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A Flexible AR-based Training System for Industrial Maintenance

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***Abstract*—Augmented Reality (AR) has been proved to be an effective tool to improve and enhance the learning experience of students. On the other hand, issues regarding the inflexibility of AR contents can strongly limit the usability of AR applications in education. This paper presents results obtained by using the AR framework designed and developed for the EASE-R^3 European project and focused on the generation of maintenance procedures for machine tools. The high system flexibility allows instructors to easily make maintenance procedures suitable for the skill level of technicians to be trained. A case study is presented and results gathered so far analyzed and assessed.**

I. Introduction

Teachers, educators, instructors and trainers are always searching for new solutions to improve the learning experience of their students. New and emerging technologies can provide tools and opportunities to stimulate the students' interest in investigating and analyzing more in depth course materials.

Augmented Reality (AR) [35] provides researchers and developers new solutions to bridge the gap between real and virtual, thus allowing the implementation of engaging and exiting user interfaces. Computer generated hints (3D animations, text labels, 2D images, and so on) are overlapped and aligned to real objects. Computer generated hints (often named assets) are information that users cannot directly experience with their own senses. These *helps* can allow users to perform real-world tasks; moreover, despite of virtual reality environments, users never loose the contact with the real world around them using AR applications.

First AR applications can be dated back to 1960s [45] and AR technologies have been extensively using in fields such as: tourism, medical sciences, entertainment, manufacturing, and so on [3]. On the other hand, AR in education has found a significative spread only in the last decade [22][23]. This can be explained by issues related to: technology acceptance [44], technological limitations [15] and pedagogical approaches [27][36]. On the other hand, AR provides educators great opportunities to enhance the learning experience of students (challenges and opportunities are well summarized in [49]). Moreover, AR helps to promote both collaborative and autonomous learning, thus changing the traditional education paradigm [33].

This paper presents preliminary results of an AR-based training for machine tools maintenance technicians. Maintenance procedures can be performed both by special purpose hardware (e.g., AR-glasses) and personal mobile devices (e.g. a tablet). The AR framework allows the instructor to easily make and change AR procedures, thus adapting the difficulty level of exercises to trainees' skill. Moreover, the instructor can also remotely assist a trainee, thus promoting autonomous learning. The proposed solution aims to tackle pedagogical issues mentioned above; in particular, this work attempts to assess the system flexibility in creating AR contents (the AR maintenance procedures), which is often a limiting factor for the spread of AR solutions in education.

The paper is organized as follows: the state of the art of AR in education (with a special focus on training for maintenance) is reviewed in Section II, the system architecture is shown in Section III, whereas the considered case study and gathered results are presented in Sections IV and V, respectively.

II. Background

Augmented reality has been deeply investigated and used in order to improve traditional learning and training paths. The possibility to create enhanced user-machine and user-user interactions by AR technologies has been the basic motivation for a lot of researchers in designing and developing AR-based systems to support teaching and learning. Moreover, AR can be also an incentive for students, thus motivating them to analyze more in the detail course materials. AR can help instructors to simulate dangerous or destructive events as well as can help learners both in visualizing microspic/macrospic scale systems and in effectively collaborating with teachers and other students.

Several fields and disciplines benefited of AR for education purposes; the following list is not exhaustive (a survey is out of the scope of this manuscript) but it is aimed to provide readers a picture of the impact AR can have on everyday life. Several applications have been proposed for the education of: medicine (e.g., [1], [32] and [42]), engineering (e.g., [30][31]), architecture and interior design (e.g., [6][10]), chemistry (e.g, [2][8]), mathematics and geometry (e.g., [24][25]), physics

(e.g., [7][26]), geography and astronomy (e.g., [28][41]), history and archeology (e.g., [13][47]), art and music (e.g., [14][19]).

A lot of works have been also proposed in the more specific field of training for maintenance. The idea to train and support technicians by conveying computer-generated instructions can be dated back to early 1990s (the reader can refer to two surveys [37] and [38]). In particular, Feiner et al. [17] showed potentialities of AR-based applications for repair and assembly tasks by supporting maintenance procedures of a laser printer. AR technologies are now used for training and support technicians in a large number of application domains: aerospace [11][12], automotive [43][48], industrial plants [18][40] and so on. Benefits of AR to support maintenance, repair and assembly tasks are well investigated and presented in [20].

As AR technologies allow researchers to develop user interfaces able to reduce the gap between real and virtual objects, a lot of works are known in the literature about AR books (e.g., [5][21]). AR books allow to provide students interactive material and 3D visualizations, thus implementing the so called *blended education* (a term used to identify a hybrid approach that uses different types of training technologies). At the same way as AR books, AR games are a type of education that allows teachers to use a highly visual and interactive form of learning: Human Pacman [9], AR^2 Hockey [39] and ARQuake [46] are just the first examples of a new frontier of AR-based education. Despite of the last decade, when AR systems were mainly based on special purpose hardware, the evolution of mobile (personal) devices allow to replace the see-through AR-interfaces by means of hand-held AR-interfaces; as the best part of mobile devices (smart-phones and tablets) is endowed with a GPS, the discovered-based learning [4] is growing up. Discovered-based learning is not only based on geo-localization (often used to teach history or geography) but also on face recognition (to provide information about a person) and, more in general, on object recognition.

All these examples show different forms of teaching/education by using augmented reality. On the other hand, an issue is shared by all the approaches: the difficulty for teachers to create AR contents [27]. For instance, in some AR systems the teaching sequence cannot be changed/adpated; in other words, instructors are not able to (efficiently and easily) accomplish students' needs. The proposed framework aims to address and mitigate this issue: a graphics and intuitive user interface allows the teacher to make training maintenance procedures as a sequence of states, at which a set of computer generated assets can be related to. Then, the teacher can generate the AR-based procedure both for special purpose AR-glasses and Android personal devices used by trainees. The level of complexity of each procedure can be easily "tuned" according the skill of students; moreover, the system allows the instructor to provide remote assistance to students: the teacher is able to see what the student's camera is framing and the state of the procedure the student is not able to perform. The teacher can dynamically make a new procedure to be sent the trainee. The framework developed for the EASE-R^3 project [16][29] has been used to support this new teaching methodology.

III. Framework architecture

The proposed framework consists of a client-server architecture, as illustrated in Fig. 1. The interaction between the instructor and the student can be split in three steps:

1) providing the procedure to the student;
2) executing the procedure and interacting with the instructor;
3) modifying the procedure and resubmitting it to the student.

This approach has been chosen to maximize the flexibility of the whole system: the instructor can easily produce a procedure for students, interact with them during the practice and update the procedure on the fly, on the basis of students' skills, feedbacks and real-time depending variables. Fig. 2 shows the building layers of the two applications.

The server side is represented by a Java-based application that runs on both Windows and Unix O.S.: the instructor's remote station. Fig. 3 shows the interface of such application: the main section of the interface contains the state machine representation of the procedure. On the bottom-left corner a set of buttons allow the instructor to define procedures and modify them. Each procedure consists of a series of edges and nodes. The nodes represent the steps of the procedure to perform and they contain all the virtual aids, or assets, chosen by the instructor. The edges represent the transitions from one state to another and are associated to a specific tracking configuration. A tracking configuration consists, in this case, of a CAD model, with a specific viewpoint and real world dimensions: it represents the real object the student should interact with, e.g. a panel to open or a switch to turn on. For each step, the instructor chooses the tracking configuration that better represents the view the student should have of the real object to be managed. On the right there are two columns: the rightmost has a widget that lists all the available assets to add at each step of the procedure and allows the instructor to adjust scale, rotation and location of 3D models and animations aids in the virtual scene. The other column contains a widget that lists the available tracking configurations and offers a preview of the corresponding CAD model. The server application is equipped with a communication module that allows the instructor to speak with a student and to see the video streamed from the client device camera.

The client side consists of an AR application providing the student a sequence of steps to be performed in order to accomplish a well defined task. The application is available in two versions, both developed with the Metaio SDK[34]: an Android application for mobile devices and a Windows application for AR-glasses, which relies on Windows drivers. This first application is intended for a better mobility, compatibility and costs as it runs on a generic Android mobile device, whereas the second option allows hand-free operations to students for better performing the maintenance procedure. The AR-glasses application comes with a speaking recognition module that maps all the commands available in the graphic

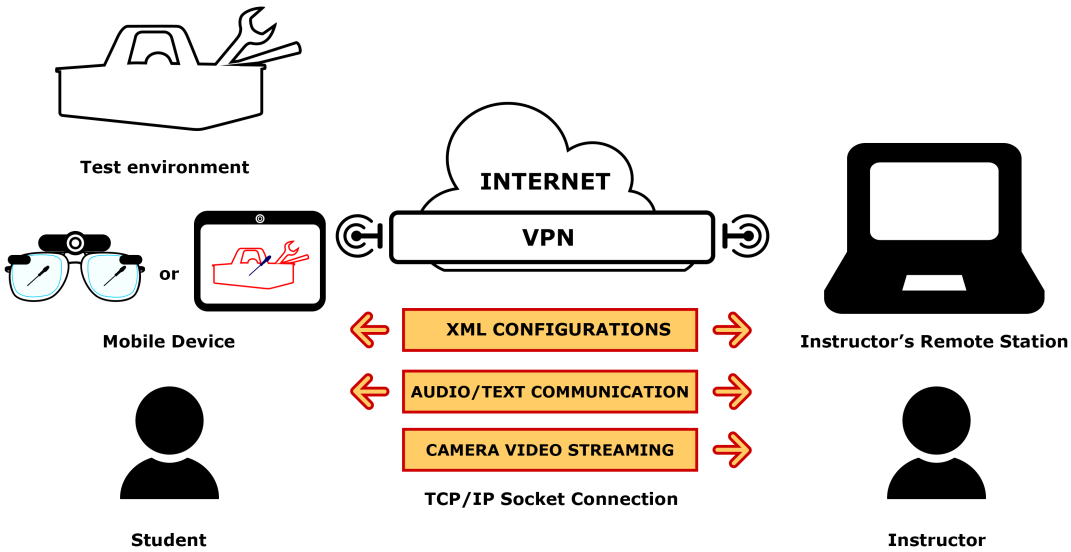

Fig. 1. The high-level architecture of the proposed framework.

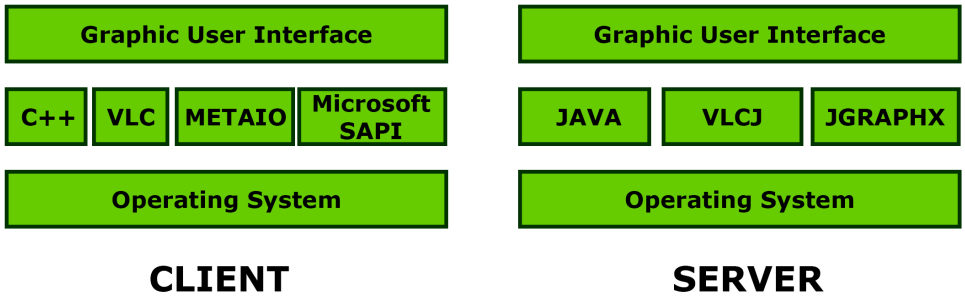

Fig. 2. Software layers of server and client applications.

interface for the Android application to vocal commands. The available commands are:

1) *start procedure* to start the practice;
2) *next* to move on to the following step of the procedure;
3) *previous* to go back to the previous step of the procedure;
4) *reload* or *restart* to repeat the tracking recognition of the real object;
5) *video* to play, if available, the video asset for the current step;
6) *instructions* to repeat the audio asset for the current step;
7) *assistance* to open the communication channel with the instructor.

Two vocal commands allow users to enable/disable the speech recognition interface in order to avoid false positive recognitions when they work in "noisy" environments or whey they communicate with the instructor.

Fig. 4 shows the user interface of the Android application. The two arrow icons at the sides of the screen let the student go back and forth through the steps of the procedures. The circle arrow at the bottom forces the tracking engine to repeat the recognition phase, e.g. to better align the virtual aids to the real object. If a video asset is available for the current step, a movie frame icon at the bottom right of the user interface allows the student to display the current step performed by an expert, thus outlining any difficult or ambiguous operations. The receiver icon at the bottom right allows the student to request a communication with the instructor for remote assistance.

When the student launches the client side application, a list of available procedures to train with is displayed. A remote assistance connections allows the student to request new procedures or update the current one. When a procedure is started, at each step, the real object has to be framed by the device camera: a silhouette representing the tracking configuration has to be aligned to the real object (the silhouette appears as a transparent 3D model on the user interface). When the tracking engine of the application recognizes the corresponding CAD model (e.g. the tracking configuration), visual and audio assets are provided to the user. When the current step is completed, the student can move on by the *next step* command. Then, the tracking engine looks for the new tracking configuration

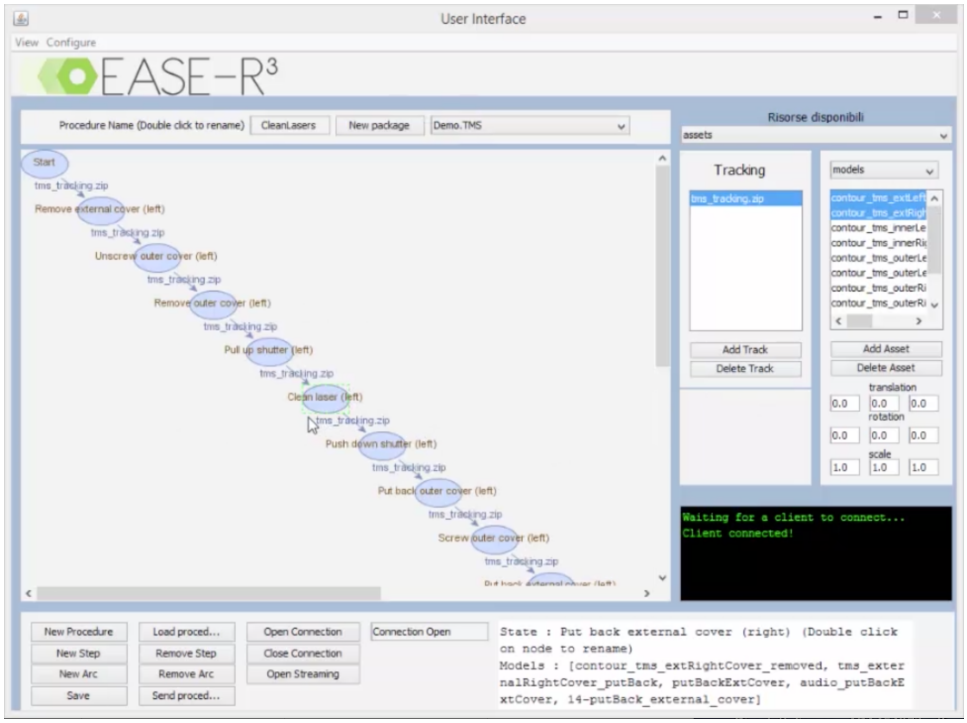

Fig. 3. The server application interface: states representing procedure steps are shown in the main area of the application, the right part allows instructor to select assets, whereas the bottom bar manages procedures and client connections.

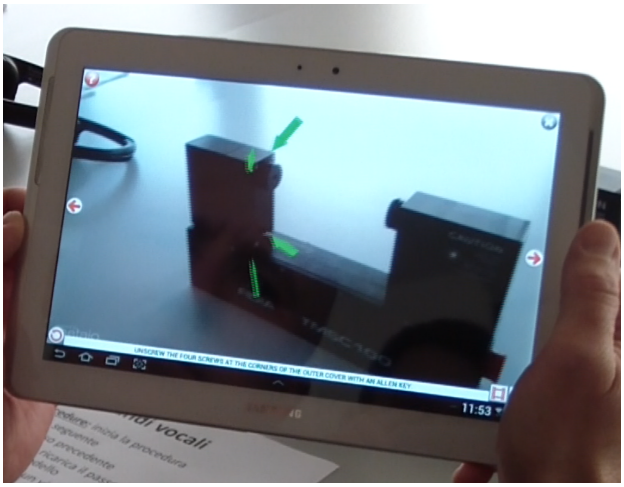

Fig. 4. The user interface of the Android mobile devices.

Fig. 5. The Fidia's TMS tool.

correspondence in the scene. The choice to offer two explicit commands to freely move back and forth through procedure steps is for providing students more flexibility; for instance, the student can skip steps when computer-generated aids are not necessary or move back to check (and possibly fix) problems. Moreover, this choice limits the number of false positives in the tracking recognition process, as the student has to confirm to be ready to move on to the next step of the procedure. If the recognition of the next step does not work properly, it could be an operation that the student has forgotten to perform in a previous step. If the student needs to interact with the instructor, the communication command allows to establish a communication channel. This function connects the AR-application to the instructor's remote station (usually over a Virtual Private Network, VPN), opens a full duplex audio channel and sends the video framed by the student's device camera to the instructor. Data are sent over a TCP/IP socket and the procedure's format is an extension of the XML schema defined by Metaio, which contains all information about the tracking configurations and asset visualization, as they are necessary to describe the machine state diagram. When the instructor receives the state diagram of the procedure, the current step of the procedure is highlighted in the graphic

interface, in this way, the instructor is informed about the step the student is actually performing. Through the audio communication channel the student may request a specific help to the instructor, thus underlining inconsistency between the procedure and the real case or requesting an explanation about the operation to perform. Eventually, the instructor may need to fix/update the procedure and send it back to the student. The application at the server side allows the instructor to change assets, tracking configurations, remove/add nodes and edges in order to provide a new and better set of instructions to the student. When the reconfiguration is completed, the instructor can send it back to the student, which can move on with the procedure starting from the last performed step.

IV. The case study

In order to evaluate the proposed framework, it has been used to support a real case proposed by Fidia, a company that designs and manufactures sophisticated machine tools (e.g., molding machines). The Fidia's training program depends both on specific knowledge and experience of technicians to be trained and on the machine tool of interest. Usually, the first level of training, proposed to inexperienced technicians, starts with the study of available manuals. After this first phase, practical exercises are proposed both by training in laboratory and training on real case situations; exercises are performed both at the production factory and at customers' sites. The time required by this two training phases may vary considerably and the second one may last from one to three months, depending on the specific tasks requested to the technicians. The training is also different between installer technicians, who perform the initial setup of the machine, and assistance technicians, who interact with customers when problems show up and need a deeper focus on problem solving skills. In the past there were instructors that had the duty to teach the other technicians the procedures required for each available systems As the number and complexity of available systems increased during the years, the choice for training was to support new technicians beside skilled ones for the same task/system.

For this case study the proposed procedure is the lenses cleaning of the Fidia's TMS (Fig. 5). A TMS is a tool that measures, through a laser beam, the condition of molding tools in order to evaluate their precision during the lifespan and eventually suggest their replacement. Usually, these tools are used in industrial context and dust, chippings and other scraps from the machinery processing can fill or cover the laser lenses. In this situation, a specific procedure to clean the lenses of the TMS is necessary to restore its working state. To evaluate the proposed framework, two procedures to perform the lenses cleaning of the TMS have been proposed: the first one is a shorter and easier version of the procedure, which aim is to evaluate if untrained, inexperienced people, which never practiced in such a field, could perform the proposed procedure in a meaningful way. The second one is a longer, more difficult procedure proposed to former technicians untrained on the specific topic; in this case, the purpose is to evaluate if the framework could speed up the learning process necessary to train new technicians and other meaningful parameters such as its usability.

The first procedure consists of the following four steps:

1) remove the cap;
2) unscrew the four screw;
3) remove the external cover;
4) pull down the shutter to expose the lenses for cleaning.

When the lenses are reachable, in the real case, they should be cleaned using compressed air from an air can.

The second procedure, which is simply an extended version of the first one, adds the following ten steps, for a total of fourteen steps:

1) clean the lenses using compressed air from an air can;
2) pull up the shutter;
3) unscrew the shutter's crew and remove it;
4) remove the lens's cover;
5) clean the lens with a soft cloth;
6) put back the lens's cover;
7) put back the shutter in position and screw the crew that hold it;
8) put back the outer cover;
9) screw the four screw that hold in position the outer cover;
10) put back the cap.

To get the students ready to the practice test, the preliminary step was to briefly illustrate them the logic of the whole system. All the students were instructed singularly, to be sure they did not forget anything before their turn to perform the practice test. Each student performed the test alone, therefore they do not acquired any experience from viewing other participants to the test. The training to the system consisted of the following steps:

1) a brief explanation of the generic task the student should perform;
2) tools available to perform the practice are shown;
3) kind of assets the AR system provides are presented;
4) the user interface of the Android client application is presented;
5) the user interface of the Windows client application is presented (the list of the vocal commands);
6) each vocal commands is singularly presented to the student;
7) the student are assisted in wearing the AR glasses in order to maximize the comfort, the field of view and the visibility;
8) the student performs a sample tracking step, thus experiencing computer-generated assets;
9) the communication with the instructor's remote station is tested.

Students started the practice with the AR glasses device. During the practice a qualified instructor supervised the student operations without interfering, just to write down the execution time of the practice and the number of errors committed. Another instructor, placed in another room, monitored the operations through the remote station, thus waiting

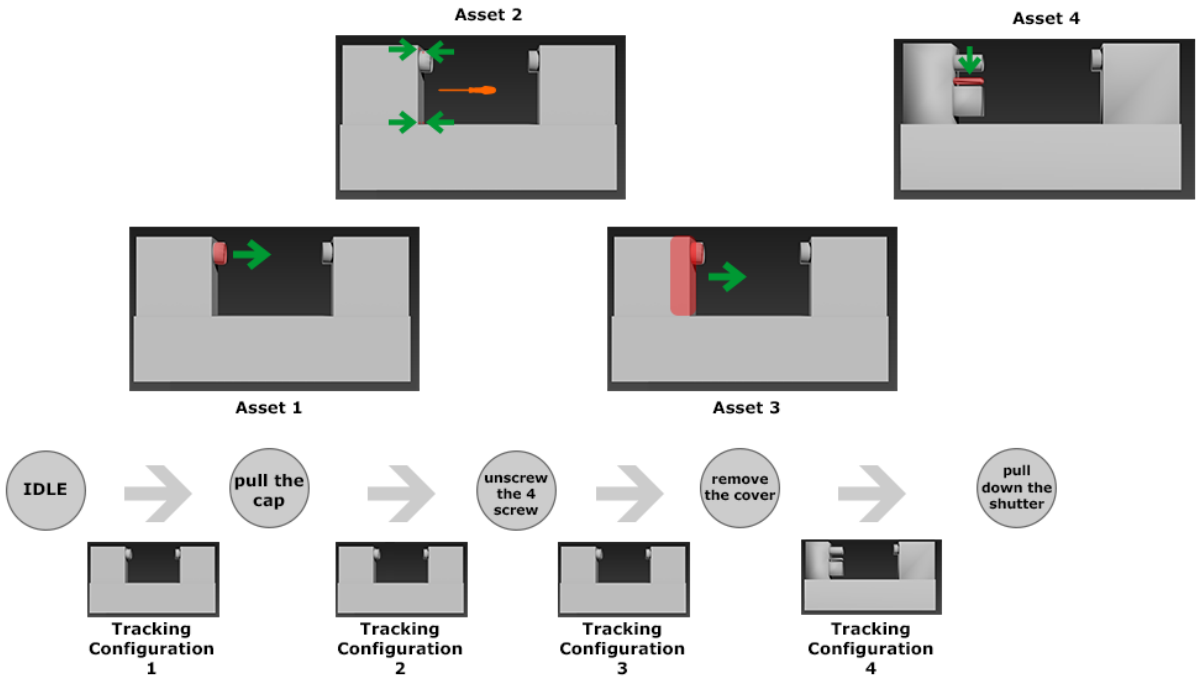

Fig. 6. A state machine diagram showing the short version of the procedure: for each state some assets and the tracking configuration to be recognized in order to move on to the next state are shown.

for help requests from the students. After completing the procedure with the AR glasses, students were also requested for repeating the procedure by using the tablet: this was necessary to evaluate advantages and drawbacks of a hand-free AR-solution, less comfortable in terms of wearing, with respect to a much handy device such a table, which instead slows down the practice when two hands are needed to perform the steps of the procedure.

Fig. 7. A student technician performing the training procedure on the TMS tool by the AR-glasses client.

V. Results

The framework was tested providing two groups of trainees by a pair of AR-glasses and an Android tablet with the client application, instructing them, one by one, as explained before. A first session of tests was performed with a group of 13 trainees (7 male and 6 female) enrolled in the BS degree in Visual Design. The aim was to check the overall framework functioning, evaluate the proposed system and verify if a group of people with no experience (and a completely different background) was able to complete the procedure (short version). A second group (8 males), selected among Fidia's technicians not previously trained for the specific task, performed the longer version of the procedure. Completion times and error rates were measured for both groups. After performing the test, trainees have been requested to compile a questionnaire to evaluate their experience.

Table I and Table II show the answers gathered by the questionnaires proposed to the two groups of trainees. Although both groups of trainees have found hard (average values: group one = 3.31 and group two = 4.12) to perform the lenses cleaning task, every candidate of both groups was able to complete the assigned procedure. Even if most of the students had not previous experiences with AR applications (question 1), the overall evaluations of the framework and of the practice experience were over the average.

Fig. 8 shows that while the first group of students, lacking of a technical background, was more prone to errors, most of the trainees of the second group performed the practice

TABLE I

THE TABLE SHOWS THE RESULTS OF A QUESTIONNAIRE PROPOSED TO ALL THE PARTICIPANTS (13) OF THE FIRST TEST SESSIONS; THE VALUES REPRESENT AN AVERAGE OF THE ANSWERS, WHERE A HIGHER VALUE MEANS A POSITIVE RESPONSE TO THE QUESTION AND A LOWER VALUE A NEGATIVE ONE IN A RANGE 1-5.

	Questions	Average	Max value	Variance
1	Have you ever used augmented reality (AR) applications before?	1.15	3	0.13
2	How familiar are you with maintenance or assembly tasks (e.g. assembling IKEA furniture, repairing bicycles)?	3.31	5	1.75
3	Did you accomplish the required task?	2.23	3	0.17
4	How do you feel about the length of time required to complete the task?	3.62	5	0.24
5	How do you feel about the level of commitment needed to complete the task?	3.31	5	1.14
6	How difficult did you find the execution of the procedure?	3.31	5	0.82
7	How comfortable did you find the AR device?	3.15	5	1.51
8	How easy did you find catching the 3D model target (alignment for enabling the procedure execution)?	4.23	5	0.95
9	How did you find the alignment of the 3D model with the real object?	4.15	5	0.44
10	How effective did you find the interaction/navigation through the procedure?	3.31	5	0.98
11	How did you find the graphics of the AR device (e.g. visualising 3D elements: contrast, brightness, clearness)?	3.15	5	0.90
12	Do you think the AR device would benefit from audio/video tools supporting the procedure?	4.84	5	0.28
13	How did you find the usability of the video support tools?	4.08	5	0.84
14	How did you find the usability of audio support tools?	4.23	5	0.95
15	Do you wear glasses?	0.15 (2)	13	0.13
16	If you wear glasses, did you feel your glasses interfered with the procedure?	3.5	5	0.25
17	How tired were you after completing the procedure?	3.61	4	0.24
18	Do you think you would now be able to complete the procedure without the AR support?	4.62	5	0.85

TABLE II

THE TABLE SHOWS THE RESULTS OF A QUESTIONNAIRE PROPOSED TO ALL THE PARTICIPANTS (8) OF THE SECOND TEST SESSIONS; THE VALUES REPRESENT AN AVERAGE OF THE ANSWERS, WHERE A HIGHER VALUE MEANS A POSITIVE RESPONSE TO THE QUESTION AND A LOWER VALUE A NEGATIVE ONE IN A RANGE 1-5.

	Questions	Average	Max value	Variance
1	Have you ever used augmented reality (AR) applications before?	1	3	0
2	How familiar are you with maintenance or assembly tasks (e.g. assembling IKEA furniture, repairing bicycles)?	4.12	5	0.61
3	Did you accomplish the required task?	2.62	3	0.23
4	How do you feel about the length of time required to complete the task?	3.87	5	1.11
5	How do you feel about the level of commitment needed to complete the task?	3.75	5	1.19
6	How difficult did you find the execution of the procedure?	4.12	5	0.61
7	How comfortable did you find the AR device?	3	5	0.5
8	How easy did you find catching the 3D model target (alignment for enabling the procedure execution)?	3.87	5	0.36
9	How did you find the alignment of the 3D model with the real object?	3.87	5	0.36
10	How effective did you find the interaction/navigation through the procedure?	4.37	5	0.98
11	How did you find the graphics of the AR device (e.g. visualising 3D elements: contrast, brightness, clearness)?	3.12	5	0.86
12	Do you think the AR device would benefit from audio/video tools supporting the procedure?	4.85	5	0.12
13	How did you find the usability of the video support tools?	3.87	5	0.86
14	How did you find the usability of audio support tools?	3.87	5	1.11
15	Do you wear glasses?	0.125 (1)	8	0.11
16	If you wear glasses, did you feel your glasses interfered with the procedure?	3	5	-
17	How tired were you after completing the procedure?	3.87	4	0.11
18	Do you think you would now be able to complete the procedure without the AR support?	4.12	5	1.11

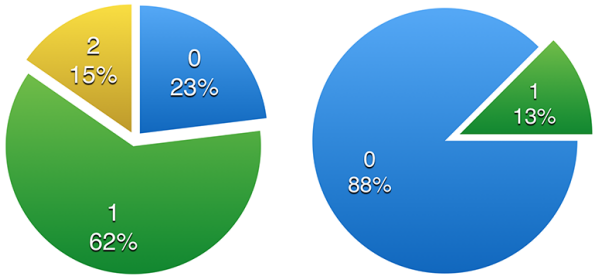

Fig. 8. The pie chart on the left shows the distribution of errors made by the participants of the first group, while the second one shows the distribution for the participants of the second one; the numbers over the percentage values represent the error occurrences.

without any mistake. Evaluating the time spent by the first group of students (Fig. 9), what stands out is that there is a wider distribution from the average value of 08 min and 38 sec., as some student had a better aptitude for the requested task or for the proposed framework and performed the practice very quickly; on the other hand, others did not adapt quickly to the system. In the second group of students the values of distribution are more close to the average value of 08 min and 06 sec.; in this case, the technical background of trainees smoothed over differences among trainee performances.

Moreover, all the students believed to have acquired enough experience to successfully repeat the procedure without neither the help of the AR application nor of the support of an expert technician. The possibility to open a video and audio channel with the instructor operating at the remote station helps

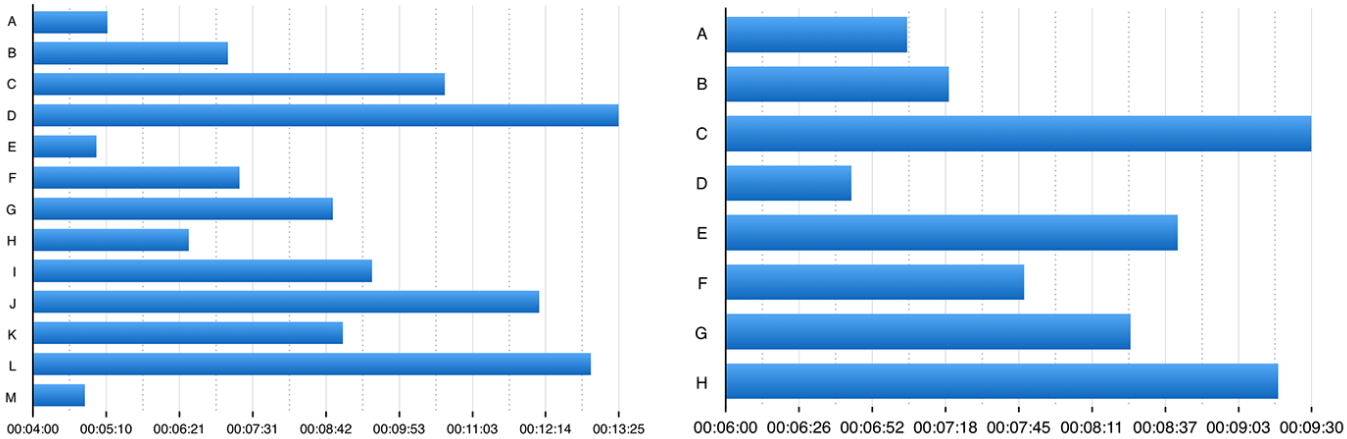

Fig. 9. The bar chart on the left shows the time spent by the participants of the first group performing the short procedure, while the second one shows the distribution for the participants of the second group performing the complete sequence of steps.

students to overcome some problems, requesting assistance to the instructor when needed and allowing the instructor to overview the procedure's fulfilment. The answers to the other questions provide useful indication about the usability of the system: higher values of variance in the evaluation of the assets and the user interface of the proposed framework (questions 8 to 14) point out which aspects could be improved, even if this kind of results may depend on an excessive user expectation for a new technology not experienced before. Answers to questions 16 and 17 show that the proposed AR-glasses are not the best available option for user that wear glasses on their own. As we got only 3 results in the two test sessions, this issue should be further investigated in the future. Finally, students believed that the two proposed devices, the AR glasses and the tablet, could offer the same experience in terms of effectiveness of the practice and task completing. The main point is that, considering advantages and drawbacks between hand-free operability and wearing comfort, students believed that both devices could be useful depending on the task to be performed and the operational environment. Moreover, the technicians from Fidia proposed to build up a support for the tablet made of a magnetic hook and a mechanical arm to position the tablet near the focus point of the procedure, thus performing hand-free the steps of the procedure.

VI. Conclusion

This paper presents the usage of an innovative AR-framework for training purpose. The main goal is to overcome issues related to the AR content production, thus enabling instructors to easily make and manage training procedures. Results obtained considering a real case study show potential benefits of the considered framework. Unskilled people are able to perform a complex task on machine tools by means the AR application; moreover, a client-server architecture allows the instructor both to provide remote assistance to trainees and dynamically change procedures in order to better support students.

Future work will be aimed to analyze and measure some indicators such as effort and time needed to train a technician and costs involved in the training process. Moreover, this analysis will be also aimed to investigate different business models related to customer assistance: for some tasks, the augmented reality tool could also replace (or more likely complementary) the traditional assistance program, thus allowing customers to perform maintenance autonomously.

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