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Review

Empirical evidence, evaluation criteria and challenges for the effectiveness of virtual and mixed reality tools for training operators of car service maintenance

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ABSTRACT

The debate on effectiveness of virtual and mixed reality (VR/MR) tools for training professionals and operators is long-running with prominent contributions arguing that there are several shortfalls of experimental approaches and assessment criteria reported within the literature. In the automotive context, although car-makers were pioneers in the use of VR/MR tools for supporting designers, researchers started only recently to explore the effectiveness of VR/MR systems as mean for driving external operators of service centres to acquire the procedural skills necessary for car maintenance processes. In fact, from 463 journal articles on VR/MR tools for training published in the last thirty years, we identified only eight articles in which researchers experimentally tested the effectiveness of VR/MR tools for training service operators' skills. To survey the current findings and the deficiencies of these eight studies, we use two main drivers: (i) a well-known framework of organizational training programmes, and (ii) a list of eleven evaluation criteria widely applied by researchers of different fields for assessing the effectiveness of training carried out with VR/MR systems. The analysis that we present allows us to: (i) identify a trend among automotive researchers of focusing their analysis only on car service operators' performance in terms of time and errors, by leaving unexplored important pre- and post-training aspects that could affect the effectiveness of VR/MR tools to deliver training contents – e.g., people skills, previous experience, cibersickness, presence and engagement, usability and satisfaction and (ii) outline the future challenges for designing and assessing VR/MR tools for training car service operators.

Contents

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1. Introduction

Virtual reality (VR) systems are defined as human–computer environments in which users are immersed in, and able to perceive, act and interact with a three-dimensional world [1,2]. However, as Milgram and Kishino [2] underlined, immersive systems represent only one, and an extreme, point in the continuum from virtual to real world. In fact, along this continuum researchers and manufacturers, by mixing virtual and real worlds, have developed different hybrid technologies to serve different goals. These mixed reality (MR) systems are designed, for instance, to augment the user experience of the real environment with virtual information (augmented reality) or to augment the virtual systems through real inputs (augmented virtuality). The debate on the application of VR/MR tools among researchers started in the late Sixties see: [3], but due to the high costs of these simulation tools only a restricted group of experts had access to this debate. It was only in the Nineties that a larger community of experts started to explore the potential of VR/MR systems thanks to the price drops of hardware and the concurrent increase of the technologies' performances [4,5].

The costs of these tools are still today a barrier that excludes many researchers from the access to, and experimental analysis of, these technologies. However, nowadays several different VR/MR systems which vary in terms of software, hardware, functioning and interaction modes [6] are used daily in different fields – e.g., manufacturing, surgery, education, military – as support for the work of professionals, and as part of programmes to train the skills of employees, specialists and managers (e.g., prototype and assembly, drive, fight, fly, surgery procedures etc. see: [7]).

As Mantovani [8] underlined VR/MR tools are used by trainers to deliver contents and to drive operators to acquire, or increase their previous know-how – intended as a set of procedural skills. In tune of that training system has to be designed in order to reach two main aims: (i) VR/MR systems have to help trainees to perform effectively and efficiently all the steps to achieve a goal [9] – i.e., perform a procedure with a minimum amount of time and following a correct order of actions. (ii) VR/MR training systems have to engage operators in the exercise of core skills for performing the procedures – such as abstract reasoning, visualization and management of complex information spaces etc. [10].

Among the different fields of VR/MR application, automotive manufacturers have been pioneers in the use of tools for prototyping and assessing a product's design – e.g., computer-aided design – and for verifying the accuracy of assembly and maintenance processes [11]. However, compared to other industries (e.g., aeronautics, military, healthcare etc.), auto-makers started only in recent times to look at the application of VR/MR as systems for training operators know-how. This interest in VR/MR tools for training has recently produced several international projects and systems for supporting operators of car service – e.g., the European projects SKILLS (http://www.skills-ip.eu/) and VISTRA (http://www.vistra-project.eu), as well as tools like the Mobile Augmented Reality Technical Assistance created by Metaio and Volkswagen (http://www.metaio.com) and the BMW Augmented Reality glasses (http://www.bmw.com/).

Car manufacturers are interested in both training and providing a support tool for professionals of car service maintenance; intended as a highly specialized multistep process in which operators have to perform in the correct way the sequences: (i) disassembly of the car and removal of faulty system components, (ii) replacement or repair of these components and, (iii) reassembly of the car [12].

Although, the main steps that an operator has to perform during a service procedure are almost the same across the industries, as researchers underlines service sectors are different [13,14] in terms of: (i) economical relevance, and (ii) approaches of service on the basis of market competitiveness. These factors affect lead to different challenges that operators of services have to face to perform a procedure.

From the economical point of view, as researchers showed, the quality of service is an important factor which affects customer loyalty and the overall brand experience [15–17]. Moreover, particularly for automotive field, service and maintenance is a very significant market which totaled, in the US alone, 166.5 billion for 2012 [18] over a worldwide market of sold cars close to 65 billion of unit in the same period [19].

Therefore, for automotive manufacturer have to invest in training operators the quality of operators work may significantly affect the brand image.

Along the history, automotive has emerged among the other industrial fields as one of the most competitive market [13]. To properly compete car-manufacturers have massively invested in the personalization and adaptations of their models to the costumers' needs. For instance, today in the market a luxury car model can have up to 10^{24} possible configurations – e.g., different engine, chassis, electronic configurations etc. [20]. In tune with that, different approaches of service were been developed and tested to answer to this level of personalization of automotive products – e.g., costumer-oriented, service-oriented etc. [13,14].

Therefore, differently from other fields, service centres play an important role in the automotive market, and, more important, service operators are often forced to deal with complex products which could strongly vary in terms of configurations. The variability of the product configurations leads often operators to face service procedures on similar car models which could vary in terms of car components, internal and electronic design and organization. Thus, operators are forced to be adaptive and perform procedures which could slightly, tough significantly, vary in terms of steps and operations on the basis of the car configuration.

In this context, for automotive manufacturers the enhancement of service operators and their accuracy in maintenance procedures is everyday more important because operators are the main interface for the customers and their needs – i.e., to solve their cars' issues, and they are an important resource to sustain the brand image in a competitive market.

VR/MR tools are considered reliable solutions to train operators of service maintenance, at least, for three main reasons underlined in literature [6,8,21]. First, after the initial investment to acquire the systems, and the maintenance costs, VR/MR tools reduce the overall training costs. Second, in line with the learning by doing approach [22], VR/MR systems allow people to visualize and interact, during a training, with simulated real artefacts. This interactive experience increases the quality of the trainees' acquisition of the skills. Moreover, these systems offer a good adaptability to the people's needs and learning style – i.e., personalization – by generally increasing the trainees' motivation during the training. Third, practitioners and trainers by VR/MR systems can easily collect a wide set of data about the trainees' performances, to check, assess and calibrate the training process. In line with that, training with VR/MR tools is considered more powerful and effective than a classic training programme. There is, however, a hot debate in the scientific literature on VR/MR tools effectiveness for training. In fact, researchers commonly analyze the efficacy of these tools with small samples and with a limited set of comparable evaluation criteria [23,24]. Therefore, the reliability of the current experimental results is still uncertain.

Some differences could be underlined among the fields of VR/MR tools applications for training. For instance in fields such as surgery or military procedures, comparable evaluation criteria (within each field) can be used by researchers for assessing the VR/MR tool effectiveness, because the tools are applied under similar: