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***Abstract*-- This paper studies the opportunities coming from the use of consumer devices like smartphones and tablets to perform maintenance and assembly procedures with Augmented Reality (AR). Pros and cons are evaluated by comparing completion times and errors made while executing a maintenance procedure with an AR-based tool and paper-based instructions.**

I. Introduction

Although Augmented Reality (AR) technologies can be dated back to 1960s, the concept of AR was formalized only in 1994, when a graphic representation of the reality-virtuality continuum was introduced [1]. Generally speaking, AR refers to applications able to offer users a set of computer-generated hints, which are overlapped and/or aligned with the real world to "augment" it. These hints, which are often called assets, can be: 3D static objects, computer generated animations, videos, text labels and sounds.

AR applications have witnessed a widespread diffusion in tourism, advertisement, shopping, social networks and, more in general, in geo-localization scenarios [2][3]. Maintenance, repair and assembly have been identified as possible fields where AR could play an important role [4][5], although large-scale solutions are still unavailable. This is partially due to the fact that special purpose hardware is often required in these contexts. Nonetheless, new and intriguing opportunities are offered by continuous advancements in mobile technologies and recent projects showed how consumer electronics might represent a valuable tool for implementing AR applications.

Mobile devices support an AR paradigm named Handheld Augmented Reality (HAR), in which costly hardware for see-through visualization (like Head Mounted Displays) is replaced by the screen of a common smartphone or tablet. The use of mobile devices in the context considered in this paper is not totally new. For instance, an AR application for handheld devices to support the overall lifecycle of facility management is presented in [6]. Mobile devices and AR applications are exploited to train technicians in [7] and [8]. AR technology is exploited to replace paper-based instructions in the car market, showing its great potential when used with mobile devices [9].

It is worth observing that up to 4% of ownership costs of a car are due to maintenance and repair [10]. Other impressive figures come from the aeronautic domain (where maintenance costs are estimated to grow up to $54 billions in 2015 [11]) and, more in general, from considering the costs related to the entire lifecycle of any given product. Figures above provide a clear evidence of the impact that AR applications running on personal consumer devices might have, both from the economic and the social point of view.

This work aims to explore the usefulness of these solutions, by outlining their possible advantages and drawbacks.

II. Handheld AR Maintenance Application

Several studies related to the impact of AR in maintenance, repair and assembly tasks are known in the literature [12]. However, they are mainly focused on measuring performances of skilled technicians while executing complex procedures with specialized hardware. This work is aimed to gather both objective and subjective indications on the use of mobile AR-based maintenance tools by people that cannot be considered "experts" of the domain. To this aim, a specific procedure for the maintenance of a netbook has been considered. An AR-based application has been designed and deployed on a tablet using a commercial SDK. User interface is shown in Figure 1.

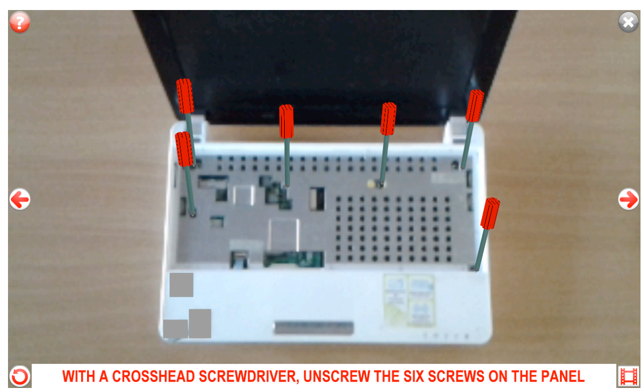

Fig. 1 A screenshot of the user interface of the AR-based application.

Left and right arrows allow the user to move backward and forward through the steps of the procedure, which has been implemented as a set of strictly-sequential states. Each step is activated when a well-defined configuration of the object to be repaired is found in the scene framed by the device's camera. The application starts to track the object once recognized with the aim of aligning the AR assets. The tracking can be either implemented "by images" or "by CAD models". In the first case, the AR application is trained by a set of photos of the real object and local feature descriptors are exploited to describe a matching with the actual view of the scene. The latter method uses a CAD model of the object to be tracked and looks for its specific geometry in the scene. The tracking by CAD models is independent of environmental conditions (e.g., illumination and shadows) and pictorial attributes (e.g., textures and materials). However, this approach requires that CAD models representing all the configurations of the object to be tracked are available. The icon on the lower left corner

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forces the application to restart the "search-for-tracking" function, thus letting the user repeat the current maintenance step. The text label is a hint explaining the operation to be performed. The on screen message is read by a text-to-speech synthesizer. The icon on the lower right corner allows the user to play a video showing the execution of the current step. The icon on the upper left corner launches a video tutorial.

III. User Study And Experimental Results

The maintenance procedure selected to test advantages and drawbacks of AR compared with traditional approaches (i.e., paper-based manuals) considers the replacement of the hard disk of a netbook. A first session of tests was carried out with 10 students (24 years old, on average) of the MS degree in Computer Science at Politecnico di Torino. All of them were used to assemble/disassemble computer parts. Only one was familiar with AR tools. The time necessary to complete the given task and the number of errors made (selection of wrong tool or wrong step/action performed) were measured as objective parameters. Moreover, a questionnaire was used to gather subjective feedbacks. The average time necessary to complete the task by using the AR-based solution resulted to be about twice the time required with paper-based instructions. However, with AR, the number of errors reduced from 10 to 3. Based on subjective feedbacks, all the testers were impressed by the AR tool and assessed it favorably.

The above results suggested that AR benefits are dependent on tester's skills. Since Computer Science students were familiar with the selected procedure, the same test was repeated with another group of 12 students of the BS degree in Visual Design (22 years old). Table I shows completion times and number of errors. It is worth noticing that performances are quite different from the first group of testers. The average times with and without the AR support are 630,5s and 671s, respectively. Moreover, the standard deviation is 102,6 for AR and 172,5 with paper-based instructions. Results clearly show that unskilled people may expect more benefits from AR, which can also help to level maintenance performances. Moreover, for the second group of testers, the number of errors decreased to 1/3 of that measured using paper-based instructions. Subjective feedbacks on the AR tool confirmed the same positive opinion gathered with the first group. Students suggested to improve the application by integrating tele-assistance functionalities (e.g., an audio-video channel to receive interactive support by remote technicians). The possibility to play a video showing the current step of the procedure performed by an expert has been really appreciated by all the testers. Results presented in Table I are equivalent to a 76 score in the System Usability Scale (SUS) [13].

TABLE I
Results of Tests With The 2nd Group of Students

Tester	Gender	[a]Method.	Time [s]	[b]Errors
1	F	AR	600	C
2	F	AR	480	-
3	F	AR	575	-
4	M	AR	750	A
5	M	AR	640	-
6	M	AR	738	C
7	F	P	996	B,C
8	F	P	678	A,C
9	F	P	563	C
10	M	P	680	B,C
11	M	P	509	-
12	M	P	600	A

[a]Method: P=paper-based instructions, AR=AR-based instructions.
[b]Error type: A= wrong tool, B= wrong step, C=wrong action.

IV. Conclusions And Future Work

This study showed that consumer electronics (specifically, mobile devices) can be a valuable tool for creating AR tools aimed to support maintenance and assembly tasks. The lower is the skill level of people in charge to perform the task, the greater is the advantage they could get by using AR-based procedures, both in terms of errors and time saving.

Future work will be aimed to integrate a tele-assistance functionality based on audio-video streaming to connect the users with the remote technical staff. Moreover, the possibility to tailor the maintenance procedures to the specific needs of on-field operators by introducing ad-hoc methods for dynamic customization and reconfiguration will be experimented.

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