, modelling a domain to support reasoning about entities. With data modelled 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 (Jantunen, 2011).

In addition to accomplish this technical aims, an AR platform may concern about this issues:

- Documentation can be altered or enhanced to reflect difficulties due to misinterpretation or a wrong utilization of certain parts.

- Use check list procedure so users do not get lost during the process and do not skip any step along the whole task.
- Reduce the time spent to consult or locate resources and materials.
- Reduce time to report problems: the application may include an option within the menus to mark a task as problematic. Normal problems that can arise are: mismatching documentation (inconsistent 3D models, tasks missing steps, lacking data, danger not alerted), inaccurate tracking (the system is not able to track the object under scope), polluted and clustered interface, insufficient time for system response (may be due to problems in networking, tracking, voice and gesture interpretation) (Oliveira et al, 2013).

3.2. Tracking

Real-time estimation of the camera's 3D position and orientation (6DOF pose) with respect to the real-world objects is an important AR technology originated from computer vision. Generally, AR systems superimpose specifically designed markers on the real-world objects (Crescenzio et al, 2011). This allows an easy tracking of markers in the camera's images, providing the necessary information to deduce camera pose in real time.

This process is divided in two parts: the quantization step and the retrieval step. In the first step, representative data points are extracted; while in the retrieval step, the best matches are searched in the database (Ha et al, 2011) .

An improvement of this technology deals with marker less camera pose estimation (example of the technique shown in figure 1). This is an indispensable requirement in some areas where the surfaces of the objects cannot include any external mark or stick, for instance, in aviation. In such a field, effective real-time natural-feature tracking is an issue. This involves visual patterns that are not fixed on physical objects but that naturally exist in the scene.

Figure 1. Markerless tracking (Metaio website)

Visual perception begins with resolving an object—knowing something is present, distinct from the surrounding environment. The next step is to identify (recognize) an object, its intrinsic properties (for example, brightness or colour, size, or shape), and extrinsic properties (for example, position, orientation, or motion).Tracking systems may be able to provide a well-balanced combination of range, accuracy, robustness, latency, ergonomic comfort, and simple user-friendly interface (Livingstone, 2005). Issues that can interfere in the correct operating of this recognition process are the sensitivity to different lighting condition; and the limitations regarding with distant decoding (Real & Marcelino, 2011).

3.3. Real and Virtual scenarios combination

Assure the appropriate monitoring and comparing processes between real video streaming and virtual objects in real time is the main concern in this ambit.

3D instructions can be even enriched of sound tracks, additional text-visual information and animation effects. Augmented reality application for assembling processes concerns software issues regarding open source tools that can be used for creation of augmented working environment. It also deals with hardware matters, especially with positioning device that was constructed for the purposes of assembly realization (Nee et al, 2012). After analysing the images, the view angle coordinates of the users may be obtained, redrawing the images according to the view angles, obtaining the environment images from the cameras, and then combining environment images and virtual images together to create a virtual reality experience. When the view angle is changed, the images are re-calculated and drawn synchronously, allowing users to watch the changing images of naturally (Chen et al, 2008).

There are still some areas where AR specialist may focus, mainly: adapt the interface to on-going situations, provide team work awareness in the interface (Nazir et al, 2012).

4. AR maintenance training

As it was mentioned before, the fields which may be supported by AR are preventive maintenance and corrective maintenance. Once identified the technologies for this purpose, a platform for multimodal AR based training will be proposed.

Regarding with preventive maintenance, the biggest issue is problem identification. To carry out this task, the background and the presence of an expert is needed. Sometimes it is rather complicated to place an expert where the machine or object to be repaired is located. Due to this circumstance, in order to allow the expert carry out his/her job remotely, a novice user could interchange information either recording video, audio, or sending images; or on the other hand, receiving health assessment information of the machine, infrared images, etc. via the Internet, simply wearing a HMD or with a handheld device. This information interchange might be complemented by AR technology by means of augmented inventory and reporting, and also supported by remote assistance (Bottecchia et al, 2010). For a technician who has to inspect different machines in a plant, his/her labour could turn easier if just wearing AR goggles or holding a device with AR technology, is able to identify which machine has to be observed and why, for instance, check if a machine that suffered a failure now operates properly. The tests to perform this task can be recorded and reported instantaneously and updating in the database and in the E-Maintenance system; and also a feedback from the expert can be provided in real-time.

In the maintenance procedure, after identifying the problem and reporting it, corrective maintenance is needed. With the help of maintenance experts, a hierarchical task analysis of the complete procedure to identify the subtasks and steps to solve a problem has to be deployed. The subtasks are the specific procedures that concern the apparatus to be checked and are divided into a number of steps. Each individual steps might be augmented (see figure 2) by applying virtual models and animations that implement different types of digital data (cited above, digital replicas of parts and subparts), graphical symbols (arrows, pointers, etc.), or acoustic instructions in order to attract the maintainer's attention or correctly guide technicians through a task. To complete this augmented information, maintenance experts should analyse the observed error risks and provide extra information by means of examples.

Figure 2. Desassembly step in air pump (Scope website)

As a result, the system guides the maintainer step-by-step through an assembly/disassembly sequence, making the AR process more interesting and intuitive (Nee et all, 2012). This area of maintenance generally implies assembly/disassembly tasks which involves both hands, so for this purpose a HMD will better that a handheld display.

A potential danger of AR applications for maintenance training is that users become dependent on AR features such as visual instructions. This point would become an issue if the user might not be able to perform the task when the technology is not available. Due to this reason, in the maintenance arena, AR training programs may be divided in different phases regarding the difficulty or the lack of augmented information. The user should pass by all the stages, which have several levels according to:

- The amount of AR features, for instance, more or less virtual components, e.g. only instructions for the current sub-task without additional information about the device, tools, etc.),
- The level of information provided by the AR features, e.g. only spatial hints without detailed instructions (Webel et al, 2011).

The main goal of this training system goes beyond a simple video tutorial displayed. The level of guidance in the training system has to be adaptable to the current training phase and the user. This training is mainly focused in the corrective maintenance part.

5. Conclusions

Maintenance can be highly enhanced in terms of efficiency if using AR technologies to identify the necessary maintenance tasks and to present the information in such a way that the instructions are clear and unambiguous. In fields such as preventive or corrective maintenance, medium and small companies can achieve profitable improvements including this type of AR-based training programmes where the user is trained and guided through the task.

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