Multi-sensor based augmented virtuality immersive technologies for large scale metrology applications

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Abstract

The interaction and merging of the real and virtual worlds creates *Mixed Reality* (MR), wherein natural and man-made / digital objects interact continuously to produce new, advanced facets of visualizations. Recently, with the advent of sensor and micro-processing technologies, MR is gaining a prevailing interest in a wide range of scientific, military, learning, entertainment and commercial application areas. Undoubtedly, the industrial manufacturing process retains a prominent position to that list. In fact, the continuously increasing demand for higher quality and more efficient assembly and generally industrial production, necessitates the need for continuous dimensional control and less error prone operations. In the past years, the prevalence of *Coordinate Measurement Machines* (CMM) either in the form of a single or a multi-sensor deployment allowed to a certain extend the examination, control and compliance with the geometrical and dimensional posed tolerances. Nevertheless, despite the wide adoption of CMM worldwide, the complexities and peculiarities associated with the industrial production processes ask for continuous, scalable, procedural and metrological assistance and inspection improvements; being a problem that still remains a challenge for the research community.

Augmented Virtuality as also Augmented Reality and Spatial Augmented Reality which stem from the MR continuum are gradually established on the metrological inspection routines. This paper focuses on *Augmented Virtuality* (AV) which is a subcase of MR and refers to the merging of physical elements into virtual worlds. The study examines the methodological framework and the parameters that define the reality 'feeding' and representation into the virtual environments of a metrological platform. The potential of a project-based augmented virtuality system for use in the frame of *Large Scale Metrology* (AV-LSM) inspection and monitoring applications is discussed.

Key words: augmented virtuality, mixed reality, multi-sensor systems, large-scale metrology

1 INTRODUCTION

Recently, the continuously growing of scientific research on immersive technologies and Mixed Reality (MR) systems have fructified their benefits in large scale metrology (LSM) and manufacturing applications. MR is the combination of the real and virtual environments that leads to a novel, hybrid space, in which both extremes complement each other to denature their status to a more informative and effective result. Augmented reality/virtuality (AR/AV) systems are evident in many applications, such as in personal assistance and awareness systems, in navigation and touring, in combat and simulation, medicine, entertainment and media, manufacturing assembly and maintenance, collaborative training, education, robot technology, etc. (van Krevelen, D.W.F. *et al* 2010). In effect, the increasing need for higher quality and less-costly industrial products emerged the necessity for real time insight across the complete spectrum of the manufacturing process stages (i.e., in-process inspection, assembly, guidance, monitoring and positioning) and has paved the way for the combined use of MR technologies.

LSM, a subset of which refers to industrial geodesy, employs geodetic and photogrammetric techniques for the accurate measurement, dimensioning and representation of manufactured objects, ranging from a few meters to several 10s of meters (Kyle, S.A. *et al* 2001). In LSM operations, object tracking and measurement accuracy form critical quality indicators for any MR system. Also, the applicability and effectiveness of a QC/QA procedure associated with the industrial fixtures and part assembling, it depends on the accompanying sensor performance. Portable Coordinate Measurement Machines (CMM) and/or other tracking devices that used mainly indoors such as Ultra-WideBand (UWB), Radio Frequency IDentification (RFID), ultrasound, inertial and optical vision systems facilitate augmentation between a simulated 3D environment (designed or reconstructed) with '*reality'* inside an advanced metrology platform (Kaisarlis, G. *et al*. 2015). In *sensu stricto,* these systems can be categorized to the class of AV systems.

This paper examines AV immersive technologies in regard to LSM applications; hereafter named AV-LSM systems. The theoretical background, the usage and innovations of MR systems as they applied to the manufacturing domain are discussed in Section Two. Section Three focuses on AV systems for LSM applications while their system architecture and influence variables are also examined. A case study originating from the naval engineering industry is presented. Conclusions are summarized in Section Four.

2 MIXED REALITY IN LARGE SCALE METROLOGY AND THE MANUFACTURING INDUSTRY

It has been already over twenty years since Paul Milgram, P. *et al*. (1994) presented virtual continuum and MR space which lies between the real and virtual-digital extremes. In this domain, both edges are combined and displayed simultaneously. The percentage between real and virtual content that becomes evident to the end user classifies the final system either as Augment Reality (AR) or Augmented Virtuality (AV).

In AV systems, reality prevails to the total virtual content and vice-versa on AR systems. The reality – virtuality spectrum can be enriched with other three classes, such as amplified reality, mediated reality and virtualized reality (Schnabel, M.A. *et al*. 2007).

AV and AR share the same system architectural principles with the crucial difference of the augmented subject (i.e., virtual world with reality or reality with virtual objects respectively). Bimber, O. and Raskar, R (2005) presented the basic elements of an augmented reality system shown in Figure 1.

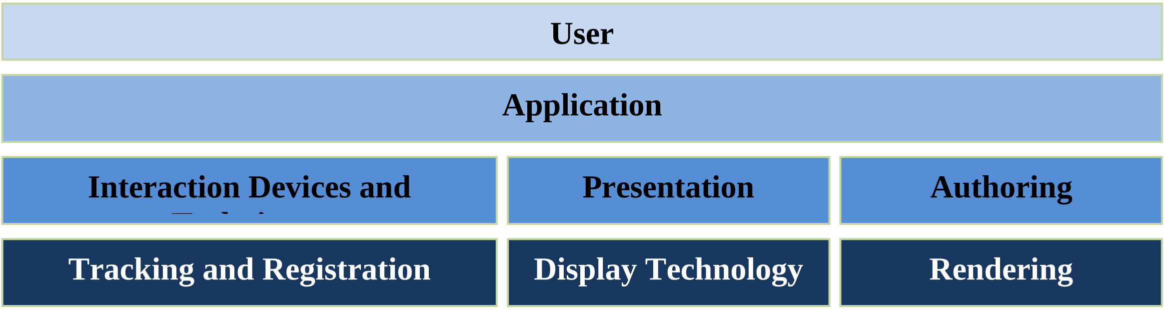


Fig.1 Augmented reality building blocks (Bimber, O. and Raskar, R. 2005)

Recently, the evolution in the domain of immersive virtual technologies, together with the tremendous improvements in accuracy, precision and robustness on measurement sensors, in micro-processing and computer science have triggered the intrusion of MR systems in the broader LSM and manufacturing industry. Potential benefits can be found on rapid prototyping, plant layout design, assembly line optimization, production process and control as well as maintenance (Caricato, P. *et al*. 2014). On their extended review paper, Nee, A.Y.C. *et al.* (2012) discuss the past and current practices while focusing on future trends on research and development of AR systems. Among others, their work presents a variety of MR, but mainly AR studies on topics such as collaborative design, robot path training, assisted maintenance systems, plant layout and operation planning, assembly design and CNC simulation. Gonzalo-Franco, M. *et al.* (2017) studied a MR metaphor for collaborative training in aerospace. The statistical significance equivalences with conventional training revealed the promising performance in the context of collaborative training. In the aerospace domain, Lapointe, J.F. *et al.* (2001) examined the development of virtualized reality systems for space tele-manipulation and improvements on control systems. Doil, F. *et al*. (2003) developed a web-based AR-system for improving the effectiveness of factory planning layout and final visualization on shop floor. Segovia, D. *et al*. (2015) examined the relationship between AR and Computer Aided Quality (CAQ) software (Q-Management software) for the accessibility to the performance information and general view of the production line. Additionally, they analyzed the benefits that evolved from the exploitation of MR systems based on statistical process control and six sigma methodology inside the automotive industry for the prevention of costly flaws. Zhou, J. *et al*. (2012) examine a spatial augmented system for the informative assistance of spot welding inspection on a physical work-cell. Novak-Maricincin, J. *et al.* (2013) highlighted the new era of virtual manufacturing, in which all stages from decision to control and dimensioning/designing and shop floor activities are enhanced by computer aided systems and immersive technologies. Lastly, MR systems can contribute to a disaster management and preventative measures of facilities and infrastructures from natural and technological disasters as pointed out in Wursthorn, S *et al.*(2004).

A more immersive trend can be observed to the early design stages of LSM hardware and software. Modern tracking sensors have abilities for on-the-fly depiction of position and orientation data in conjunction with CAD files, digital terrain models and other survey information by using the capabilities of the on-board software (e.g. Leica Captivate). Furthermore, the majority of metrological software has already started to embody elements from immersive technologies. Today, their core design allows the vivid presentation of complex 3D CAD models. The virtual content is augmented with real data from measurement sensors by transforming the platform to an AV system. For instance, *Spatial Analyzer*®, *PC-DMIS, 3DReshaper, Metrolog XG, PolyWorks|Inspector*™, *Geomagic*® Control X™, *PowerInspect* are members of an indicative list of metrological software with the aforementioned technical characteristics; however, the exhaustive reference on metrology vendors and products is beyond the scope of this paper. Interactive devices (e.g. *Geomagic*® Touch™ Haptic Device) as well as total mixed reality systems have also started to appear in LSM market (e.g. *Faro*® *Visual Inspect AR*, *Trimble SketchUp Viewer*).

Despite the great potential and the increasing use of MR technologies in the industrial and LSM applications, the number of limitations and technological challenges still to resolve are evident. Contrary to other application areas, such as in gaming and entertainment, manufacturing MR systems are still facing the need for accurate and direct tracking (e.g. tolerances of mm or sub-mm are required), the (auto)calibration and valid superposition of augmented information, the minimization of static and dynamic errors during registration, elimination of latency issues due to tracking and/or image rendering, the fast compression and loading of datasets and models and the provision of an immersive interfacing technology (Nee, A.Y.C. *et al*. 2012; Holloway, R.L., 1997; Wursthorn, S. *et al*. 2004). Furthermore, portability, ergonomy and acceptability aspects of MR systems are other issues that should be taken under consideration.

3 LARGE SCALE METROLOGY AUGMENTED VIRTUALITY SYSTEMS

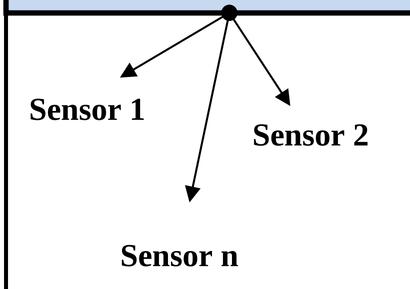
Today, modern commercial and/or customized metrology software platforms are functioning as Augmented Virtuality (AV) systems. The virtual environment which is realized by the graphical windows is augmented with input from the real word through feeding from a single or multi-sensor configuration. The virtual content may take the form of 3D models, design data, GD&T annotations prepared on a computer-aided design software or even reconstructed surfaces of real counterparts (Holloway, 1997). Computer core and graphic processing unit (CPU/GPU) selected display devices and render configurations (tessellation facets, multiplier value) adjust the fidelity and final representation of the virtual environment (e.g., native CAD files, measurements, '*avatar'* reflectors/markers/instruments, meshes). Problems with occlusion, shadow – casting, as well as system lagging and mis-registration need to be approached on the graphic engines (Bimber, O. and Raskar, R. 2005). Otherwise, the user will be frustrated and it will be difficult the comparison between virtual and real. On AV-LSM systems, the metaphor of presence mainly includes monitor based displays with multi-scoping imaging and exocentric viewing (without excluding more immersive trends).

Updates obtained from tracking sensors in various forms (e.g. polar coordinates, point fixes, point clouds, digital photos) are being registered, filtered, processed and presented as downstream information such as, spatial relationships, vectors, 2.5D maps and reporting to the display peripheral data in comparison to a CAD entity.

Each examined LSM case study has different questioned objective targets. The scalability on the types and values of the inspection tolerances lead to the selection of the proper coordinate measurement sensors. Also, a number of operational parameters and quality features, including working range, accuracy, measurement frequency, proximity limitations, etc. define sensor characteristics depending on specific measurement operation (Muelaner, J. *et al*., 2008). Laser-based spherical coordinate measurement systems, iGPS, articulated measurement arms, fixed coordinate measurement machines, optical scanners, photogrammetric systems are typical sensor accessories employed for the identification, assurance and acceptance of the geometric and dimensional tolerances.

Because an AV-LSM system represents a projection of reality superimposed on a predominantly virtual environment (Pouke, M. 2015), the degree of reality in the mixed world is defined by the technical ability and robustness of the selected sensors and application technique. Table 1 provides a summary classification of the critical factors that define the final outcome in an AV-LSM system (Kalantar-Zadeh, K. 2013;Paffenholz, J.A. *et al*, 2016).

Table 1: Variables that define the degree of reality in an AV-LSM system

<table>
<tr><th>Sensor</th><th>Environment</th><th>Object of Interest</th></tr>
<tr><td>
</td><td>• Temperature/Humidity/Pressure
• Refractive Index
• Heat currents
• Thermal inhomogeneous zones
• Attenuation</td><td>• Material on the same object and on the surrounding area
• Reflectivity
• Establishment of control/check points
• Differential movements</td></tr>
<tr><td rowspan="2">○ Accuracy
○ Precision
○ Repeatability
○ Working Range
○ Resolution/Sampling Rate
○ Signal-to-Noise Ratio
○ Drift
○ Synchronization (Temporal Referencing)
○ Registration (Spatial Referencing)
○ Data Fusion
○ Sensitivity
○ Hysteresis
○ Latency/Collection and Response Time
○ Calibration / Systematic Error</td><td colspan="2">Metrology Platform</td></tr>
<tr><td colspan="2">▪ Host – computer delay
▪ Mathematical and stochastic model of measurements
▪ Proper modeling of all variables that contribute to the final results
▪ Processing Algorithms
▪ Reliability
▪ Processing and Graphic Engine
▪ Display and Render Delay</td></tr>
</table>

In the remaining of this section, the benefits resulting from an AV system on the manufacturing process are highlighted based on the personal experience of the first of the authors. The case study stems from a quality inspection of an erected ship. The main measurement objective was the real-time inspection of the ship hull (CAD file in *.igs format) against the actual constructed hull surface. In this case the AV system was realized via a *Leica TDRA6000* industrial total station with relevant Break Resistant Reflectors (BRR). The metrology platform employed by the *Hexagon Spatial Analyzer*. The software runs on a *HP EliteBook* mobile workstation. The geodetic sensor is communicating with the instrument interface via a network TCP/IP protocol as shown in Figure 2.

After the initial geolocation to the object coordinate system (registration), the CAD file was imported to the metrology platform. Observations and 3D model had a common georeference and therefore, the deviations from the nominal surfaces could directly be displayed and documented on multiple graphic views. A heads-up display presented the resulted measured points. The general pipeline of the specific case study is presented in Figure 3.

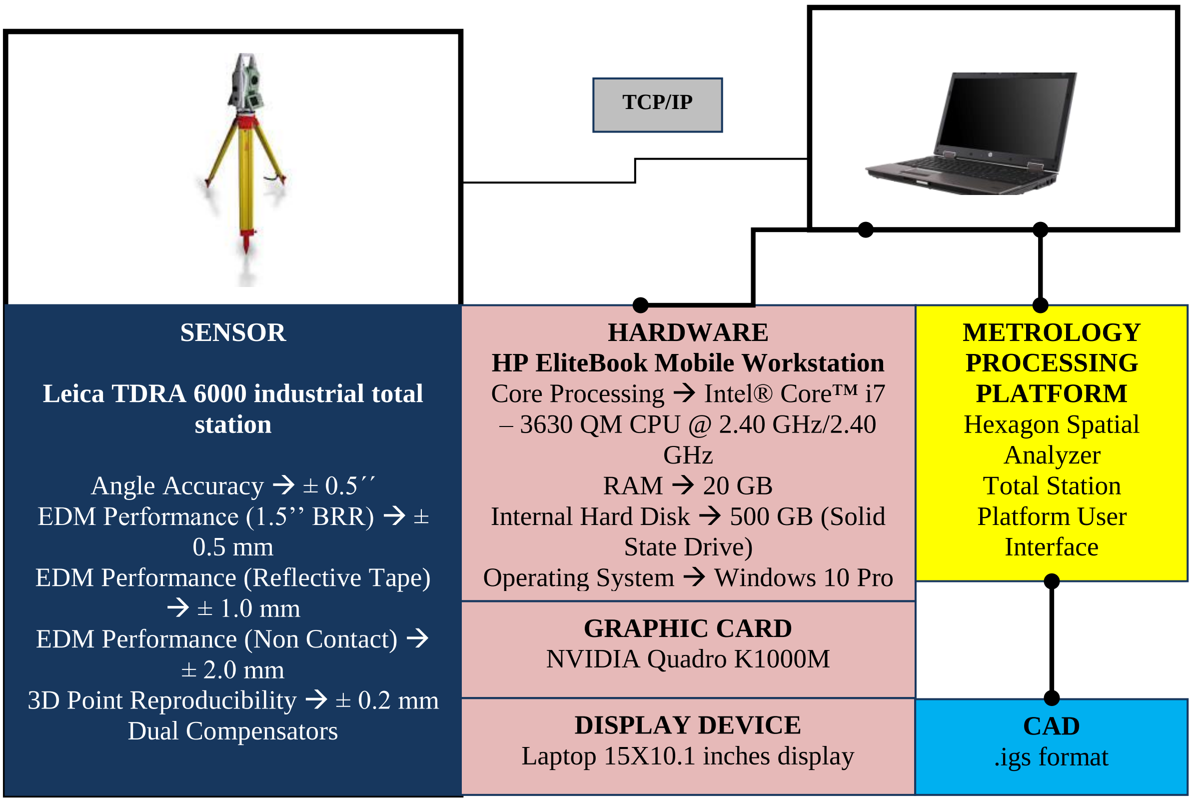


Fig.2: System architecture

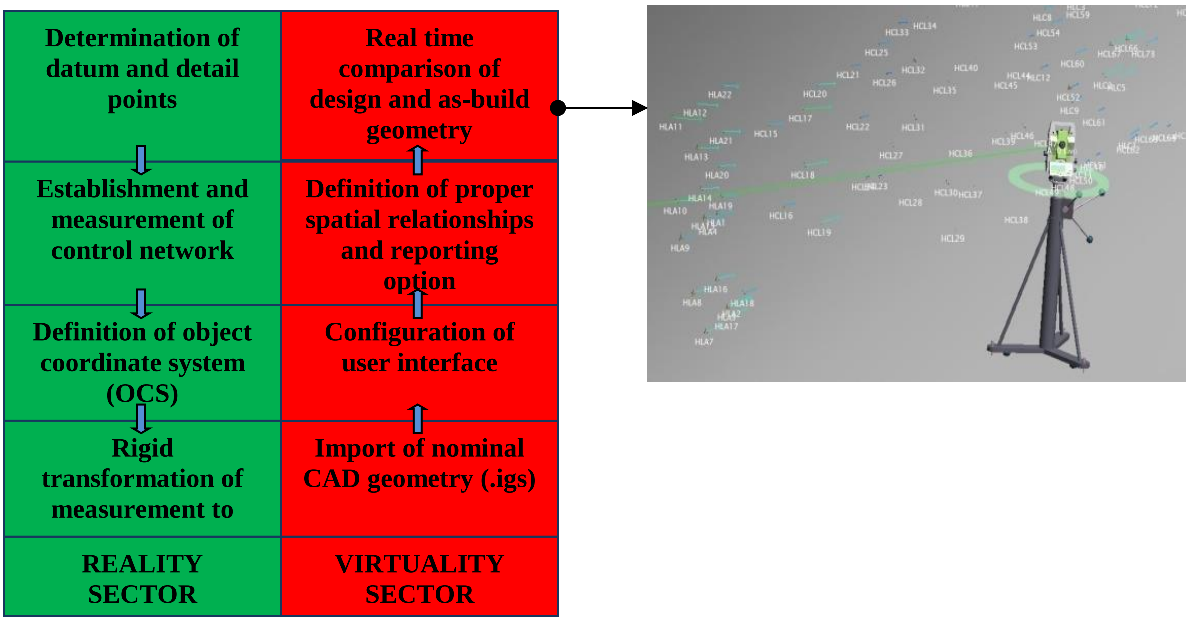


Fig.3 Case study of an AV-LSM workflow

The evaluation of the observation / processing set-up in the aforementioned case study as well as the outcome from similar applications reveal the advantages and great potential of AV-LSM systems in the quality inspection process. By exploiting the wide spectrum of analytical and reporting functionalities of the platform, the end user is capable to identify and successfully resolve artifacts and, therefore, meet tight QC product line schedules. User friendly interfaces and heads-up displays attribute an informative role and improve the critical analysis. Furthermore, geo-referencing tools that integrate information obtained from multi-sensor systems and the use of CAD model representations enable the seamlessly interaction of heterogeneous data that could further enhance the decision making process.

4 CONCLUSIONS

The wide use of AV-LSM and MR systems are close to the establishment of a *status-quo* on the sector of mass assembly lines and the manufacturing industry. In this regard, the academic and research interest focuses on the many challenging issues still present in most industrial applications, such as requirements concerning accuracy, proper synchronization and direct response of all members of the system into an immersive virtual environment. State-of-the art of metrology platforms seems to adopt the aforementioned trend and to be turned to more and more immersive perspective regarding their visualization, processing and interaction functionalities.

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