Title:
An Augmented Reality System for Operator Training in the Footwear Sector

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Introduction:
In the increasingly competitive industrial world, companies are facing an emerging important issue: the preservation of knowledge at design, manufacturing and organizational levels. Valuable knowledge can be generally acquired after many years of experience [9]. Focusing on manufacturing industries, the manual assembly and finishing are essential phases of the production process, for many industrial products as cars, biomedical devices, etc. [3]. The quality and quantity of training activities play a critical role to shorten the learning period and reduce the accident rates [8]. Recent studies also demonstrated that a lack of training could potentially constitute a barrier to employment [11].

Despite the importance of training seems clear, new inexpert operators in real industrial contexts are mainly trained through classical approaches and documents, as on-the-job training, learning by doing, work shadowing, paper guides, etc. [2][6]. 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 virtual/augmented reality (VR/AR) [1][5]. For instance, Jiang et al. [4] presented a virtual training system that integrates physics engine and haptic feedback. As reported by Sorko and Brunnhofer [10], AR systems demonstrate very interesting potentialities for industries to improve the digitalization and learning processes. This is confirmed by the study of Webel et al. [12], who developed a concept and platform for multimodal AR-based training of maintenance and assembly skills. They argue 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.

From the state-of-the-art review it emerges that none of the proposed VR/AR applications are focused in the field of 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 [7]. Training of human resources is essential to maintain knowledge, in cases of staff turnover, and, as a consequence, high quality of final products and brand positioning. 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.

Methodology

The development of the AR training system is based on a three-step methodology. 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, 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.

During the first step, the main project objective was defined, i.e. to support the training of new 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. By 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 un-formalized and essentially based on learning by doing procedures, where one experienced operator assumes the role of "tutor" and shows to the new one, during his/her work shift, how to perform several tasks that occur during the daily production activities. This situation continues for several days until the new resource is able to autonomously perform the desired operations. Furthermore, some companies provided production lines with documents for various operations (e.g., descriptive procedures, internal conventions). Operators can consult these documents during their working activities and be supported in case of uncertainty. The analysis of training processes allows identifying several limits: training processes are usually very long; training processes impact on production activities, thus determining a reduction of production efficiency or a time contraction of tutoring time; experienced operators do not have the necessary skills and time to share 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;
- Make the trained operator independent during the learning process;
- Provide intuitive and usable tools that show precise and accurate information;
- Provide a comfortable and safe training environment.

AR training system

The AR training system is based on a multi-layer software architecture and on several hardware technologies (Fig. 1). 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 operator could stop the visualization of training materials and directly interact with the "real world". The AR viewer selected for the training station is the Microsoft HoloLens 1 smart glasses.

The software architecture is composed by three layers: (i) interface, (ii) management, and (iii) data. Each layer contains several modules. In the user interface layer, through a simple and effective interface, the user can navigate the main interface and access the training sections. The user experience is based on the possibility to visualize AR contents, which allow the user to learn notions by viewing, listening, and/or reading training materials. Videos, photo, and CAD files enriched with AR information are some examples of the provided training materials. After stopping viewing of AR training contents, the user can return to the real working station and test the understanding of training contents by directly doing the operation.

The management layer, accessible through an administrator interface and containing a section for the manager log-in, allows the management of users and training contents, according to knowledge and complexity levels respectively. Operators to train are in fact grouped according to their knowledge level, and training material is organized according to the complexity of the work/operation it faces.

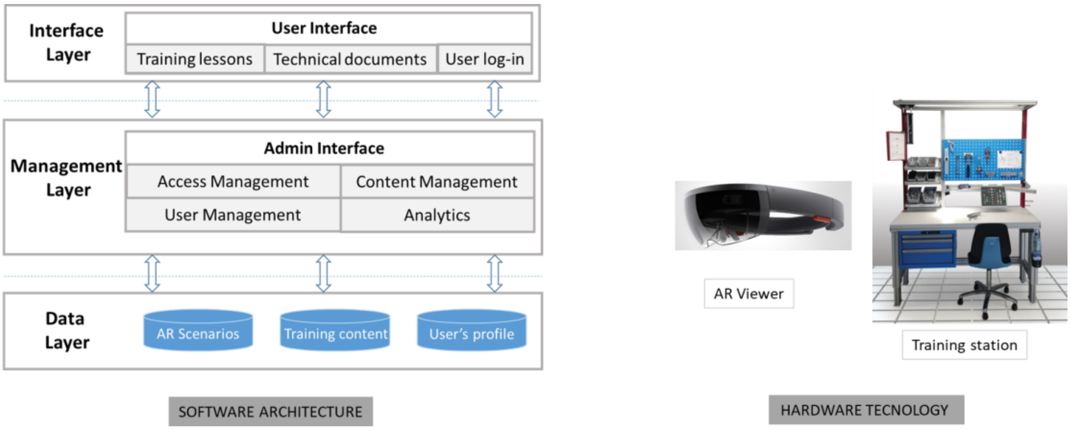

Fig. 1: AR training system schema.

Within the management layer, the content management module, allows generating training material, collecting it according to a hierarchic structure into folders, providing for each material a brief description and the indication of which user group can visualize it. Only users, which belong to the specified group, can visualize the related materials. The user management module, instead, allows managing the affiliation of operators to a specific training group (five groups were defined, from beginner to specialist), to update their knowledge degree and to define training programme for each operator's groups. The operators are furthermore divided into active or non-active users (on the basis they belong or not to a training session) and mandatorily each active user must belong to a training group. The analytics module allows the management team to visualize statistics deriving from the use of the training system. 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 (both operators and administrators), training materials in different forms: 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 a virtual model.

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. 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; tools use guide; a set of rules according to materials and colors and videos showing the different techniques and steps. In Fig. 2, two screenshots of the user interface are shown.

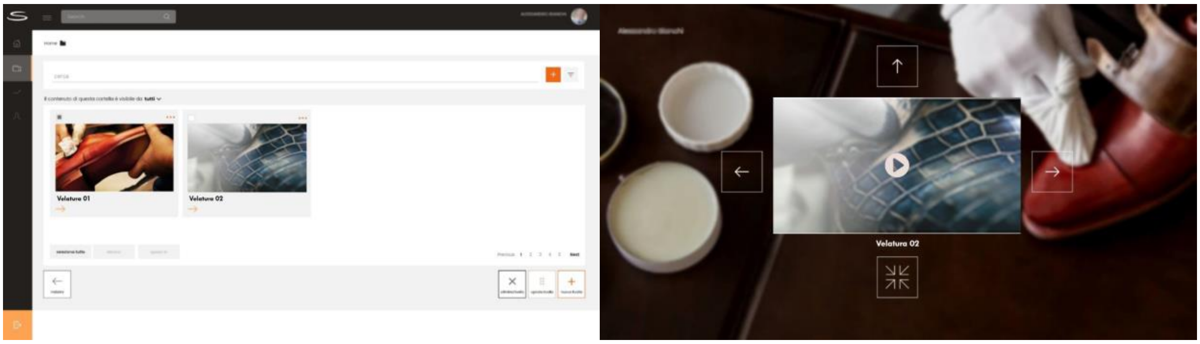

Fig. 2: Data management by the administrator (left) and video visualization by the user (right).

Benefits assessment protocol
The system benefits are evaluated according to the protocol shown in Fig.3. In particular, the following items are compared:

- Performance of newly hired operators that follow different training paths (traditional vs AR);
- Skills that the operator has already acquired through traditional training programs ("pre" skills) and those he/she achieves with the new training system ("post" skills).

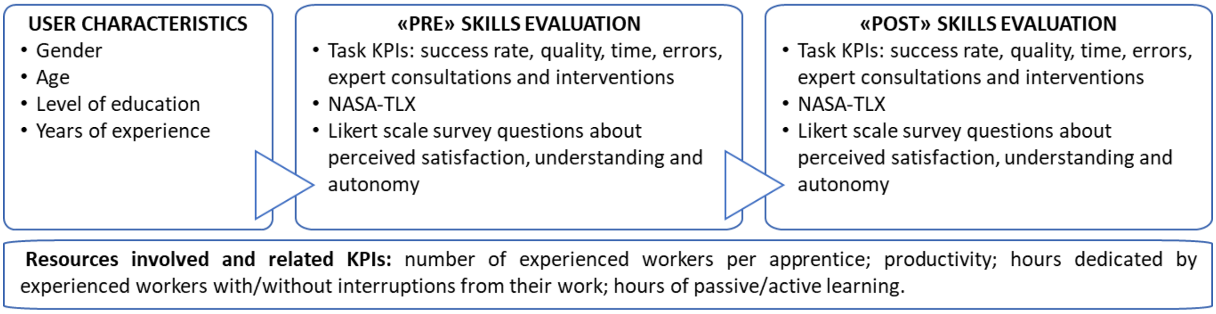

Fig. 3: Evaluation of training system.

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. A 5-point Likert scale survey question (from very poor to excellent) is used to measure operator perceptions about his own level of satisfaction, understanding and autonomy. Finally, the following 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).

Preliminary results
To date, the evaluation protocol has not yet been implemented. However, the AR system has been preliminary validated involving two apprentices of the glazing department. 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.

Conclusions:

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 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 a greater number of users will be involved.

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