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Augmented reality on large screen for interactive maintenance instructions

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ABSTRACT

We present an empirical study that evaluates the effectiveness of technical maintenance assisted with interactive augmented reality instructions. Our approach consists in an augmented visualization on a large screen and a combination of multiple fixed and mobile cameras. We used commercially available solutions. In our test, 14 participants completed a set of 4 maintenance tasks based on manual inspections of a motorbike engine. Tool selection, removal of bolts, and part dis\assembly, are supported by visual labels, 3D virtual models and 3D animations. All participants executed similar operations in two modalities: paper manuals and augmented instructions. Statistical analyses proved that augmented instructions reduced significantly participants' overall execution time and error rate.

1. Introduction

Maintenance was defined as "a complex combination of all the technical, administrative and management activities planned during the life cycle of an entity, to keep it or return it in a state where they can perform the required function (UNI EN 13306, 2003)". The maintenance process is nowadays an important aspect of competitiveness and profitability. Many factors, such as environment sustainability, globalization, safety, costs\time reduction and materials recycling, have moved modern product maintenance from corrective to preventive. However, even if predictive maintenance establishes procedures in relatively static and predictable environments, a major industrial challenge is to deal with its complexity in terms of number of operations, safety, tracking and rapid obsolescence of technical data. In particular, maintenance tasks are more challenging than manufacturing and recycling operations, because they are target driven, they are dependent on the components and may require either partial or complete disassembly.

Usually this complexity is left to individual skilled personnel, who become the protagonists of the maintenance process and keep personally most of the know-how. One additional problem is that expert training is difficult, particularly for mechatronic systems and for developing problem-solving skills. A novice operator usually requires months or even years to develop sufficient knowledge in maintenance, while even expert operators constantly refer to manuals for infrequent or highly complex procedures. In fact, current trends of agile manufacturing and Total Productive Maintenance have the drawback of continuously improving and changing maintenance processes and procedures. A promising solution, proposed a few years ago in aerospace industry, is to assist maintenance by augmented reality (AR). AR technology registers and overlays virtual information on real world in real time, therefore it simplifies the understanding of the problem, the localization of specific components and task operation [1].

AR technology in maintenance, visualizing digital instruction in real time on the real working area, can potentially lead to the following advantages:

- employ less-skilled operators;
- data are up to date (e.g. linked to PLM);
- time and cost saving (e.g. transfer of experts on site);
- error rate reduction;
- registered multimedia content (i.e. less text needed);
- knowledge is retained in the system and not in people;
- level of information can be adapted to user's skills.

Most of the AR solutions in literature employ head mounted sisplays (HMDs), which have several drawbacks in terms of ergonomics, cost, limited field of view, low resolution, encumbrance and weight. For this reason, mainstream innovation leaders like Google (i.e. project glass) and Apple (i.e. iGlasses) are actively researching on the development of next generation HMDs.

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However AR technology is not limited to HMDs [2]: a lower level, called "screen-based video see-through displays" (SBVD) augmented reality, can provide a less immersive augmentation (i.e. not co-located with the user line of sight) without the drawbacks of current HMDs. Moreover, while the benefits in maintenance of AR technology compared to paper have been demonstrated in literature, the advantages of HMD AR compared to a SBVD desktop AR were reported as not statistically relevant in some experiments [3].

The main motivation for our work is to provide an effective and feasible approach to AR maintenance and validate it by comparing user performances against paper documentation. Using pragmatically present time technologies, we believe that a SBVD approach (Fig. 1) can successfully assist each operation with text instructions, 2D images, 3D static\animated models and audio guidance.

2. Related work

This work draws knowledge from two main areas of research: computer learning and the second, more specific, AR technology applications.

Ganier [4] proposed a 4-stage model of how a user moves from perceiving instructions to performing the relative actions. He suggested that accompanying text with pictures and animations will enhance the mental model, because of the similarity of structures of external representations with equipment.

Watson et al. [5] demonstrated, with assembly task experiments, the immediate benefit of using animated instructions over text and diagrams, especially for the first build. This is an interesting aspect because a maintenance process is rarely a repetitive task even for experts (vs. as happens for mass production assemblies). As a result, cognitive research suggests providing multimedia means to improve information retention.

Webel et al. [6] presented an interdisciplinary study of AR-based maintenance using cognitive science and psychology. In particular, they focused on training of procedural skills: the ability of following repeated sets of actions, step-by-step, in order to achieve a specified goal. They showed that it is important to provide only minimal information because an active exploration of a task increases the ability to solve the problem. Therefore the amount of information should depend on the skill level of the trainee: detailed in the early phases and then it should gradually become more essential. They proposed four main concepts: the augmented adaptive visual aids (AVAs), the progress bar, the device display and the vibro feedback. The AVAs consist of a combination of overlaid and registered 3D objects information with 2D content (text, images and video). The progress bar provides an overview of the current status in relation to the whole task. The display device provides information about the successive steps, rather than subtask, belonging to a logical group. Finally, the vibrotactile bracelet is used for spatial guidance by translational and rotational feedback. They reported a preliminary evaluation about the criteria of design using experts from packaging industry, with positive feedback for the first three aids.

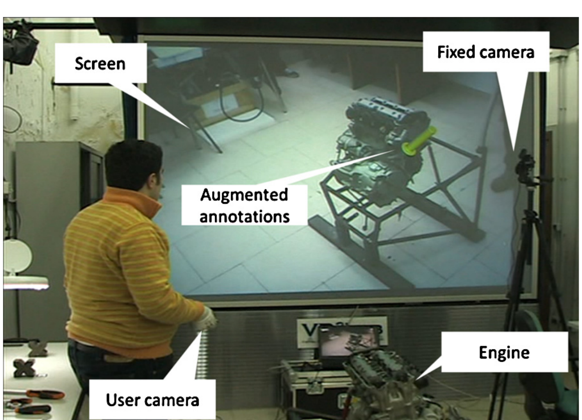

Fig. 1. Interactive augmented reality instructions on large-screen.

An interesting research was proposed by Tang et al. [3]. They compared assembling operations of toy blocks with four different instructional modes: 1) printed manual, 2) images on a laptop with 15″ display, 3) static images on a see-through HMD and 4) spatially aligned 3D models on a see-through stereo HMD using a magnetic tracker (full AR). It is important to notice that, in the desktop display configuration, only 2D static images were presented. They measured: time of completion, number of errors and mental workload using NASA Task Load Index. As far as regards the time of completion, their test verified a relevant improvement passing from the paper manuals to the computer supported ones. Full AR, the fourth mode, resulted to be better than the first one in total operation errors, dependent error and perceived mental workload. Another important result was that full AR does not appear to have a statistically significant time advantage compared with other computer assisted approaches.

Henderson and Feiner [7] presented a comparison of three setups for maintenance operations of a military vehicle: AR with a stereo HMD and registered contents, the same setup with untracked content and a 19″ LCD display with unregistered 3D scenes. The display was fixed in a convenient position inside the working area. In all the tested configurations, user had a wireless wrist-mounted touchscreen controller as main interaction device. Their approach was to enhance task completion by: (i) on-screen instructions, (ii) directing attention symbols, (iii) overlaid registered labels, (iv) close up views, and (v) 3D animated models. The tests in a complex maintenance scenario (i.e. the cramped interior of an armored vehicle turret) with professional mechanics revealed that AR does not convey significant effects on completion time. Moreover participants rated the LCD as the preferred device. Nevertheless, the users were able to locate tasks more quickly and with less head movement than the baseline.

In conclusion, the presented previous works show the potential, but also the limits of AR technology in assisting complex maintenance processes. The technological demands for AR are much higher than for other computer interfaces and the issues hide behind the details of setups, authoring procedures, integration with enterprise data, tracking, camera calibration, user interface and visualization management. In particular the advantage of current HMD technology is still argument of debate at conceptual level, because of the tradeoff between the advantage of the registered overlaid information and the cost of the visual interference. The authors firmly believe in HMD based AR when lightweight and performance devices will be available at low cost. Nevertheless, at the moment we prefer to explore more practical and feasible solutions [8,9].

According to the authors, large screen projection technology can be a valid alternative to HMDs and an improvement compared to monitor based desktop AR. The specifications and the cost of the last generation of beamers allow effective projection with almost every lighting condition and on not prepared surfaces.

Two are the novelties of the presented work: first we introduce an industrial feasible method for screen based AR instruction system and, second, we compare it with the industrial practice on an engine service test.

3. Our approach

In the development of our HMD-less AR system we followed the four guidelines descripted by Moreno et al. [10] for a cognitive