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Text legibility for projected Augmented Reality on industrial workbenches

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ABSTRACT

Augmented Reality is a promising technology for the product lifecycle development, but it is still not established in industrial facilities. The most relevant issues to be addressed relate to the ergonomics: avoid the discomfort of Head-Worn Displays, allow the operators to have free hands and improve data visualization. In this work we study the possibility to use projection-based Augmented Reality (projected AR), as optimal solution for technical visualization on industrial workbenches. In particular, text legibility in projected AR is difficult to optimize since it is affected by many parameters: environment conditions, text style, material and shape of the target surface. This problem is poorly addressed in literature and in the specific industrial field. We analyze the legibility of a set of colors prescribed by international standards for the industrial environments, on six widely used industrial workbenches surfaces. We compared the performance of 14 subjects using projected AR, with that using a traditional LCD monitor. We collected about 2500 measurements (times and errors) through the use of a test application, followed by qualitative interviews. The results showed that, as regards legibility, projected AR can be used in place of traditional monitors in most of the cases. Another not trivial finding is that the influence on legibility of surface irregularities (e.g., grooves, prominences) is more important than that of surface texturization. A possible limitation for the use of projected AR is given by the blue color, whose performance turned out to be lower than that of other colors with every workbench surface.

1. Introduction

Augmented Reality (AR) is a human–computer interface which improves the user perception of real world with external digital information superimposed in real time [1].

Nowadays AR is used with profit in many applications like marketing, videogames, and tourism, but it is far to be accepted by the industrial world.

However, AR can be very effective in industry and in particular in some critical phases of the product lifecycle as maintenance operations, where most of personnel time is spent retrieving technical data, task instructions and localizing parts [2]. AR can improve both preventive maintenance by delivering the required tasks in a contextual way, but also by assisting troubleshooting with a direct access to manuals, web, documents, etc.

Previous studies have shown the potential of the use of AR in industrial applications, but also stated how there are still many issues to be addressed [3,4,5,33].

In the design of an optimal software interface to support technical documentation visualization, we must fulfill a major requirement: the operator must be able to use both hands to accomplish his/her tasks. Common AR applications use Head-Worn Displays (HWDs), which suffer from bad ergonomics, low resolution, excess of weight, limited/fixed focal depth [6]. Industrial operators have to wear the HWD for long sessions and for this main reason, AR is not well accepted in industry. An alternative approach to HWD is to use handheld devices like smartphones and tablets. Although this kind of AR is very easy to implement in practice due to the availability of low cost and powerful devices, it has various limitations. One of the most important is that the operator should employ one or even two hands for the visualization, thus limiting his/her ability to operate.

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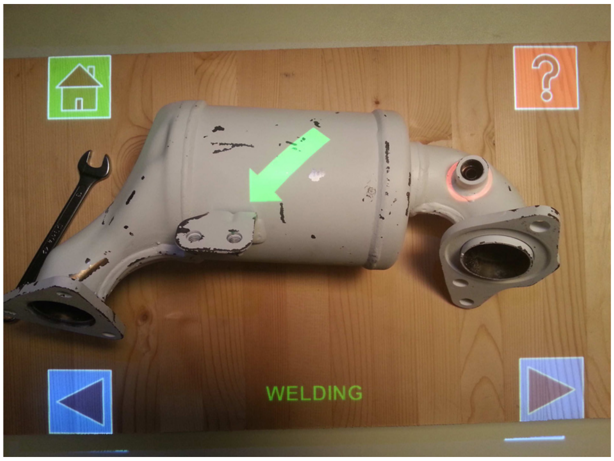

Fig. 1. Example of use of projective SAR on an industrial workbench.

Considering the emerging need to have digital documents at hand in a workspace, new display paradigms must be explored. According to the authors, projected Augmented Reality (projected AR) can be an optimal solution for the visualization of both instructions and technical information directly on the industrial workbench (Fig. 1). In a real working environment, the operator stands in front of the workbench and is currently assisted by instructions on monitors usually placed on their workbenches or on tool carts. Projected AR makes use of digital projectors to superimpose virtual data (text, symbols, indicators, etc.) directly on the real environment [7].

Cebulla [32] listed the main advantages of projected AR displays:

- Projectors can directly project onto the object.
- The eye of the observer does not need to switch focus between the image plane and the real environment.
- The image plane of projectors can have various shapes and might be non-planar.
- A projector can be much smaller than the image it projects.

He also considers as main disadvantages the low light-intensity and the displaying of objects in mid-air. However, he says that the former is not a problem for stationary projectors as those intended to be used in our context, while the latter situation is not expected in an industrial environment. Besides those highlighted in [32], we can list other advantages of the use of projected AR in industrial facilities:

- The user do not to wear HWDs or handle devices (displays, gloves, sensors, pens, etc.): ergonomics is improved.
- The tracking of the user is not required: user's movements (especially of the head) do not affect visualization.
- Information can be displayed all around the object, since occlusion can be reduced with a well-designed multi-projection system: information can be shared by multiple users.
- There is not the tunnel vision effect induced by the view through an optical display (like in HWDs and handheld devices): this effect can be potentially harmful if one needs to be visually aware simultaneously of dangerous stimuli (safety of operators must be ensured) approaching from a peripheral position in space.

However, projected AR, as all new technologies, requires some feasibility studies and optimization processes before it is introduced in the industrial environment. One of the most important issues is the correct visualization of technical information. In particular, in this work we want to study the legibility of projected text information in industrial applications. Gabbard et al. [8] consider text as one of the most fundamental elements in graphical user interfaces as opposed to icons, lines, or bitmap. In the specific industrial context, text is the basic of all technical data and is widely used to convey dimensions, special treatments, annotations, etc. In order to support complex maintenance or assembly processes, text can be also supported by 3D models, pictures and animations, but the visualization of this complex elements will be addressed in future works.

In the context of a first stage of research, we evaluated the possibility to project text directly on workbench surfaces (without the need to calibrate the scene), comparing users performance with that deriving from the use of a normal LCD monitor. As far as the authors know, there are few studies on this topic and there are no widely accepted guidelines to follow in the design of this kind of system.

The paper is organized as follows: in Section 2, we present related works on projected AR; then in Section 3, we describe the method; in Section 4, we illustrate the results achieved in the experiment, while in Section 5, we provide a detailed discussion. Finally, we present our conclusions and future works.

2. Related works

Some studies in literature analyzed different AR displays technologies taking into account application, background, lighting, etc. [6,9]. They clearly state that there is no one ideal display fitting all scenarios. The use of projected text information can theoretically solve some big issues in industrial applications, mainly because of leaving the user free from wearing or holding any device. Nevertheless, the literature on this topic is scarce.

Raskar and Low [11] proposed a Spatial Augmented Reality (SAR) framework for the integration between projective surfaces and input devices to integrate the digital information directly in the real scenario. They introduced new calibration and rendering techniques to create a simple procedure to illuminate effectively the surfaces. To create an optimal integration of virtual information on real elements, these techniques take into account: the position of the user, the projection parameters of the display devices and the shape of the real objects in the physical environment.

Bimber et al. [12] aims to find solutions to project directly on the paintings using a traditional video projector. With direct projection, the main issue was the perception of the projected color and intensity. This is caused by the physical color pigments that neutralize what is projected. To solve this problem, the authors used a new film material, which is transparent and, at the same time, diffuses part of the light projected on it. The new film material is composed of very fine particles deposited on both sides of a polyester base, without visible artifacts. In this way, the 20% of the light striking the film is diffused, allowing a better view of projected information, while the remainder comes on the canvas.

Olwal et al. [13] present an industrial application of the projection on a numerical control machine CNC. They noted that, for direct projection, it is important to assess the environmental conditions and industrial surfaces. The authors highlight the importance of the use of a screen for applications that require a direct visual feedback of the worker. In particular, they used a holographic optical element overlaid onto the machine's safety glass as optical combiner, which allows us to see simultaneously the real environment, as well as superimposed 3D graphics, when we look through this transparent display.

Servan et al. [14] proposed laser projection for supporting the mounting process in an aeronautical industry, where great precision is required. The mounting documentation provides information on the equipment to be used and the sequences of