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Preliminary study of Augmented Reality based manufacturing for further integration of Quality Control 4.0 supported by metrology

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Abstract: Augmented Reality (AR) is a key technology enabling Industry 4.0, which enriches human perspectives by overlaying digital information onto the real world. The maturity of AR technology has grown recently. As processes in the automotive and aeronautic sectors require high quality and near-zero error rates to ensure the safety of end-users, AR can be implemented to facilitate workers with immersive interfaces to enhance productivity, accuracy and autonomy in the quality sector. In order to analyse whether there is a real and growing interest in the use of AR as assisting technology for manufacturing sector in general and quality control in particular, two specific research questions are defined. In addition, two well-known research databases (Scopus, Web of Science) are used for the paper selection phase in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology to conduct a preliminary study and evaluate the current development of AR applications in manufacturing sector in order to answer the defined questions. It is found that while the development of AR technology has widely implemented to assign real-time information to several systems and processes in assembly and maintenance sectors, this tendency has only emerged in the quality sector over the last few years. However, AR-based quality control has proved its advantages in improving productivity, accuracy and precision of operators as well as benefits to manufacturing in terms of product and process quality control across different manufacturing phases.

Keywords: Augmented Reality, Industry 4.0, Metrology, Assembly, Quality 4.0.

1. Introduction

In recent years, Augmented Reality (AR) that is one of the key technologies enabling Industry 4.0 [1] has been gradually adopted by key companies on industrial innovation, such as General Electrics, Airbus [2] and Boeing. It has been implemented for productivity advancement, product and process quality enhancement (reducing error rates) [3] or higher ergonomics in various manufacturing phases. In the automotive and aeronautic sectors, automatic measuring systems have been widely applied when designing prototypes or assembling the relatively large volume parts. The accuracy of metrological data collected by those measuring systems is crucial to assure the high quality of product and contribute to the saving of prevention costs in the quality sector. However, the most accurate systems are usually slow due to the involvement of several essential manual operations like targets placement, setting up devices, etc. In addition, the quality of measuring results can also be influenced by workers' experience [4]. In order to solve these challenges, AR technology is investigated and a systematic literature review is



preliminarily studied for further developing of the AR-based quality control (QC) application integrated with 3D metrology.

2. Background

2.1. Augmented Reality (AR)

AR is a technology overlaying digital information onto the real world to enrich humans' perspectives about the surrounding environment, thus innovating the interaction between human, digital information and physical world. The augmented information can be in the form of visual augmentation [3], audio [5], haptic feedback [6] and multimodal feedback [7]. Visual augmented reality applications are currently dominant in industrial manufacturing. However, there is also a tendency of increasing interest in multimodal AR applications, which are mainly based on visual augmentation combined with another sensing feedback.

Although the research trend in AR technology has been investigated and rapidly evolved over the past 20 years, the earliest of humankind's experience into immersive reality can be dated back to 1968. It was when Ivan Sutherland invented the first head-mounted display (HMD) device connecting to a computer to create the "Sword of Damocles" [8]. This invention greatly influenced the way human interacting with industrial AR today. Then in 1990, the term Augmented Reality was first formulated and official contributed to Thomas Caudell, who was a Boeing researcher. In a paper, he presented his idea of designing and prototyping of an application, which supports manual manufacturing process by integrating heads-up display (HUD) technology [9]. Four years later, Milgram et al. introduced the Reality-Virtuality Continuum (RV continuum) to classify different levels of immersive experience depending on the type of dominant content: reality information or virtual information [10]. In 1997, three main technical characteristics of AR were defined by Azuma based on its technology, which are combining real and virtual, interacting in real-time and registering real/virtual objects in 3D [11].

Technically, a general AR system is constructed of software built on a selection of four fundamental elements of hardware: processing unit, input device, tracking device and display device. The processing unit is for modelling augmentations, controlling devices' connection and adjusting the position of superimposed information in the real scene. About the tracking technology of AR, it depends on the selected tracking devices and can be classified based on tracking methods into three groups: computer vision-based tracking (CV-based tracking), sensor-based tracking and hybrid tracking. The input device is to get the stimuli signal from users or the environment to trigger the augmentation functions. The processing data are visualised onto the display device via a user interface (UI) enhancing two-way communication between the user and the system. The current display devices belong to two groups: in situ display (desktop monitor, projection-based augmentation, spatial augmentation, etc.) and mobile display (hand-held device HHD, head-mounted device HMD).

2.2. Quality 4.0

Quality is one crucial class of manufacturing attributes besides cost, time and flexibility [12]. It focuses on ensuring the final product or service to meet the specifications, thus satisfying customers' requirements. In an organisation's context, the current highest level of quality is Total quality management (TQM) which organise the quality improvement by holistically considering internal and external customers' needs, cost of quality as well as developing systems to assist improvement. As a part of TQM, quality control (QC) is essential in fulfilling technical specifications with inspection using techniques like statistical process control (SPC) or statistical sampling to maintain the in-line quality on the shop floor manufacturing [13]. In contrast, quality assurance (QA) focuses more on the pre-manufacturing phases like design, prototyping, planning, etc., to ensure the accomplishment of quality requirements for manufacturing products.

Industry 4.0 is an emerging paradigm for the manufacturing digitisation, observable in all modern manufacturing levels. It creates an innovative value chain to enable interaction between the worker, machine and cyber-physical system (CPS) thank to different enabling technologies such Internet of

Thing (IoT), cloud computing, artificial intelligence (AI), AR, etc. By combining the state of quality and industry 4.0, quality 4.0 can be considered as an integral part of industry 4.0. It is the digitalisation of TQM or application of industry 4.0 technologies to quality. The value propositions for quality 4.0 are augmentation or improvement of human intelligence; productivity and quality of decision-making enhancement; transparency and traceability improvement; human-centred learning; changes management and prediction [14-16].

Applied metrology is a subset of metrology and a measurement science developed toward manufacturing and other processes to assure the suitability of measurement instruments together with their calibration and quality control. Nowadays, the measuring technologies are not only used for ensuring the finished product but also for controlling all the manufacturing process in a proactive way. With the superimposition advantage of AR and the power of metrology, for the long-term success of quality 4.0, metrology integrated AR could be a good starting point.

3. The methodology of documents identification

The first step of the study is documents identification. Two well-known technology research databases, which are Scopus and Web of Science (WoS), are used for finding high-quality literature resources. The search was carried out in September 2020 following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) [17], which is a straightforward reporting framework for systematic reviews that supports authors to enhance their reviews and meta-analysis reporting, to answer the two research questions (RQs):

- RQ1: What is the current state of AR-based applications in manufacturing?
- RQ2: How does AR-based quality control benefit manufacturing in industry 4.0 context?

The articles are selected and approved based on the following criteria:

- search terms: “augmented reality”, “mixed reality”, “manufacturing”, “industrial application”, “quality”, “assembly”, “maintenance”
- publication year: 2010 – 2020 (extracted in September 2020)
- publication language: only English
- focusing on peer-reviewed articles from conferences and journals

For the initial database search, 803 articles are found in total: 429 articles from Scopus, 374 articles from WoS. After removing duplications, 697 articles are considered for relevant screening based on their Title, Abstract and Articles' keywords following the predefined criteria above. After this step, there are 255 remaining articles for Eligibility assessment. At this stage, the full text of 225 articles are assessed whether they are relevant and provide useful information to answer the defined RQs. As a result, 104 articles are suitable for further analysis.

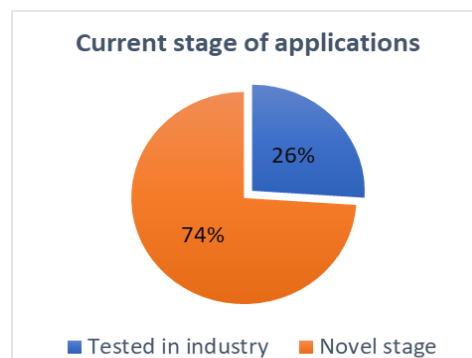


Figure 1 Classification of applications based on industry adoption.

4. AR-based applications analysis

Firstly, the selected articles are analysed and categorised into two classes depending on their industry adoption stages, which are “tested in the industry” and “novel stage”. The application is classified into “tested in the industry” class when it was already tested in a real manufacturing environment or a novel environment imitating the same conditions of a shopfloor environment. While the “novel stage” is more relevant to applications focusing on solving specific issues of AR technology like tracking, calibration, etc. rather than finding solutions for real industrial case studies. The result shows that 74% of applications are still at the novel stage and the other 26% of applications are tested in the industry as in figure 1.

Although the novel stage applications achieve promising results, human-centric issues, user interaction and user interface are still a gap that needs to be solved for adopting AR widely and effectively in manufacturing [18]. Because AR is a technology that enriches users’ perspectives, a universal human-centred model for AR-based applications can help in reducing the gap between academia and industry context [19,20]. This human-centred model can be developed by utilising a simplified AR pipeline [21] and elements of the AR system [22] with a value-sensitive design approach for smart operator 4.0 [23].

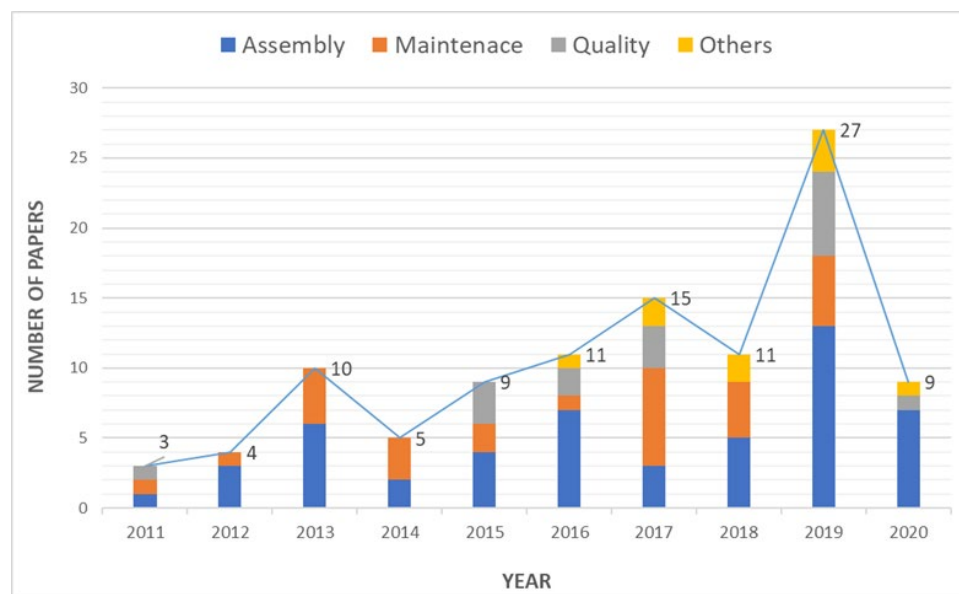


Figure 2. Distribution of AR based applications in manufacturing over years.

Secondly, the distribution of AR-based assembly, maintenance, QC and other relevant applications are 49%, 27%, 15% and 9% respectively as in figure 2. It shows a consistent interest in AR-assisted assembly, which reached a peak in 2019. Maintenance is the second dominant sector when considering the AR-based application in manufacturing. The number of AR-based maintenance applications fluctuate over the years and get the highest consideration in 2017. Although the investigation of AR applications in QC sector is still far less than in the assembly and maintenance fields, it has recently emerged. Other sectors including AR-assisted robot programming [24,25], cyber-physical machine tools [26,27] as well as real-time manufacturing modelling and simulation [28] have gradually increased.

The main advantage of implementing AR-based applications for maintenance and assembly instructions is the intuitive display. Thus, digital information in forms of text labels, 2D symbols, CAD models, etc. could be presented directly on the relevant objects [29-33]. An evaluation study comparing maintenance efficiency in using different supporting tools such as paper manuals, video instructions and AR assisted application proved that AR technology could improve productivity, reduce maintenance time and ensure the quality of maintenance works comparing to other tools [34]. Similarly, a series of

works on the comparison between AR-based instructions and 2D documents for the assembly was done by Fiorentino et al. [30] and Uva et al. [35], which proved that assembly efficiency significantly improved with AR-based instructions [30]. Additionally, AR-assisted instructions also boosted the memorisation of assembly order [35].

Regarding quality sector, AR assisted quality control has emerged from a simple indicating tool by projecting 2D information onto parts for in situ quality inspection of welding spots using Spatial AR (SAR) [36] to an advanced level that utilises real-time 3D metrology data and smart glasses Hololens for on-line quality assessment of polished surfaces [3]. In some cases, AR-based quality applications also work as an innovative Poka-Yoke tool. For example, setting up the die cutters is an important step in the packaging sector but it is error-prone causing low-quality products. Thus, correction templates made of paper and marked with tapes in different colours are used to balance the press differences of die cutters. These correction templates are created by using the concept of traditional Poka-Yoke method for mistake prevention. They are then digitalised and directly projected in the die cutter which resulted in several advantages reducing warehouse costs for storing correction templates or preventing data loss from damaged templates [37]. In another application, SAR is applied to improve the precision and accuracy of the manual spot-welding in the automotive industry [38]. Several types of visual cues with different colours (red, green, yellow, white and blue) and sizes are defined and augmented on the welding area to help the operators focus the weld guns towards the correct welding location. Additionally, AR-based applications using CAD models are implemented as tools for design discrepancies [39] and design variations detection [40]. Point cloud data integration with an interactive SAR system is developed and validated for the quality assurance of sheet metal parts in the automotive industry [41].

5. Conclusion

The investigation of AR applications in QC sector is still far less than in assembly and maintenance fields, despite the fact that several AR-based QC applications benefit manufacturing in terms of non-conformity management [38], quality monitoring [42], change management [43], etc. It can be explained by the nature of these processes. Most assembly and maintenance operations can get benefits from AR by replacing paper instructions, engineering design with relevant digital information. By overlaying digital information onto a specific product or process, human errors can be reduced. In contrast, AR applications in QC need to consider not only the finished product but also the holistic philosophy of process monitoring and product quality controlling across different manufacturing phases. They also require higher accuracy in tracking and superimposing information. Moreover, the type of data used in AR-based QC context is very diverse from 2D instruction to 3D point cloud data depending on specific inspection task such as discrepancies check [39], design variations [40], surface quality check [3], etc. or different level of users like production managers [44], QC workers [45], in-line operators [46], etc.

Regarding the gap between industry and academia of AR-based manufacturing application, a universal human-centred model implementing AR-based application can be developed by utilizing results and methodologies of studied applications. This model can then be combined with an AR-based metrology application as digital guidance or digital Poka-Yoke tool to ensure the quality of measuring data, which is essential for quality 4.0 implementation. Then, to achieve quality 4.0 in the long term, a ubiquitous AR-based QC architecture could be built up to enhance data-driven metrology integration and allow different end-users to exploit metrological data and quality data efficiently. As a result, productivity, efficiency and accuracy can be improved across relevant manufacturing processes in real-time.

6. Future work

By utilising the current identified documents and findings, a set of extended research questions as well as the second round of documents search using PRISMA extended version will be carried out to draw a roadmap and propose a framework for the further development and implementation of AR-based quality application in the context of industry 4.0.

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