An Augmented Reality System for Operator Training in the Footwear Sector

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Abstract. This study presents an augmented reality-based system for the training of assembly line operators in the context of the high-end footwear industry. The proposed multi-layer software architecture, in combination with the AR viewer (Microsoft HoloLens™), guides operators of the shoe assembly/finishing line during the offline training activities. An evaluation protocol has been defined and preliminary experimentation of the system have been conducted in an Italian company that produces classic and luxury leather shoes.

1 INTRODUCTION

In the increasingly competitive industrial world, companies are facing an emerging important issue: the preservation of knowledge [29]. With the diffusion of the Industry 4.0 paradigm and its related technologies, the humans and their skills can be considered the core of current manufacturing systems [1]. Human resources are intangible assets, essential for companies to maintain competitive advantages and to improve their business performances [16][17]. Human training and continuous learning processes are key aspects for human capital generation and preservation [3][4].

At the design level, knowledge about past experiences is needed to rapidly and efficiently solve recurrent problems, develop new feasible solutions and adapt existing products to new customer requirements. At the manufacturing level, advanced skills on manual and semi-automatic operations (e.g. assembly tasks) are essential to finally obtain high quality products, reduce the process and throughput times, minimize the non-conformities and, as a consequence, the waste of time and resources. At the organizational level, the presence of skilled managers is an essential factor to set the most appropriate mid/long-term strategies for the success of a company [7]. However, valuable knowledge in a specific sector and context can be generally acquired after many years of experience [25].

Focusing on manufacturing industries, the manual assembly and finishing are essential phases of production processes, for many complex industrial products as cars, biomedical devices, fashion products, etc. [11]. The quality and quantity of training activities play a critical role to shorten the learning period and strongly contribute to reduce the accident rates, since training increases the aware of operators about potential risks [22][24]. In this sense and considering the Industry 4.0 context, learning factories are assuming increasing importance to provide advanced skills to operators, not only from the technical point of view, but also considering decision making, group work and performance skills [26]. Recent studies also demonstrated that a lack of training could potentially constitute a barrier to employment, especially in case of aging workforce [30]. In addition, it was demonstrated that the customer service quality and the job satisfaction are directly and indirectly influenced by training [27].

Despite the importance of training seems clear, new inexpert operators in real industrial contexts are still mainly trained through classical approaches and documents, as on-the-job training, learning by doing, work shadowing, paper guides, etc. [3][13][19]. Thanks to the spread of innovative virtual technologies, during the last years several research studies have been focused on the development of training methods/systems based on digital technologies, especially virtual/augmented/mixed reality (VR/AR/MR) [2][15]. For instance, Menn and Seliger [23] proposed and experimented the use of interactive 3D-PDFs that simply integrate CAD contents as enabling technologies for increasing knowledge regarding assembly processes. Jiang et al. [12] presented a virtual training system that integrates physics engine and haptic feedback. Loch et al. [16] integrated physical tools and components with a VR system to facilitate the knowledge transfer for industrial manual procedures.

As reported by Sorko and Brunnhofer [28], AR systems demonstrated very interesting potentialities for industries to improve the digitalization and learning processes. AR allows to enrich the reality with virtual elements (e.g. virtual objects, information, instructions). In the context of learning processes, AR systems are innovative learning media to develop specific human skills also in case of manufacturing applications [19]. Hořejší [10] proposed the use of a web camera to shoot a workplace, successively elaborated by a dedicated software tool that adds 3D model instructions in the real-world space. De Crescenzio et al. [5] used the AR technologies to develop a training system based on interactive and wearable visualizations systems to display documentation useful to train technicians involved in the maintenance of aircrafts. An interesting solution, strictly correlated with the present study, was developed by Webel et al. [31], who presented a concept and platform for multimodal AR-based training of maintenance and assembly skills. They argued that the main advantage is the possibility to interact with the "real world", by simultaneously access indications provided by the "virtual world". However, it is necessary to pay attention to technology acceptance and to the "dependence" from visual instructions that are not generally available during the online assembly/maintenance activities. Lang et al. [13] discussed the application potentials of Microsoft HoloLens™ (i.e. the same head-mounted display used in the present study), considering this equipment as a MR device instead of an AR device. Indeed, HoloLens exhibits superior features in comparison with tablets and other hand-held devices, thus it could be useful in case of industrial training and planning activities, but not for the integration in shop floors [7].

From the state of the art it emerges that a high number of VR/AR applications dedicated to operators' training have been proposed, especially in the last years. Among them, AR and MR-based systems demonstrated the most interesting potentialities for training production and logistics operators of the manufacturing sector [13]. However, the applications in real industrial contexts are still scarce. In addition, none of them is dedicated to the footwear industry. In this sector, products are manufactured through the collaboration of many semi-artisanal partners, and the knowledge of expert operators strongly influences the different manufacturing processes [21]. Training of human resources is essential to maintain knowledge and, as a consequence, high quality of final products and brand positioning, in cases of staff turnover. In this context, the objective of the paper is to propose and preliminarily experiment an AR-based training system dedicated to high-end shoes manufacturers. The multi-layer software tool, in combination with the AR viewer, guides operators of the shoe assembly/finishing line during the offline training activities performed in a dedicated

training station. Such a system allows reducing the workload of expert operators for training activities, and potentially leads to improvement of the learning curve, reducing the time needed to complete a training program for new resources.

The rest of the paper is organized as follows. After this Introduction, Section 2 illustrates the methodology used to define the system requirements and features. Section 3 describes the AR training system with its software and hardware modules. Section 4 presents the case study and some results of the preliminary experimentation, carried out in collaboration with an Italian company. Finally, Section 5 summarizes outcomes, limitations, and future work.

2   METHODOLOGY

The development of the AR training system is based on a three-step methodology (Figure 1). In the first step, after the definition of objectives, the analysis of the current training situation allows the identification of its main limits. In the second step, the definition of the system requirements, as well as the design and development of the training system are performed. Finally, validation and benefits analysis are carried out through preliminary tests, definition and quantification of representative KPIs, and quantitative assessment of system performances.
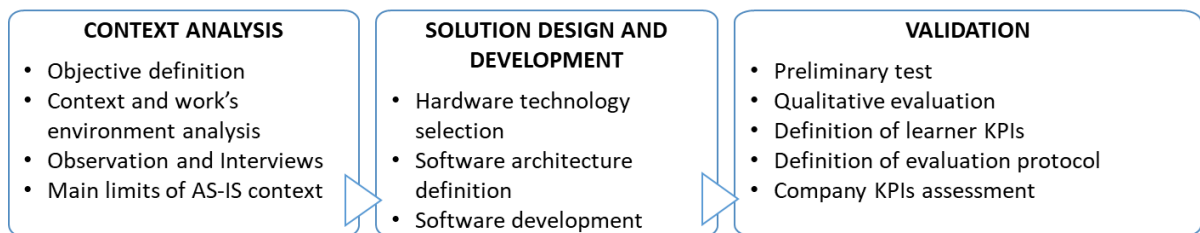
CONTEXT ANALYSIS	SOLUTION DESIGN AND DEVELOPMENT	VALIDATION
• Objective definition • Context and work's environment analysis • Observation and Interviews • Main limits of AS-IS context	• Hardware technology selection • Software architecture definition • Software development	• Preliminary test • Qualitative evaluation • Definition of learner KPIs • Definition of evaluation protocol • Company KPIs assessment

Figure 1: Methodology steps.

During the first step, the main project objective was defined, i.e. to support the training of newly hired and/or young employees in the footwear industry, in particular in the luxury leather shoe sector, characterized by semi-craft processes, and essentially based on high-specialized knowledge owned by few experienced operators.

Through the direct observations of work environments and interviews of operators, as well as of production managers, the analysis of the as-is context of training activities was realized. In this sector, current training processes appear unformalized and essentially based on learning by doing procedures, where one experienced operator assumes the role of "tutor" and shows to the new operator, during his/her work shift, how to perform several tasks that occur during the daily production activities. This activity generally continues for several days until the new resource is able to autonomously perform the desired operations. Furthermore, some companies provided production lines with documents containing instructions for operators, e.g. OPL (One Point lesson) and/or JES (Job Element Sheet).

In the analyzed case, the company has developed a common template in which operating standards are shown and explained through simple sentences accompanied by images (Figure 2). Operation steps and related controls to perform are presented in the upper part of the document, while the bottom one shows several images of correct and incorrect operations. Operators can consult these documents during their working activities and be supported in case of uncertainty.

The analysis of the as-is training processes allows identifying several limits:
- training processes are usually very long, since they are realized during daily activities and are not structured and do not follow a standardized plan;
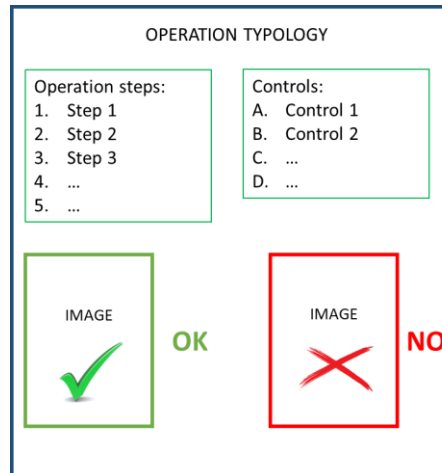
Figure 2: Instruction template.

- training processes significantly impact on production activities, thus determining a potential reduction of production efficiency or a time contraction of tutoring time;
- experienced operators do not have the necessary skills and time to share or collect their knowledge in an effective way;
- there is not a dedicated training environment where operators can acquire competences in an increasing level of difficulty.

Starting from these limits, the following requirements for the AR training system have been defined:

- Low interference of the training process with production process daily activities;
- High efficiency of the training process through a step-by-step approach, which reflects the complexity level of operations;
- Effective collection and sharing of useful knowledge;
- Make the trained operators independent during the learning process;
- Provide intuitive and usable tools that show precise and accurate information;
- Provide a comfortable and safe training environment.

3   AR TRAINING SYSTEM

The proposed AR training system is based on a multi-layer software architecture and on several hardware technologies (Figure 3).

The concept at the basis of the system is that operators to train need to be located in a dedicated training room, with a dedicated workstation. The workstation must contain shoes' elements, useful tools and materials to try and to realize in practices the notions acquired during training sessions. Thanks to the use of an AR viewer the learner can interact with the system, listening and observing the training contents and then he/she can directly interact with the "real world" which is enriched with instructions and training contents. The AR viewer selected for the training fruition is the Microsoft HoloLens 1 smart glasses.

The software architecture is composed by three layers: (i) interface layer, (ii) management layer, and (iii) data layer. Each layer contains several modules, allowing to perform a specific task for specific users. Three user classes can access to the software:

- the administrator who has the main role to organize training activities and to evaluate the effectiveness of the established programs;
- the trainer who is an expert operator in charge of preparing training materials;
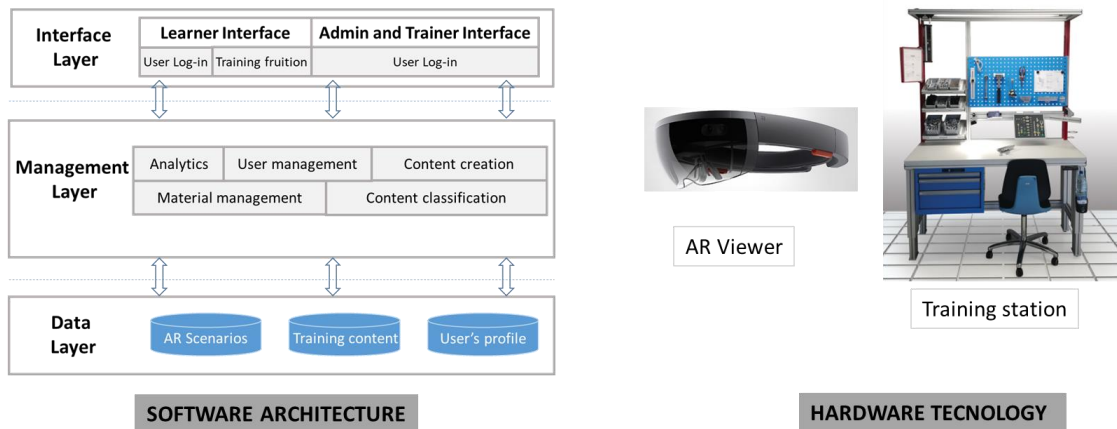- the learner who is the subject to train.

Figure 3: AR training system software architecture (left) and hardware infrastructure (right).

The interface layer allows users to interact with the system and to realize tasks. The learner accesses to the interface layer by the HoloLens. He/she can log-in and navigate the contents for which he is authorized; he/she can monitor the progress and the training program defined for him/her. Through a simple and effective interface, the learner can navigate the main interface and access the training materials. The fruition of training contents occurs by gesture or voice commands and by means of audio instructions and information listening, video and CAD model visualization.

The learner experience is based on the possibility to visualize training contents, with three levels of interaction: basic, intermediate, and advanced. In the basic level, the learner works in the real world and giving a command (voice or gestures) he/she receives virtual instructions or information. In the intermediate level, the AR system recognizes objects from the real environment and is able to provide, automatically, related instruction and information (e.g. information on the tools present in the environment and instruction on how to use them). In the advanced level, thanks to data provided by specific sensors and algorithms (e.g. tracker, color recognition algorithm), the system recognizes learner operations, his/her errors and it is able to provide feedbacks and instructions for the correct execution of tasks.

Each user has a specific flow and interacts with the training DB structure (Figure 4). The admin and the trainer access to the interface layer by the backend area of a web portal, where they can log-in and then enter into the management layer. It allows the management of users and training programs. In particular the administrator:

- Registers the learners and classifies them into groups according to the level of their knowledge (three groups were defined: beginner, basic and expert);
- Defines a training program for learners, by authorizing them in the material consultation and defines related timing;
- Defines milestones for learners or group of learners;
- Updates the learners' knowledge degree;
- Defines into active or non-active all the learners present in the system (each active learner must belong to a training group, and only active learners can use the training system).

The trainer manages the training materials, i.e. its creation and organization. In particular the trainer in the management layer:

- Is in charge of the realization of training materials (videos, AR information, CAD files, etc.);
- Classifies and organizes the materials according to the complexity level of the activities to learn (for beginner, basic or expert learners);
- Classifies and organizes the materials according to the production phase to which they are referred (e.g. upper assembly, glazing, sewing);

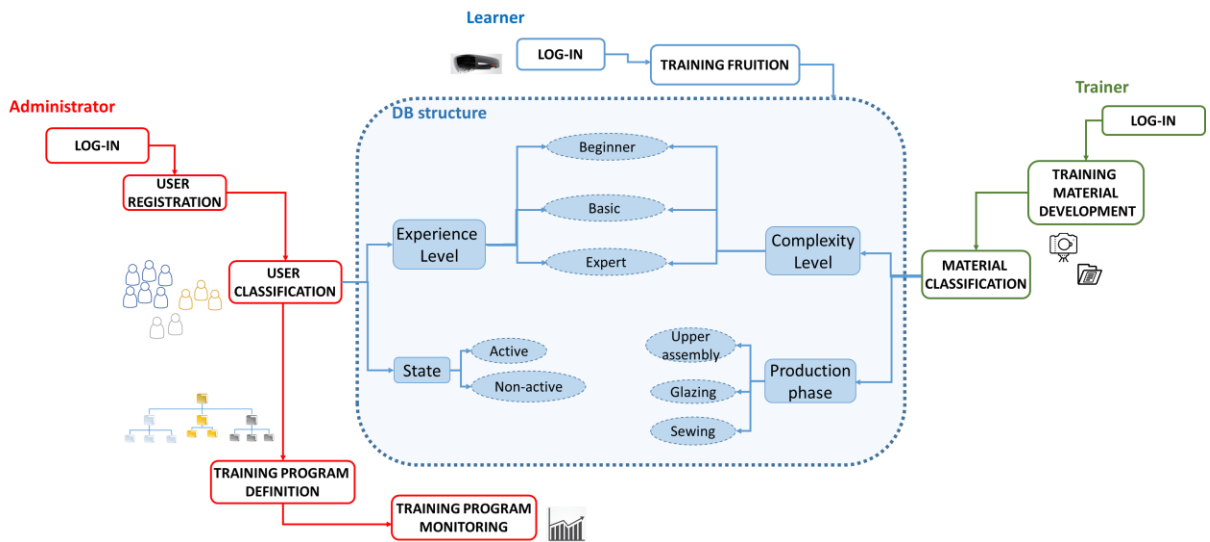- Classify and organize the material according to the interaction level.

Figure 4: User flow and DB structure.

The analytics module allows the administrator to visualize statistics deriving from the use of the training system from learners. In particular, several indicators have been defined, among them: the number of access vs the number of training material, the number of visualizations for single user vs number of training material, the access' distribution for user groups, and the access trend during the time.

For what concerns the data layer, it collects the user profiles (for learners, administrators and trainers), training materials collected in folder according to experience and complexity level and organized in different forms, and AR scenarios: videos enriched with AR information, photo enriched with AR information, CAD files useful for the visualization of shoes parts and the localization of specific working areas in virtual models, instruction file, etc.

4   CASE STUDY

The experimentation of the system took place in an Italian company that produces classic and luxury leather shoes. In particular, it was preliminary tested in the glazing department, which is the heart of the company's artistic craftsmanship. The manual coloring of the shoe is carried out according to a particular technique that requires several hours of processing due to the application up to fifteen different color passages to the leather. The colors are applied by hand with slow movements, one after the other, using a small woolen cloth and then a brush to define the details. The result is a unique product, with irreproducible nuances. This process requires experience and artisanal competence in terms of familiarity with materials, knowledge of specific techniques and skill in the use of tools. These elements are not easy to pass down, making the training activity a real challenge.

4.1   Training System Design and Development

In the current training model newly hired operators firstly receive the main instructions from an experienced worker, then observe him/her during his/her work and finally learn by doing under his/her supervision. For the implementation of the new AR training system the most experienced workers were involved in the definition and collection of training materials. In particular, the following elements were produced and insert in the system:

- An interactive CAD-based guide about shoe components and characteristics. It allows increasing the products and nomenclature awareness and better understanding the assembly process;
- Tools use guide that supports operators to select the most appropriate tool for a specific process and use it safely and effectively;
- A set of rules according to materials and colors, which allows to reduce human errors and meet quality requirements;
- Videos showing the different techniques and steps aimed at improving the movements and process learning.

The access to the system is managed according to the permissions of the following three user classes: administrator, trainer and learner.

The admin has the full control of the backend area by the web portal (left part of Figure 5). In particular, he/she manages users' database, regulates their access to contents, tracks their behavior through specific indexes (i.e. analytics module) and manages the training path (e.g., folders tree, milestones).

The trainer has visibility on his/her own learners and topics and can create and manage the related training material (right part of Figure 5).

The learner interacts with the interface layer by the HoloLens. He/she only accesses the contents for which he/she is authorized (Figure 6) and can monitor his/her progress. The learner browsing experience is based on the principle of mixed reality, therefore, he/she can enhance his/her field of view with digital information. Giving a voice command the learner can receive the instructions for the next step while practicing; the information related to a specific tool (specifications, applications, and videos) and the requirements and rules related to products, components, materials, and colors. It allows making information easily accessible in real-time. Moreover, the user can navigate the system contents and interact with virtual information (e.g., start and stop a video) by gestures. The HoloLens headset also allows reception of audio content.
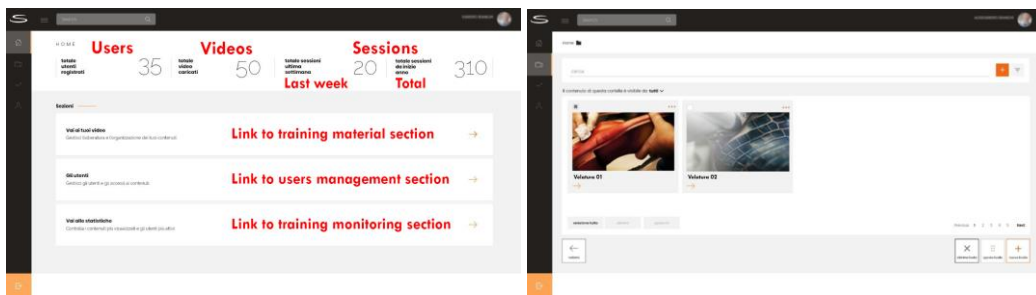

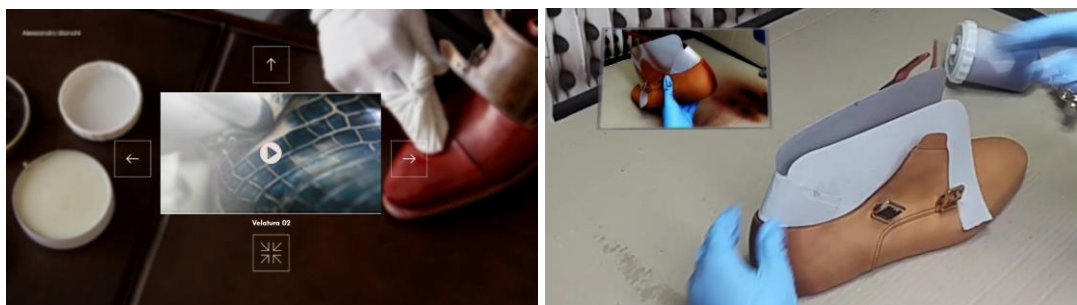**Figure 5**: Screenshot of the admin dashboard (left) and the data management by a trainer (right).

Figure 6: Screenshot of the video visualization by the learner, offline (left) and online (right).

4.2 System KPIs and Evaluation Protocol

The system benefits are evaluated according to the data summarized in Figure 7 and the protocol shown in Table 1. In particular, the following items are compared:
- Performance of newly hired operators that follow different training paths (traditional vs AR);
- Skills that the junior operator has already acquired through traditional training programs ("pre" skills) and those ones he/she achieves with the new training system ("post" skills).

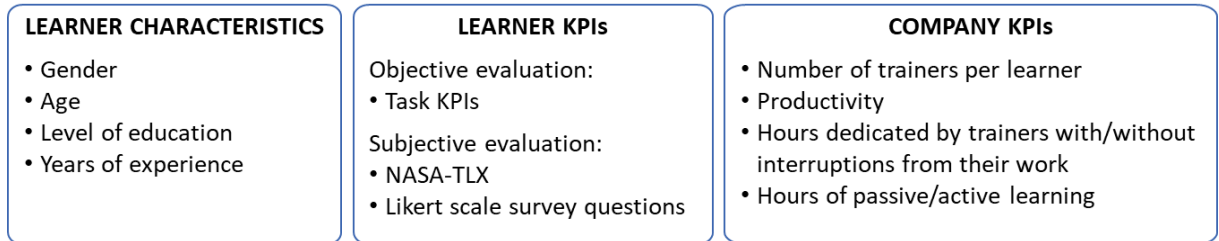| LEARNER CHARACTERISTICS	LEARNER KPIs	COMPANY KPIs
• Gender • Age • Level of education • Years of experience	Objective evaluation: • Task KPIs Subjective evaluation: • NASA-TLX • Likert scale survey questions	• Number of trainers per learner • Productivity • Hours dedicated by trainers with/without interruptions from their work • Hours of passive/active learning

Figure 7: Data for the evaluation of the training system.

Once the newly hired operators have consulted the CAD-based guide about shoe components and characteristics the trainer tests their knowledge through closed-ended questions. The tool use is evaluated through the learner direct observation by the trainer. Newly hired users are asked to use the tool they have just learned, while junior operators are asked to select the most appropriate tool for a specific application and use it. The learning of a technique and the related rules is assessed through the observation of its execution by the learner.

When the learner achieves a milestone, he/she is asked to fulfill the NASA-TLX and the survey. The NASA Task Load Index (NASA-TLX) is exploited to rate the apprentice perceived workload in terms of mental demand, physical demand, temporal demand, performance, effort and frustration [7]. A 5-point Likert scale survey question (from very low to very high) is used to measure learner perceptions about his own level of satisfaction, understanding, autonomy and pressure.

Finally, the following company KPIs are considered: number of experienced workers per apprentice and their productivity; hours dedicated by experienced workers with/without interruptions from their regular working activities and hours spent by apprentices in passive learning (observation) and active learning (learning by doing).

Topic	Newly hired		Junior skills		KPI
	Traditional	AR	PRE	POST	
Shoe	Test by trainer	Test by trainer	-	-	Success rate Errors
Tool	Tool use	Tool use	Tool selection and use	Tool selection and use	Success rate Errors Expert consultations
Technique	Process execution	Process execution	Process execution	Process execution	Success rate Quality Time Errors Expert consultations Expert interventions
Milestone	NASA-TLX	NASA-TLX	-	NASA-TLX	Mental demand Physical demand Temporal demand Performance

				Effort
				Frustration
Survey	Survey	-	Survey	Satisfaction • Trainer • Training contents • Training tools • Training modality Understanding Autonomy Pressure

Table 1: Evaluation protocol of the training system.

4.3 Preliminary Results

To date, the system validation consisted in preliminary tests that allowed optimizing the prototype, a qualitative evaluation involving end-users and the company KPIs assessment. In particular, the AR system has been preliminary validated involving two apprentices of the glazing department without previous experiences on VR/AR systems. After three days of training, they were interviewed to collect positive and negative feedbacks with respect to the current training programs.

The main pros are:
- more contents available because they are not related to the current production or senior workers background;
- expert intervention only when needed with positive relapses on productivity;
- possibility to go back to "lessons" as many times as users need;
- apprentices feel less under pressure;
- high adaptability to users' characteristics;
- contents formalization supporting knowledge sharing.

On the other hand, the following two main cons emerged: smart glasses can be uncomfortable with prolonged wearing and lack of awareness of the mistakes made during practice. Possible solutions can be to alternate the use of smart glasses with traditional training methods and to provide real-time feedbacks while practicing.

Focusing on the user interface, the use of a head-mounted display allows the user to have both hands free when working, and this aspect is fundamental in the hand-crafted sector. Other solutions (e.g., screen, tablet, smartphone) could interfere with processing the task. Moreover, the HoloLens does not require a cable connection to a computer, so it does not complicate the workplace layout. Another interesting device's feature is the internal tracking system that avoids the use of additional markers to correctly project virtual contents. On the contrary, the main limit is the small field of view, as already demonstrated by literature [13]. However, the HoloLens 2 could solve this problem and offer new opportunities.

Table 2 compares the company KPIs related to the traditional training modality and their estimate for the AR training system. Overall, AR allows increasing the training hours of learners and reducing the time spent by trainers thanks to the raise of learners' engagement and autonomy. It entails a lower teacher-learner ratio and a greater flexibility for experts in the management of the time dedicated to training, reducing interruptions from their work, and increasing daily productivity. Indeed, the explanations are mainly entrusted to the AR system in favor of the experts' observation during the execution of their work. On the other hand, the time dedicated by trainers with interruptions from their work can now focus on giving feedback to learners during active learning or verifying the milestone achievement.

Company KPIs	Traditional	AR

Number of trainers per learner	1:1	1:5
Productivity	-	+10%
Time dedicated by trainers WITH interruptions from their work (% of total training hours)	20%	10%
Time dedicated by trainers WITHOUT interruptions from their work (% of total training hours)	80%	90%
Hours of PASSIVE learning per shift	-	+80%
Hours of ACTIVE learning per shift	-	+150%

Table 2: Comparison of traditional and AR training modality in terms of company KPIs.

5   CONCLUSIONS

This study presents an AR-based system for the training of assembly line operators in the context of the high-end footwear industry. The different layers and modules of the developed system allow providing useful documents during a training session held in the dedicated offline training station. The preliminarily observed benefits are mainly related to the availability of "augmented" training contents during the completion of a training activity and the reduction of interference with the production activities. Quantitative benefits will be measured with the full application of the validation protocol and with the involvement of a greater number of users. The involvement of a significant users' sample will allow performing a static analysis (e.g. ANOVA) to validate results. This paper represents an early state of the research; future milestones will address the object recognition (e.g. the shoe model), to automatically adapt digital information, and the monitoring of learner activity to provide real-time feedback about errors or the achievement of the desired quality level.

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REFERENCES

[1]   Arena, D.; Perini, S.; Taisch, M.; Kiritsis, D.: The Training Data Evaluation Tool: Towards a unified ontology-based solution for industrial training evaluation, Procedia Manufacturing, 23, 2018, 219-224. https://doi.org/10.1016/j.promfg.2018.04.020

[2]   Borsci, S.; Lawson, G.; Broome, S.: Empirical evidence, evaluation criteria and challenges for the effectiveness of virtual and mixed reality tools for training operators of car service maintenance, Computers in Industry, 67, 2015, 17-26. https://doi.org/10.1016/j.compind.2014.12.002

[3]   Danvila-del-Valle, I.; Estévez-Mendoza, C.; Lara, F.J.: Human resources training: A bibliometric analysis, Journal of Business Research, 101, 2019, 627-636. https://doi.org/10.1016/j.jbusres.2019.02.026

[4]   Danvila-del-Valle, I.; Sastre-Castillo, M.A.: Human capital and sustainable competitive advantage: an analysis of the relationship between training and performance, International

Entrepreneurship and Management Journal, 5, 2009, 139-163. https://doi.org/10.1007/s11365-008-0090-3

[5] De Crescenzio, F.; Fantini, M.; Persiani, F.; Di Stefano, L.; Azzari, P.; Salti, S.: Augmented Reality for Aircraft Maintenance Training and Operations Support, IEEE Computer Graphics and Applications, 31(1), 2011, 96-101. https://doi.org/10.1109/MCG.2011.4

[6] Goulding, J.; Nadim, W.; Petridis, P.; Alshawi, M.: Construction industry offsite production: A virtual reality interactive training environment prototype, Advanced Engineering Informatics, 26(1), 2012, 103-116. https://doi.org/10.1016/j.aei.2011.09.004

[7] Hanson, R.; Falkenström, W.; Miettinen, M.: Augmented reality as a means of conveying picking information in kit preparation for mixed-model assembly, Computers & Industrial Engineering, 113, 2017, 570-575. https://doi.org/10.1016/j.cie.2017.09.048

[8] Hart, S.; Staveland, L.: Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research, Advances in Psychology, 52, 1988, 139-183. https://doi.org/10.1016/S0166-4115(08)62386-9

[9] Helming, S.; Ungermann, F.; Hierath, N.; Stricker, N.; Lanza, G.: Development of a training concept for leadership 4.0 in production environments, Procedia Manufacturing, 31, 2019, 38-44. https://doi.org/10.1016/j.promfg.2019.03.007

[10] Hořejší, P.: Augmented Reality System for Virtual Training of Parts Assembly, Procedia Engineering, 100, 2015, 699-706. https://doi.org/10.1016/j.proeng.2015.01.422

[11] Hou, L.; Wang, X.: A study on the benefits of augmented reality in retaining working memory in assembly tasks: A focus on differences in gender, Automation in Construction, 32, 2013, 38-45. https://doi.org/10.1016/j.autcon.2012.12.007

[12] Jiang, W.; Zheng, J.-j; Zhou, H.j.; Zhang, B.-k.: A new constraint-based virtual environment for haptic assembly training, Advances in Engineering Software, 98, 2016, 58-68. https://doi.org/10.1016/j.advengsoft.2016.03.004

[13] Lang, S.; Dastagir Kota, M.S.S.; Weigert, D.; Behrendt, F.: Mixed reality in production and logistics: Discussing the application potentials of Microsoft HoloLens™, Procedia Computer Science, 149, 2019, 118–129. https://doi.org/10.1016/j.procs.2019.01.115

[14] Leder, J.; Horlitz, T.; Puschmann, P.; Wittstock, V.; Schütz, A.: Comparing immersive virtual reality and powerpoint as methods for delivering safety training: Impacts on risk perception, learning, and decision making, Safety Science, 111, 2019, 271-286. https://doi.org/10.1016/j.ssci.2018.07.021

[15] Leu, M. C.; ElMaraghy, H. A.; Nee, A. Y. C.; Ong, S. K.; Lanzetta, M.; Putz, M.; Zhu, W.; Bernard, A.: CAD model based virtual assembly simulation, planning and training, CIRP Annals - Manufacturing Technology, 62(2), 2013, 799-822. https://doi.org/10.1016/j.cirp.2013.05.005

[16] Lim, L.L.K.; Chan, C.C.A.; Dallimore, P.: Perceptions of Human Capital Measures: From Corporate Executives and Investors, Journal of Business and Psychology, 25, 2010, 673-688. https://doi.org/10.1007/s10869-009-9150-0

[17] Liu, X.; van Jaarsveld, D.D.; Batt, R.; Frost, A.C.: The Influence of Capital Structure on Strategic Human Capital: Evidence From U.S. and Canadian Firms, Journal of Management, 40(2), 2013, 442-448. https://doi.org/10.1177/0149206313508982

[18] Loch, F.; Ziegler, U.; Vogel-Heuser, B.: Integrating Haptic Interaction into a Virtual Training System for Manual Procedures in Industrial Environments, IFAC PapersOnLine, 51(11), 2018, 60-65. https://doi.org/10.1016/j.ifacol.2018.08.235

[19] Makris, S.; Karagiannis, P.; Koukas, S.; Matthaiakis, A.-S.: Augmented reality system for operator support in human–robot collaborative assembly, CIRP Annals - Manufacturing Technology, 65(1), 2016, 61-64. https://doi.org/10.1016/j.cirp.2016.04.038

[20] Marconi, M.; Favi, C.: Eco-design teaching initiative within a manufacturing company based on LCA analysis of company product portfolio, Journal of Cleaner Production, 242, 2020, 118424. https://doi.org/10.1016/j.jclepro.2019.118424

[21] Marconi, M.; Papetti, A.; Rossi, M.; Di Domizio, G.: Improving the Shoes Customization Process Through a Digitally-Enabled Framework. In: Rizzi C., Andrisano A., Leali F., Gherardini F., Pini

F., Vergnano A. (eds) Design Tools and Methods in Industrial Engineering. ADM 2019. Lecture Notes in Mechanical Engineering. Springer, 2020. https://doi.org/10.1007/978-3-030-31154-4_27

[22] Marsical, M. A.; López-Perea, E. M.; López-García, J. R.; Herrera, S.; García-Herrero, S.: The influence of employee training and information on the probability of accident rates, International Journal of Industrial Ergonomics, 72, 2019, 311-319. https://doi.org/10.1016/j.ergon.2019.06.002

[23] Menn, J. P.; Seliger, G.: Increasing knowledge and skills for assembly processes through interactive 3D-PDFs, Procedia CIRP, 48, 2016, 454-459. https://doi.org/10.1016/j.procir.2016.02.093

[24] Nazir, S.; Johnstone Sorensen, L.; Ivar Øvergård, K.; Manca, D.: Impact of training methods on Distributed Situation Awareness of industrial operators, Safety Science, 73, 2015, 136-145. https://doi.org/10.1016/j.ssci.2014.11.015

[25] Roldán, J. J.; Crespo, E.; Martín-Barrio, A.; Peña-Tapia, E.; Barrientos, A.: A training system for Industry 4.0 operators in complex assemblies based on virtual reality and process mining, Robotics and Computer Integrated Manufacturing, 59, 2019, 305-316. https://doi.org/10.1016/j.rcim.2019.05.004

[26] Schallock, B.; Rybski, C.; Jochem, R.; Kohl, H.: Learning Factory for Industry 4.0 to provide future skills beyond technical training, Procedia Manufacturing, 23, 2018, 27-32. https://doi.org/10.1016/j.promfg.2018.03.156

[27] Shen, J.; Tang, C.: How does training improve customer service quality? The roles of transfer of training and job satisfaction, European Management Journal, 36, 2018, 708-716. https://doi.org/10.1016/j.emj.2018.02.002

[28] Sorko, S. R.; Brunnhofer, M.: Potentials of Augmented Reality in Training, Procedia Manufacturing, 31, 2019, 85-90. https://doi.org/10.1016/j.promfg.2019.03.014

[29] Suárez-Warden, F.; González Mendívil, E.; Rodríguez, C. A.; Garcia-Lumbreras, S.: Assembly Operations Aided by Augmented Reality: An Endeavour toward a Comparative Analysis, Procedia Computer Science, 75, 2015, 281-290. https://doi.org/10.1016/j.procs.2015.12.249

[30] Taylor, M. A.; Bisson, J. B.: Changes in cognitive function: Practical and theoretical considerations for training the aging workforce, Human Resource Management Review, 2019, 30(2), 100684. https://doi.org/10.1016/j.hrmr.2019.02.001

[31] Webel, S.; Bockholt, U.; Engelke, T.; Gavish, N.; Olbrich, M.; Preusche, C.: An augmented reality training platform for assembly and maintenance skills, Robotics and Autonomous Systems, 61(4), 2013, 398-403. https://doi.org/10.1016/j.robot.2012.09.013