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Evaluating the application of augmented reality devices in manufacturing from a process point of view: An AHP based model

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A B S T R A C T

Augmented Reality (AR) systems in last few years show great potentialities in the manufacturing context: recent pilot projects were developed for supporting quicker product and process design, as well as control and maintenance activities. The high technological complexity together with the wide variety of AR devices require a high technological skill; on the other hand, evaluating their actual impacts on the manufacturing process is still an open question. Few recent studies have analysed this topic by using qualitative approaches based on an "ex post" analysis – i.e. after the design and/or the adoption of the AR system - for evaluating the effectiveness of a developed AR application. The paper proposes an expert based tool for supporting production managers and researchers in effectively evaluating a preliminary ex-ante feasibility analysis for assessing quantitatively most efficient single AR devices (or combinations) to be applied in specific manufacturing processes. A multi-criteria model based on Analytic Hierarchy Process (AHP) method has been proposed to provide decision makers with quantitative knowledge for more efficiently designing AR applications in manufacturing. The model allows to integrate, in the same decision support tool, technical knowledge regarding AR devices with critical process features characterizing manufacturing processes, thus allowing to assess the contribution of the AR device in a wider prospective compared to current technological analyses. A test case study about the evaluation of AR system in on-site maintenance service is also discussed aiming to validate the model, and to outline its global applicability and potentialities. Obtained results highlighted the full efficacy of the proposed model in supporting ex-ante feasibility studies.

1. Introduction

Augmented Reality (AR) tools have been applied in several industrial contexts as they could provide effective contributions in phases characterizing the product life cycle. In brief, an AR application combines the real scene viewed by the user and a virtual scene generated by the computer that augments the scene with additional information. Several pilot projects have recently outlined that AR systems are now becoming mature technologies for application in manufacturing as well as service systems (Dangelmaier et al., 2005; Chong, Ong, Nee, & Youcef-Youmi, 2009; Serrano & Fischer, 2007; Ong, Yuan, & Nee, 2008; Elia & Gnoni, 2013; Novak-Marcincin, Barna, Fecova, & Novakova – Marcincinova, 2013): one focal point characterizing the information system in a manufacturing plant is to develop an effective and real-time communication between individuals and production departments (Morkos et al., 2012). AR applications are facing this issue aiming to enhance company performance in terms of shorter lead-times and process quality (Souza, Sacco, & Porto, 2006; Luh, Wang, Chang, Chang, & Chu, 2013). AR applications especially ones based on mobile devices could allow users to interact dynamically by sharing information with and from the real working environment.

Several recent pilot projects focused on demonstrating the applicability of AR systems in different manufacturing processes, such as product design, production planning and control, plant and product maintenance, etc. These studies are mainly focused on evaluating technical performance of such AR system for supporting critical manufacturing processes: on the other hand, less research effort could be outlined in proposing models to evaluate most "fitting" AR device and/or systems before starting its technological design. Even if the technological development of an AR system is based on quite common features, the evaluation of the most effective AR system for supporting a specific manufacturing process is a complex task, as technical and organizational factors have to be assessed in an integrated way. As an example, an AR system for supporting a more effective product design process could be developed based on the same technological equipment (e.g. sensors,

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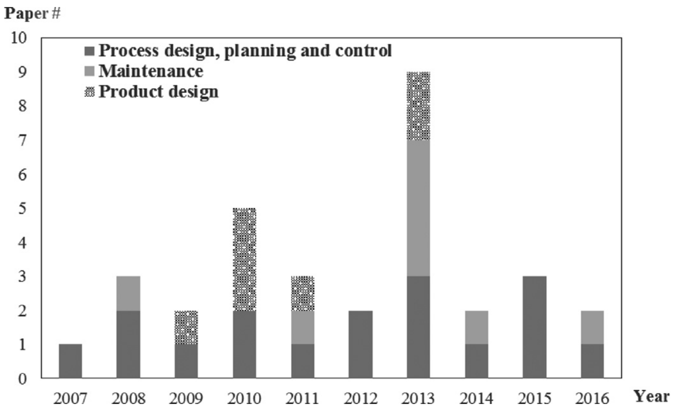

Fig. 1. Temporal distribution of analysed papers under the three main categories.

dynamic monitor, etc.) of one designed for product maintenance, but, its overall feasibility heavily depends on process specific requirement.

The study proposes a decision support system based on a multi-criteria analysis to support production managers in evaluating most effective AR devices for a specific manufacturing process. The proposed model integrates technological with process based criteria aiming to provide an effective assessment of different factors affecting the AR application in a specific manufacturing process. The proposed tool aims to support researchers and practitioners for developing an effective early evaluation – i.e. before the full technological design- of the AR system, based both on the assessment of technological features characterizing the AR system and requirements required by the manufacturing processes.

The reminder of the paper is organized as follows: a brief analysis of recent pilot or full scale applications of AR technology in the manufacturing sector is proposed in Section 2: AR applications have been analysed according to a process based point of view, by focusing on the specific field of application in the manufacturing sector rather than on technological issues. The proposed multi-criteria model is discussed in Section 3, and a case study for validating the approach is detailed in Section 4.

2. Applications of AR systems in manufacturing: a process-based analysis

A literature review carried out in the Science Direct database from 2007 to February 2016 about the application of AR systems in manufacturing, show four main areas of application, such as:

- product design: it refers to the product conceptualization process and its interaction with the manufacturing one;
- process design, planning and control: the first two involve both tactical (e.g. technological design of a manufacturing process) as well as the operational (e.g. machining programming) level. The process control category refers to both the whole shop floor or a single equipment control process;
- equipment or asset maintenance: mainly refers to industrial equipment maintenance;

Another study category regards the assessment of such AR application in specific industrial sectors.

The total number of paper is 33: 17 papers regard design, planning and controlling processes and 7 and 8 papers for product design and the maintenance process respectively; studies discussing the assessment process of an AR system are very low, i.e. 3. Fig. 1 shows the temporal distribution of papers under the three main categories previously introduced; the last one has not been introduced in the figure due to its low significance.

In the following, each of the four areas has been analysed in detail.

2.1. AR applications in the product design process

In the product design, AR systems have been applied to support a faster and effective design process: using AR technologies allows to develop a semi-immersive design environment where the users (i.e. designers as well as customers) could interact in the real world while performing feature modelling on a virtual product. Based on current recent applications, AR tools for product design could be divided into two main categories (Shen, Ong, & Nee, 2010) based on their main functionality: *visualization-based design* and *co-design* systems. The first type provides a full immersive AR-based environment allowing to visualize, inspect and modify the 3D product models collaboratively. By analysing current research projects, the first type aims to support a more participatory design process by involving designers as well as product users/customers; the latter focuses on providing a more collaborative design process especially where the design process is carried out by different and remote contributors. Some examples, recently proposed by Ng, Ong, and Nee (2010), Ng et al. (2011) and Luh et al., 2013, developed an AR system to support a more effective participatory design process by directly involving customers. By combining virtual and real objects in the same environment, designers could provide customers with a tool to create, visualize and contextualize objects. Arbeláez-Estrada and Osorio-Gómez (2013) described a mobile AR-based system, which allows customers to easily send effective feedback to designers; the AR system allows contextualizing in the customer environment product thus improving the overall design process efficacy. Otherwise, co-design systems focus on providing a 3D space where designers can create and modify collaboratively models in the 3D space: the focus is on supporting interactions between multiple and remote users. Multiple users (e.g. members of a multi-disciplinary team, customers, and designers) in different locations can work together during the early design stage of a product to reduce the redesign iterations and cost. Ong and Shen (2009) and Shen et al. (2010) proposed a client/server architecture where multiple users in a distributed environment can create and modify simultaneously product features in a 3D physical space.

2.2. AR applications in process design, planning and control processes

Another relevant field of AR technology application is the assembly process: two main phases - such as the assembly Product Design and Planning (PDP) and assembly Workplace Design and Planning (WDP) currently represent the main field of AR application. The first one mainly affects the assembly process design, e.g. in terms of activity and sequence definition; the latter mainly affects work place design and layout. Several studies focused on analysing how AR technologies could support faster product design by introducing simultaneously physical constraints due to workplace layout. Ong, Pang, and Nee (2007) proposed an AR system to support a more reliable and integrated assembly design process by manipulating virtual prototypes in a real assembly workplace. The proposed integrates the PDP process with WDP, as actual workplace constraints are outlined through AR technology. A recent update is proposed in (Ong & Wang, 2011), where the authors proposed a AR-based tool characterized by several automatic and reliable interaction features, such as an automatic on-line constraint recognition system which allows to remove the importing process from a CAD software and a 3D interface system providing a more realistic visual feedback during assembly.