A Mobile Augmented Reality System to Support Machinery Operations in Scholar Environments

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ABSTRACT: This paper proposes a mobile augmented reality (MAR) system aimed to support students in the use of a milling and lathe machines at a university manufacturing laboratory. The system incorporates 3D models of machinery and tools, text instructions, animations and videos with real processes to enrich the information obtained from the real world. The elements are shown when the user points the camera of a mobile device to specific parts of the machinery, where augmented reality (AR) markers are placed. The main goals of the project were (1) create an AR system that guides inexperienced users in machinery handling and (2) measure the acceptance rate and performance of the system in the school manufacturing laboratory. The guidance is provided by means of virtual information about how to operate the machinery when the trainer is not present. The system was implemented as a mobile app for Android devices and it was tested by 16 students and teachers at the university manufacturing laboratory through a survey. The results of this study revealed that students, laboratory technicians, and teachers had positive opinions and good acceptance about the use of the MAR system in the manufacturing laboratory. Comput Appl Eng Educ 24:967–981, 2016; View this article online at wileyonlinelibrary.com/journal/cae; DOI 10.1002/cae.21772

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INTRODUCTION

In engineering education, it is typical assisting to the laboratory to learn a particular skill and to realize several practices with the goal of confirm a knowledge obtained in classrooms. The instructor offers to the learners a basic explanation about the practice to perform using traditional methods such as lectures, whiteboard, or projected slides, and after that, the hands on activity starts. However, a lot of times, the instructor cannot pay attention or help all the learners at the time, due to big number of students. The aforementioned implies that, sometimes, students perform the activities in wrong way, which can lead to decompose a device or machine or in the worst case the students gets hurts.

Several proposals have been presented in the literature to address the described problem, and almost all the solutions proposed the addition of information and communication technologies (ICT) to the teaching–learning process [1–3]. The ICT refer to all kinds of visual, aural, printed, and written technological tools providing rapid flow of information and though [4].

The technology has become an integral part of education and it has been used to facilitate effective instruction. According to

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Ref. [5], lessons that are supported by technology will lead to more innovative forms of teaching and learning. The use of technology involves real-world problems, current informational resources, simulations of concepts, and communication with professionals in the field.

The first attempts consisted on include desktop computers and laptops inside the learning environments. However, stationary desk-based computer interaction through single-screen environments with little connectivity has been replaced by mobile multi-screen and multi-connectivity-enabled devices, providing an "always on" ubiquitous computing experience [6].

Fortunately, the past decade has been the time when mobile devices have been extended to almost every field of our society [7]. Mobile devices have evolved to include powerful processors, sensing capabilities, global positioning system (GPS), compass, cameras, voice recognition, among others. Therefore, mobile devices allow access to graphic information, videos, and Internet anytime and everywhere. As a consequence, the students feel very familiarized and engaged with the use of this kind of devices, then, a potential opportunity to integrate mobile devices to learning environments emerges. The type of learning which allows learners to obtain learning materials anywhere and anytime using mobile technologies and Internet is called mobile learning (m-learning) [8].

The main goal of m-learning is to create innovative techniques for information visualization that can improve the current teaching models. The virtual worlds or simulated environments are the classical tools used for m-learning. In those environments, the learners create an avatar for manipulate virtual objects inside the virtual environment. However, a more realistic interaction with educational objects which promotes collaborative interactions among students is still necessary [9].

One of the most promising technologies that currently exist to overcome this issue is known as augmented reality (AR). According to Ref. [10], AR can be defined as "a real-time direct or indirect view of a physical real world environment that has been enhanced/augmented by adding virtual computer generated information to it." Therefore, AR is a novel way of superimposing digital contents into the real context.

AR for educational purposes, offers an innovative learning space by merging digital learning materials into the format of media with tools or objects, which are direct parts of the physical space. AR is well aligned with constructivist notions of education where learners control their own learning through the active interactions with the real and virtual environments [11]. With the use of AR, the students are free to explore wide open spaces, to learn through success and failure, and can arrive at multiple possible outcomes. Therefore, AR is now revolutionizing the way to teach and learn, making these experiences more entertaining and rewarding [12].

Educational researchers have recognized AR as a technology with great potential to impact affective and cognitive learning outcomes. Nowadays, AR has entered into its mobile era. The trend is to implement educational systems in mobile devices, which is known as mobile augmented reality (MAR). The key benefits obtained with MAR learning are that it is easy and inexpensive to setup, and there are no costs for making mistakes, as they are not real [13].

In the mechatronics program at the Autonomous University of Ciudad Juarez, a problematic situation occurs in initial manufacturing courses. For example, in the subject of manufacturing processes. The aim of the subject is to cover all about the basic handling of milling and lathe machines. The basic tasks to learn include tools setup, setup of working material, and machinery setup and start up. However, by carefully monitoring the operation of the two machines at the university laboratory, it was detected that a great number of students did not performed correctly the basic machinery handling. Therefore, it would be adequate the design of an alternative tool which could help students to perform the basic tasks even without the instructor attendance. By all of the above, the aim of this paper is to present a MAR system for supporting the lathe and milling basic operation tasks in a university manufacturing laboratory environment and to observe the system performance and acceptance level by mechatronics students.

The rest of the paper is organized as follows. In Related Works section, the works related to the use of AR in educational and non-educational environments are presented. The steps followed to design the proposed MAR system are presented in MAR System Design section. The setup used to perform the experiments is shown in Experiment Setup section. In Experimental Validation and Results section, the results obtained from the evaluation of the MAR system are presented. Finally, the conclusions and further works are presented in Conclusions section.

RELATED WORKS

Research in education using AR is a strong and growing area. There are several fields such as medicine, mathematics, physics, and astronomy, which have taken advantage of AR showing promising results. In this section, a brief discussion of 32 works which uses AR in formal learning environments (17), and in non-educative environments (15) is presented. It should be noted that discussion is offered only for the newest literature works (2011–2016), older works are out of scope of this research.

An AR environment to learn physics was presented by Ref. [14]. The learning physics through play project (LPP) engaged 6–8-year-old students in a series of scientific investigations of Newtonian force and motion. The pre- and post-tests results obtained from 43 students show that students were able to develop a conceptual understanding of force, net force, friction, and two-dimensional motion after participating in the LPP. It was observed that neither gender nor age was correlated to post-test performance. The proposal demonstrated that with the use of LPP young students were able to learn force and motion concepts at an earlier age than thought possible. The results show that young children need not be limited to memorization of science facts or unstructured explorations just because they cannot design controlled experiments for inquiry.

The work presented by Ref. [15] discusses the results obtained with the application of an AR system in a chemistry course. The application targeted the composition of substances, where the students could control, combine, and interact with a 3D model of micro-particles using markers. The AR tool was tested in practice with 29 junior high school students in Shenzhen, China. With the results obtained the authors asseverates that AR has a significant supplemental learning effect as learning tool, that AR is more effective for low-achieving students than high-achieving ones, that students generally have positive attitudes toward AR and that the learning attitudes of students are positively correlated with their evaluation of the software.

An AR application to learn the basic concepts of electromagnetism was proposed by [13]. The work compared the AR-based application with its equivalent web-based application in order to study its learning effectiveness and student's level of enjoyment. Both applications were designed to provide the same information and workflow capabilities. A total of 64 high school students participated in the study. The results showed that AR approach was more effective in promoting students' knowledge of electromagnetic concepts and phenomena. Also, the results indicate that AR led participants to reach higher flow experience levels than those achieved by users of the web app.

An application called pARabola to learn the fundamental concepts of quadratic equations was presented in the work of [16]. A pilot study was conducted with 59 students at a Mexican undergraduate school, to obtain feasibility insights on how MAR could support the teaching–learning process and to observe the students reaction to the technology and the particular application. The comments expressed by the users after the AR experience were positive, supporting the premise that AR can be, in the future, a valuable complimentary teaching tool for topics that benefit from contextual learning experience and multipoint visualization such quadratic equations.

A prototype to learn the topic of anatomy of the human skeletal structure called human anatomy in mobile augmented reality (HuMAR) was shown in the work of Ref. [17]. The pilot test used the experimental method with 30 sciences students from three different universities. The objectives of the pilot test were to consolidate the user experience from a didactic and technical point of view. Based on the results of the pilot test, it is concluded that students were satisfied with HuMAR in terms of its usability and features; which in turn could have a positive impact in their learning process.

A chronological summary of 17 works that use AR for educational purposes is shown in Table 1.

On the other hand, in the literature can be found a number of AR works to support tasks in which big complexity, sensitivity, and operational risk were included. In those works, AR was used to show complex devices handling by means of superimposing 3D models to real scenarios that can be manipulated to observe them from different angles. This type of AR applications can be found in many fields such as military, marine, medicine, aeronautic, driving safety, among others.

For the case of military operations, the work of Ref. [29] proposes the use of an AR adaptive intelligent tutoring system for instruction of military tasks. AR was used to create realistic scenarios for more effective training that closely matches the physical aspects of soldier tasks. The system was fully developed for training scenarios such as threat assessment and mission rehearsal.

Regarding systems to support marine operations, the paper of Ref. [30] presents the assumptions for the concept of a full mission ship's bridge simulator prototype using innovative augmented virtuality technology. Two potential applications were presented, the first one, about operator motion capture (MoCap) tracking techniques, which entails interacting with the environment and generating of synthetic images via head up display (HUD), and the second one, about data gathering and analysis methods, to replace current visualization methods and equipment used in maritime simulators.

In order to support medical applications, the paper of Ref. [31] presents a method for real-time AR of internal liver structures during minimally invasive hepatic surgery. Vessels and tumors computed from pre-operative computerized tomography (CT) scans can be overlaid onto the laparoscopic view for surgery guidance. The method was able to locate the in-depth positions of the tumors based on partial three-dimensional liver tissue motion using a real-time biomechanical model.

In the aeronautic field, the study presented in Ref. [32] focuses on AR prototype that may help controllers dealing with zero/low visibility conditions, and increased traffic density at the airport. The prototype allows the collaborative work among several air traffic controllers. The algorithm was capable of generating a constant and coherent overplay between the AR layer and the outside view from the control tower.

Finally, in relation to driving safety, a study to determine the costs and benefits of dynamic conformal AR cues to alert experienced drivers to potential roadway hazards was presented in Ref. [33]. A total of 27 drivers participated in a 54 mile driving simulator. Each participant received AR cues to potential roadside hazards in six simulated straight rural roadway segments. AR cueing increased response rate for detecting pedestrians and warning signs but not vehicles.

A chronological summary of 15 AR works to support tasks with big operational risk is shown in Table 2.

As can be observed from Tables 1 and 2, several AR experiences to learn/train different topics have been presented in the literature, and it can be divided in applications for formal learning (students from different levels), and the others for industry training (mainly machinery operators). That was the main reason due to which the column related level was suppressed from Table 2 compared with Table 1. All the works discussed try to demonstrate the advantages of using AR in learning/training environments, and how it can be adopted as a medium increasingly accessible to train practical and motor skills, and to acquire hands-on experience inclusive for young users.

A number of papers can be found regarding to machining simulation, but not for instruct how to perform the basic tasks to use the machinery in a manufacturing laboratory using 3D glasses, which is a risk or hazard operation. In fact, the adoption of AR applications focused on core manufacturing processes still remains limited.

MAR SYSTEM DESIGN

Manufacturing is the process of transforming raw materials and information into finished commodities with good value-added for the satisfaction of human needs [44]. Particularly, in the mechatronics program of UACJ, the course of manufacturing processes plays an important role in the training process of students. In the manufacturing subject, the students try to obtain relevant skills and theoretical knowledge of manufacturing systems and processes. In order to accomplish this, the students need knowledge about how to perform the basic tasks in a milling and a lathe machine.

In this paper, a marker-based MAR system is presented. Generally, a marker-based MAR requires a marker to register the position of a virtual object to be displayed into the user's perceptions of the real world. The system operates on five items: (1) computing device; (2) software; (3) marker label; (4) camera; and (5) display device.

The proposed MAR system includes a tutorial on how to perform the basic tasks of tools setup, setup of working material, and machinery setup and start up for a milling and a lathe machine.

Table 1 A Summary of 18 Studies Using AR for Educational Purposes

Authors	App name	Sample	Subject to learn	Level	AR type	Technology
Enyedy (2012) [14]	Learning Physics through play project (LPP)	43	Physics	Elementary	Collaborative	Webcam
Chen (2012) [18]	Augmented reality library instruction system (ARLIS)	116	Library instruction	Elementary	Single	Webcam
Mejías (2012) [19]	Augmented remote lab (ARL)	20	Digital systems, robotics, and industrial automation	High school	Single	3D glasses
Kamarainen (2013) [20]	Eco MOBILE	71	Environmental	Middle school	Collaborative	Mobile device
Di Serio (2013) [21]	Italian renaissance art	69	Art	Middle school	Single	Webcam
Yen (2013) [22]	Phases of the moon	104	Astronomy	Undergraduates	Single	Webcam
Bressler (2013) [23]	School scene investigators (SSI)	68	Forensic science	Middle school	Collaborative	Mobile device
Ibáñez (2014) [13]	AR-based electromagnetism	64	Electromagnetism	High school	Single	Mobile device
Cai (2014) [15]	The composition of substances	29	Chemistry	High school	Single	Webcam
Blanco (2014) [24]	REENACT	42	History	Undergraduates	Collaborative	Mobile device
Barraza (2015) [16]	pARabola	59	Quadratic equations	Undergraduates	Collaborative	Mobile device
Wei (2015) [25]	AR creative classroom	16	Creative design	High school	Single	Webcam
Westerfield (2015) [26]	Motherboard assembly tutor (MAT)	16	Motherboard assembly	Undergraduates	Single	HMD
Salmi (2015) [17]	Human anatomy in mobile augmented reality (HuMAR)	30	Human anatomy	Undergraduates	Single	Mobile device
Gutiérrez (2015) [7]	ElectARmanua	25	Electrical engineering	Undergraduates	Single	Mobile device
Huang (2016) [27]	–	30	Art	Kindergarten	Single	Mobile device
Akcayir (2016) [28]	AR-assisted laboratory manual	76	General Physics	Undergraduates	Single	Mobile device
Our proposal (2016)	MAR manufacturing tutor	16	Lathe and milling operation	Undergraduates	Single	3D glasses

The goal is to support students in machinery handling by providing virtual information (augmented) in real time. The development of the system includes an analysis of real world elements to be "augmented." The augmented elements encompass (1) 3D models of machinery and tools such as spanners and Allen wrenches. (2) Text instructions to describe how to perform the basic tasks. (3) Labels, which help the user for locating machinery components and tools. (4) 3D arrows to indicate flow direction. (5) Real time videos that include task explanations performed by experts.

The general structure of the developed MAR system, which is called "MAR manufacturing tutor" is shown in Figure 1. The main elements of the system are grouped into hardware, software, video integration, and application flow. Each element is explained in the following subsections.

Hardware

In the first stage, a computing device to perform the typical AR processes such as rendering, recognition, and tracking is needed. Additionally, a display device for displaying the mixture of real and virtual content is also necessary.

When somebody is handling the machinery, it is important to keep both hands free to perform the tasks with accuracy and security. In the first stage, it is important selecting a hardware device that can meet this necessity. The smart phones were discarded because the user need holding the device with the hands to observe the AR. Therefore, devices such as AR glasses or head mounted displays (HMDs) were considered as an appropriate hardware for computation and displaying purposes. This kind of devices include an internal display and a video camera that is attached to the device body.

The glasses and HMDs allow the user to have a personal perspective on the augmented space and to be able to use their hands to easily manipulate the AR experience [45]. Two hardware devices were selected to implement and test the MAR system. The first one, consists of an optical see-through glasses where the real world is observed through transparent mirrors placed in front of the eyes of the user. The mirrors are also used to reflect the computer-generated models into the eyes of the user, thereby optically combining the real and virtual world view. The second one, consists of a video see-through HMD, where the real world view is captured with a video camera mounted on the head gear. The computer-generated images are electronically combined with the video representation of the real world. Both devices allow the users to view the virtual information given by the system while performing the machine operations with both hands. An example of both hardware devices selected for this paper is shown in Figure 2, in addition, a brief description of each device is offered following:

ORA-1 AR Glasses. The device includes a 5 megapixels camera, 1.2 Ghz dual core processor, 1 GB of RAM memory,

Table 2 A Summary of 15 Studies Using AR for Training Big Operational Risk Industry Processes

Authors	App name	Sample	Subject to learn	AR type	Technology
Livingston (2011) [34]	Military operations in urban terrain (MOUT)	14	Military situation awareness	Collaborative	HMD
Hofmann (2012) [35]	Tower simulators (ToSim II)	9	Air traffic control	Collaborative	Holographic screen
Rusch (2013) [33]	Driver simulator	27	Roadside hazards	single	Flat panel
Hussain (2013) [36]	Augmented reality vehicle (ARV)	44	Left turn driving	Single	HMD
Morgère (2014) [37]	Marine mobile augmented reality system (MMARS)	1	Marine navigation	Single	Laster see-through glasses
Kang (2014) [38]	Stereoscopic AR system	2	Laparosopic procedure	Single	Stereoscopic vision system + laparoscope
Wang (2014) [39]	Augmented reality for oral and maxillofacial surgery (AROMS)	1	Dental surgery	Single	Stereo camera
Champney (2015) [40]	Augmented immersive team training (AITT)	5	Call for fire (CFF) mission	Single	HMD
LaViola (2015) [29]	Augmented reality wild (ARWILD)	1	Soldier training in risk operations	Collaborative	Oculus rift
Haouchine (2015) [31]	AR for hepatic surgery	2	Invasive hepatic surgery	Single	Stereo Endoscope
Gralak (2016) [30]	Augmented virtuality marine simulator	1	Full mission ship's bridge	Single	Mobile eye tracker + HMD
Silva (2015) [41]	Augmented tower vision (ATV)	1	Air traffic control	Single	2 HD cameras
Cardenas (2016) [42]	Augmented reality for teleoperation of underwater manipulators	–	Underwater manipulators	Single	Webcam
Masotti (2016) [32]	Augmented reality in the control tower	1	Air traffic control	Single	HUD
Jenkins (2016) [43]	Bayesian assessments and real-time rider alerting and cueing for upcoming danger avoidance (BARRACUDA)	15	Roadway hazards for motorcycles	Single	HUD

8 h battery life, and a semitransparent screen. The wireless connectivity can be obtained with Bluetooth and Wi-Fi interfaces. The system is controlled by means of a touchpad, located at the right sidepiece of the glasses, which is used as a computer mouse. The user manipulates the pad to navigate through different menus of the "MAR manufacturing tutor" using the right hand in order to locate the cursor on a system button, and then clicking on it. The glasses also include a microphone for voice commands and a headphone jack to hear all the necessary instructions. Control by voice would be more appropriate to control the proposed system. However, voice control has to be robust to get the users commands without problem, so its implementation is planned as future work.

VR-PRO AR HMD. Includes a VGA 640 × 480 pixels camera, stereo audio and a 640 × 480 24 bit color depth screen. In this device, the image acquired with the camera is transferred to the computer, then it is processed and transferred back again to the device screen using a VGA input. The processed images can be shown both in the device and in the computer. In this case to control the system, it is necessary to use a computer to navigate through the interface, so the system must be controlled by two persons at the same time. This hardware can be used as a teacher–student learning tool as the hardware allows to transfer the image to an external device. However, the HMD does not have a manipulating control, so the system cannot be navigated by the person using the machine. Control by voice is planned for the soon future to enable the student to manipulate the system by himself.

Software

Once that the devices for computing, capturing, and displaying the AR were selected, the stage of selecting the software to perform the algorithms is executed. For this research, a marker-based MAR

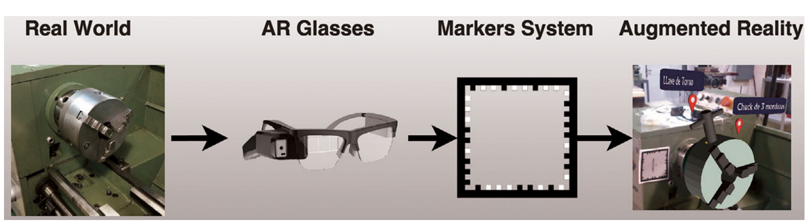
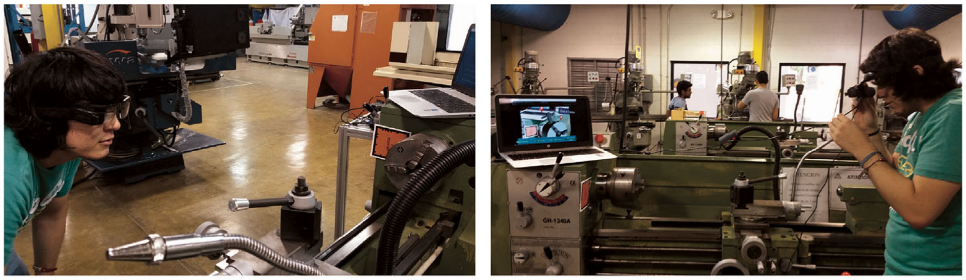


Figure 1 General structure of the developed MAR system. [Color figure can be viewed at wileyonlinelibrary.com]



(a) (b)

Figure 2 Example of hardware devices used in MAR manufacturing tutor. (a) ORA-1 AR glasses. (b) VR-PRO AR HMD. [Color figure can be viewed at wileyonlinelibrary.com]

system was developed. A marker system was selected due to the less computational power required to process each frame obtained from the camera of the hardware device. The markers are composed by defined patterns that are introduced in the real environment and are automatically recognized using the computer vision algorithms.

The system captures an image of the environment, and immediately, the operations to detect and recognize if a marker is presented inside the real scene are carried out. If a valid marker is detected, the location and orientation of the camera are deducted, then, a virtual object is positioned on top of the marker and displayed on the screen, which leads to the augmentation sensation.

In order to give the system the abilities to recognize and track the markers, Vuforia software developer kit (SDK) libraries were selected. Additionally, the Blender 3D graphics software was selected to create the virtual models that will be associated to each marker.

On the other hand, the game creator engine Unity 3D was used to mix Vuforia computer vision algorithms, the AR markers, and the virtual objects created in blender. In Figure 3, the architecture of the software system is shown.

System Markers. Two different kinds of markers, from the set offered by Vuforia, were selected to create the MAR system. The frame markers (FM) are default patterns with a binary code in the boundary. Vuforia includes 512 default FM which are incorporated in the SDK. When a FM is detected the binary code is processed and the virtual content associated to its ID number is displayed. On the other hand, the image targets (IT) are 2D real world images defined by the user which are processed by Vuforia to detect features such as borders, corners, among others. Depending on the features that are encountered inside the IT, Vuforia assigns a rate (rate scales goes from 5 to 0 stars) of detection or "augmentation" which means the ease of detecting and tracking the IT. The more stars are allocated better detection is obtained. An example of the feature detection and assigned rate of an IT are shown in Figure 4.

FM and IT were used for three different purposes: (1) detect the machinery; (2) show machinery tools; and (3) show explanation videos to the user. Recognizing the machinery was made by scanning a specific IT defined for every machine, Figure 5c for the case of lathe, and Figure 5d for the case of milling. By using IDs, the lesson markers (IT or FT used to show the different lessons for every machine) can be the same for both machines, which leads to reduce the size of the markers database. The set of all the markers used in the MAR system are depicted in Figure 5.

Objects such as specific keypads or control pads of the machinery were selected as ITs, due that they are flat objects and also have defined characteristics that can be detected by Vuforia. ITs were stored in a local database. After that, a comparison is made with each camera frame until an IT marker is recognized. At the end, its correspondent augmented model is associated. Moreover, markers were used to show videos with lessons performed by teachers and laboratory technicians. The videos are shown in two ways depending on the used device, to give a better experience and avoid losing contact with the real world. For example, the videos are shown in full screen, and inside the marker area when the marker is visible in the device camera for the case of ORA-1 AR glasses. For the case of VR-PRO AR HMD, a full screen video is not used due it will block all the contact with the real world. The videos are displayed with a frame rate of 30 frames per second on top of marker.

Blender Software. The main purpose of the software was to design each one of the virtual objects used for both milling and lathe lessons. Around 40 virtual elements such as machinery pieces and tools were created to augment the real world when the

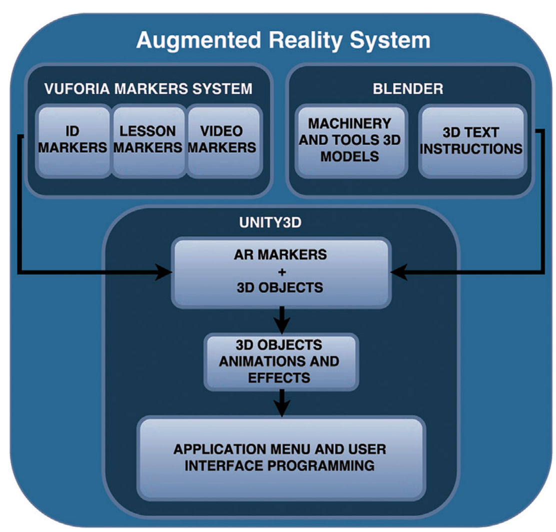


Figure 3 The software system architecture. [Color figure can be viewed at wileyonlinelibrary.com]

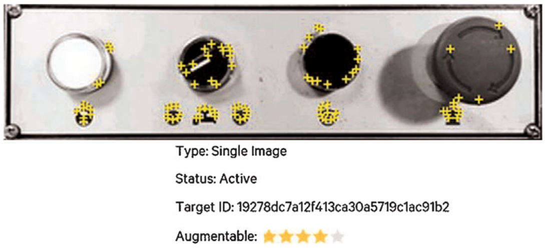


Figure 4 Features detected and rate of an IT. [Color figure can be viewed at wileyonlinelibrary.com]

markers are pointed with the camera of the hardware device. To design the objects, it was required to use 2D and 3D operations to basic geometric figures to reconstruct the real objects. One of the advantages of using Blender was that it allows us to easily add different materials to the final objects to add them a more realistic appearance for the user. After modeling the real objects, we got a *.blend file which was added to Unity 3D library and to use this objects later to build the lessons. The same software was used to create 3D text instructions.

Unity 3D. The main purpose and advantage of using Unity 3D was its integration with Vuforia and Blender. Unity allows to integrate Vuforia markers and *.blend files generated from Blender and set their position, rotation, and size regard to the markers. Also, each of the objects can be programmed separately using C++ scripts to respond to user's actions, such as clicking a button or selecting lessons from the graphical user interface (GUI) interface. For creating the interface, Unity provides 2D objects such as buttons, layers, text, among others. This 2D objects are placed on the first layer of the camera screen to show the menus of the application, and marker's virtual objects are placed on the second layer to never occlude the menu buttons.

In addition, Unity 3D includes other features such as a simple interface to record the translation and rotation of objects over time to create animations. In each lesson, animations were used to explain the user the machinery tools movements. For example, how to place a tool, how to screw, display rotation direction, among others. Moreover, sound effects, light effects, scripts programming, among other features were used to create the system interface and give the user a more realistic experience.

Video Integration

To create the video algorithm, the first step was to add a plane on the top of the video marker. Then, the images were extracted from the video (by using Matlab 2010) at a rate of 30 frames per second. After that, the first image of the video was added to the plane. Also, the audio was extracted from the video. When the user pointed to the video marker, he can start the video by tapping the plane object programmed to respond to the user interaction.

The script associated with the plane, changes the texture of the plane at a rate of 30 frames per second and reproduced the audio file to simulate a real video file. The algorithm seems to work fine; however, only short videos in low resolution were added due that the number of images added to the project increased the application size in a big way. Video algorithm must be improved to allow the system to include long duration videos with a better resolution.

Application Flow

At the beginning, the user needs to run the application and point the camera of the device to the main menu marker, which is an augmented menu as it is shown in Figure 5a. The menu displays two options: (1) start the application and (2) get system help information. By selecting the start button, the user can proceed to scan the marker ID corresponding to the machine that will be used, by pointing the device camera to the marker. On the other hand, by selecting the help option, the user will receive all the instructions to use the application. After scanning the ID, the corresponding machine tutorial (lathe or milling) starts and the lesson markers are activated. By pointing the camera of the device to one of the

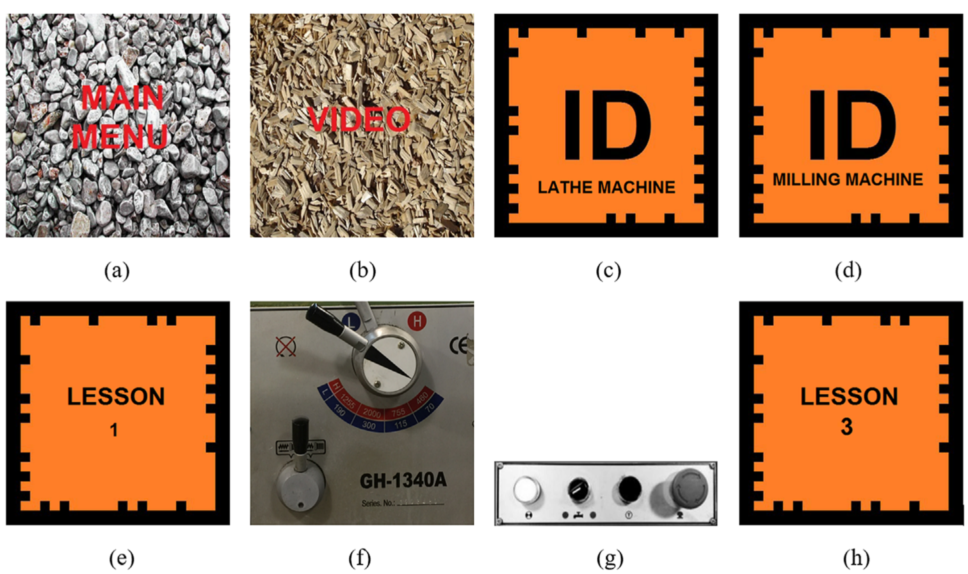


Figure 5 Markers used in the MAR system. (a) IT: Menu. (b) IT: Video. (c) FM: Lathe ID. (d) FM: Milling ID. (e) FM: Lesson 1. (f) IT: Lesson 2. (g) IT: Lesson 2. (h) FM: Lesson 3. [Color figure can be viewed at wileyonlinelibrary.com]

lessons markers (Fig. 5e–h), the related multimedia content is displayed to the user. An example of a task composed by four stages is shown in Figure 6.

Animations, 3D models, and instructions were used to explain to the user how to setup pieces, tools, and machines. The videos (Fig. 5b) were used to explain very complex tasks, or tasks where markers could not be placed, for example low places of the machine or recurrent moving parts. The complete flow diagram of the MAR system is shown in Figure 7.

All the lessons presented in the system are shown in Table 3. Due to the big implementation time, some virtual elements were not included for milling tutorial. All the elements presented were introduced in a GUI, where the users can interact with the whole system. The application can run on devices with Android operating system 4.2.1 and up.

EXPERIMENT SETUP

This section is devoted to explain the experiences performed for the testing stage of the developed MAR system. A total of 16 persons randomly selected at UACJ manufacturing laboratory participated in the study. The group was composed by students enrolled in mechatronics engineering, with an average age of 25 years. Although the main interest of the system is on students, school teachers and laboratory technicians were also included in the group. The experiments were performed to measure and asses the acceptance and performance, as an alternative learning tool, of the "MAR manufacturing tutor."

An introduction to AR and the basic operation of the MAR system was offered to the group, and immediately each person had the opportunity to test the system using one of the devices (ORA-1 AR glasses or VR-PRO). The participants were able to test each of the lessons and then answer a survey. The survey includes 10 questions about system acceptance and performance. The items of the survey applied to the participants are shown in Table 4.

It is important to mention that the system was designed for the use of only one user at the same time. This is a natural environment when a machine is manipulated. Almost always only one user utilizes the machine at a time, this is mainly due to security reasons.

EXPERIMENTAL VALIDATION AND RESULTS

The acceptance and performance of the system were measured through the survey shown in Table 4. Participants evaluated the system by answering eight questions using a Likert scale ranging from 1 to 5, where 1 means "very bad" and 5 means "very good." The survey also included question about the use of AR and one open question where the user explains the experience while using the system. Each of the eight questions in the survey evaluates one characteristic of the system. The results obtained for each question are shown in Table 5.

The percentages of response for each question are depicted in Figure 8. The diverging stacked bar chart allows to compare the participant's answers in a fast way by using a common baseline of zero. On the right side, percentages for respondents who rate the system as good are shown, and on the left side, percentages of people that rate the system as bad are displayed. It should be noted from Figure 8 that most of the characteristics of the system were rated as good or above by comparing both sides of the zero line.

In terms of percentages, and by adding the blue bars in the plot, it should be noted that 75% of the respondents rated as good/very good the experience satisfaction while using the system, the system speed and thought that the information given by the system was precise and explanatory. Moreover, 93.75% of the people

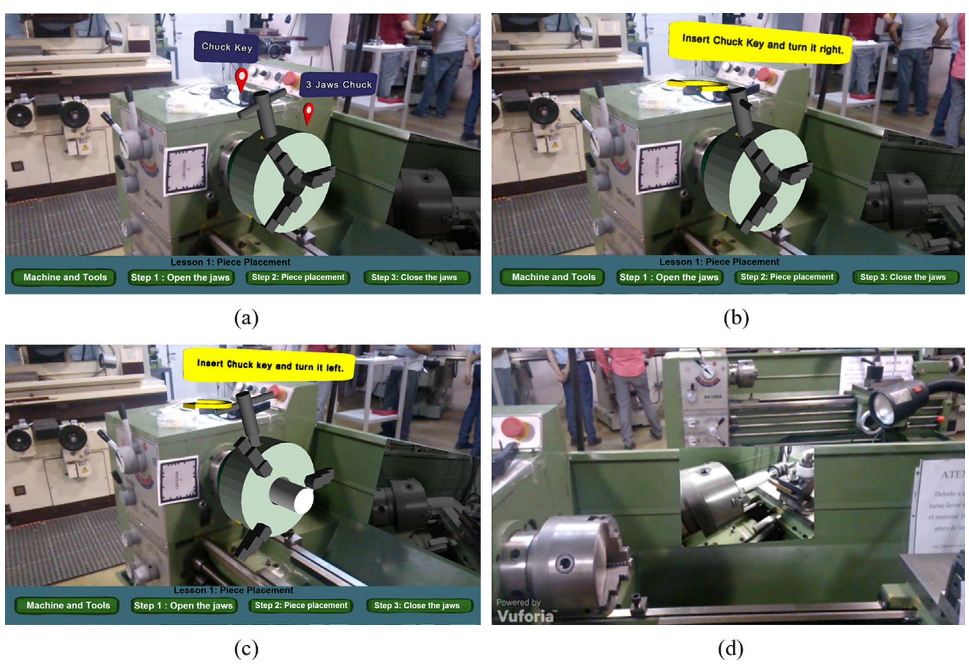


Figure 6 Example of a piece setup. (a) Labels. (b) Open chuck. (c) Piece collocation. (d) Video. Example of augmentation. [Color figure can be viewed at wileyonlinelibrary.com]

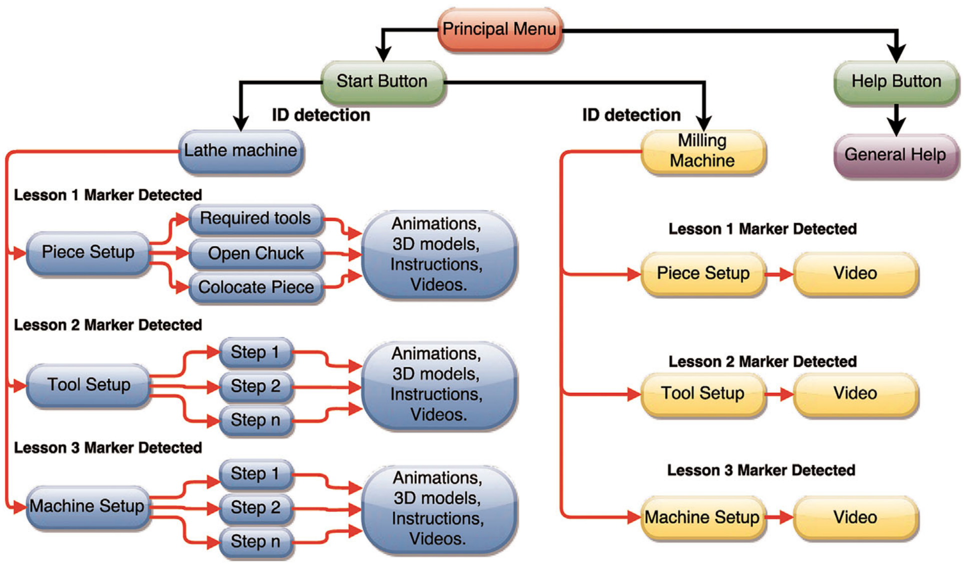


Figure 7 The flow diagram to use the MAR system. [Color figure can be viewed at wileyonlinelibrary.com]

qualifies as good the understandability of the information offered by the system, and 87.5% qualify as good the system attractiveness. Talking about system interface, only 50% of the people rated the interface as good, which means that a system enhancement stage is imperative. Finally, 81.25% said that markers detection was good as well.

Two plots were created by dividing the survey items in two groups: (1) questions 1–5 belonging to system acceptance and (2) questions 5–8 belonging to system performance. The aim of each plot is to depict a comparison of the response rates for every characteristic of the group and its related central tendency (median). For the case of system acceptance, the Figure 9 shows that central tendency was rating the system as good by obtaining a median value of 4.0. This means that people grade as good or above their experience while using the system, they though the system was precise while giving the information. The participants understood most of the information given by the system, and comment that the system lessons were explanatory and the system was attractive.

Table 3 Lessons Implemented for the MAR System

Machine	Lesson	Components
Lathe	Piece setup	Machine components and tools
		Opening the Chuck's jaws
		Collocating the piece
		Closing the jaws
	Tool setup	Necessary tools
		Tool setup
		Counterpoint setup
		Tool alignment video
	Machine setup	Machine components
		Speed adjustment
		RPM selection
Milling	Piece setup	Explaining video
	Tool setup	Explaining video
	Machine setup and start	Explaining video

On the other hand, talking about performance, it should be noted from Figure 10 that the GUI was the least rated characteristic with a median of 3.5. The users did not consider the interface and menu navigation very easy to use. However, speed and marker system were well rated by obtaining a median of 4 and 4.5, respectively, meaning that system speed was good and markers detection was fast.

In response to question number 9, it was outstanding that only 4 of 16 individuals in the experiment have known, and used an AR system, but the other 12 individuals have never heard about AR. However, most of the students that participated in the experiment were mechatronics engineering students who are in contact with technology most of the time, so it was not a problem for them to understand and feels familiarized with the use of computer vision and technological systems.

In addition, several opinions from the participants regarding to system characteristics, usability, performance, and some suggestions were obtained with question 10. It is important to mention that four persons in charge of the manufacturing laboratory including class teachers and technicians, were very interested in using the system as a teaching–learning tool. Some of the opinions of the system were the following:

- "My experience was satisfactory as I have never used an AR system. Comprehension can be easier through it."
- "The system is excellent and efficient. But if follow-up is given, the system can improve to an optimal approximation."
- "It can be used as a very good teaching-learning system."
- "It is difficult to watch the screen of the device and at the same time make the machine set-up."
- "The system interface is not easy to use. It can get better by adding more menu options or voice navigation."

Discussion

Based on the results and opinions offered, it was observed that most of the students rated the system as a valuable and appealing tool to learn the basics about lathe and milling manipulation. In

Table 4 The Survey Used to Evaluate the System

Question	Evaluation scale				
	Very bad	Bad	Regular	Good	Very good
1. How satisfactory was your experience during system utilization?	1	2	3	4	5
2. Do you consider that the system shows precise information about machinery use?	1	2	3	4	5
3. Do you consider that you can understand in a better way class lessons complementing them with this kind of systems?	1	2	3	4	5
4. Do you consider that MAR systems could explain the lessons better than a user's manual?	1	2	3	4	5
5. Do you consider the system attractive?	1	2	3	4	5
6. Do you consider it an intuitive system (easy to use)?	1	2	3	4	5
7. How good was the system performance?	1	2	3	4	5
8. How good was the marker detection performance?	1	2	3	4	5
9. Have you ever used a mobile augmented reality system?	Yes or No				
10. Describe your experience while using the system.	Open answer				

addition, students mentioned that system performance was good, and offered suggestions for further improvement. Following, a brief discussion of the benefits and drawbacks detected when using the system is offered.

First of all, the system could be a potential teaching–learning tool, when it will be used in everyday laboratory scenario; because the system offers an innovative way of presenting the learning contents to undergraduate students. The results showed the robustness of the system related to markers detection, tracking, and object recognition. Moreover, the system represents a real possibility to expand the machinery handling support offered by the instructor.

Regards to computer vision techniques used, it should be important to mention that the system was robust to work on a non-controlled light environment, and with the real poor conditions presented in the manufacturing laboratory such as several individuals working around, a number of the machine parts are dirty, the existence of a lot of noise, among others.

Also, it will be important to note that AR provides a combination of real and virtual environments that is almost impossible with the use of other technologies. AR can engage, stimulate, and motivate students to explore materials from different angles. AR can help students to take control of their learning, and can motivate the collaboration between students and instructors.

On the other hand, several drawbacks and limitations of the system were detected after results analysis, such as implications in the sight of people when using both kind of displays. This problem was lesser when user observes through stereoscopic display such as VR-PRO, and increases when observes through monoscopic display such as ORA-1. With the use of ORA-1 a similar scenario to a desktop system was provided, therefore, the typical visual fatigue could be presented when using the system in large periods of time. Also, the short viewing distance, the short display size, and the motion perception were involved in human eye fatigue. On the other hand, when using VR-PRO, slightly different images were presented to the two eyes, therefore, problems such as vergence (simultaneous movement of both eyes in opposite directions), and dissociation of accommodation (eyes changes optical power to maintain the focus of an object) were presented causing observing blurred images.

Table 5 Ratings Given by the Participants of the Study

System evaluation response rate	Very bad	Bad	Regular	Good	Very good
Q1 Satisfactory	0	0	4	8	4
Q2 Precise	0	1	3	6	6
Q3 Understandable	0	0	1	7	8
Q4 Explanatory	0	1	3	8	4
Q5 Attractive	0	0	2	6	8
Q6 Interface	0	2	6	7	1
Q7 Speed	0	1	3	6	6
Q8 Marker system	0	1	2	5	8

At the end of the experiment which lasted 10 min (time used only to test the system, and not the time used to fulfill the survey), some students showed eyestrain, especially those students who usually used lenses. Also, students who used ORA-1 glasses show more visual tiredness than those who used VR-PRO. The students mentioned that they started to have problems with focusing after a short period of time while using ORA-1. However, the time that every person was able to use the glasses depended on their eyes conditions, therefore, it is not recommended to use the displaying devices for an extended time period. As in the experiment mentioned in Ref. [46], almost 10% of individuals using HMDs experience high eye strain that they gave up the experiment. Also, the use of HMDs in long time periods may cause, in long term, central vision loss, tunnel vision, among others. Finally, due to the short time used for experimentation, any students reported problems of strain, nausea, dizziness, and headaches which are typical when using glasses or HMDs.

Regards to student collaboration, we noticed that it will be difficult for two or more students manipulating the system at the same time. This is mainly because markers have to be pointed from a minimum distance, and angle to be detected, and display objects correctly. Depending on the size of the markers and the camera resolution, the detection rate changed. For instance, there were some problems detecting markers using VR-PRO because the camera resolution was lower than ORA-1, hence, ORA-1 was always rated higher by students.

Another limitation of the system is the inability to add lessons in an easy way, this is because knowledge about programming, design, and AR is required to design full lessons. Moreover, teachers will have to spend long time working with design and implementation of AR content. Another limitation to implement the system in the school laboratories is the cost of the

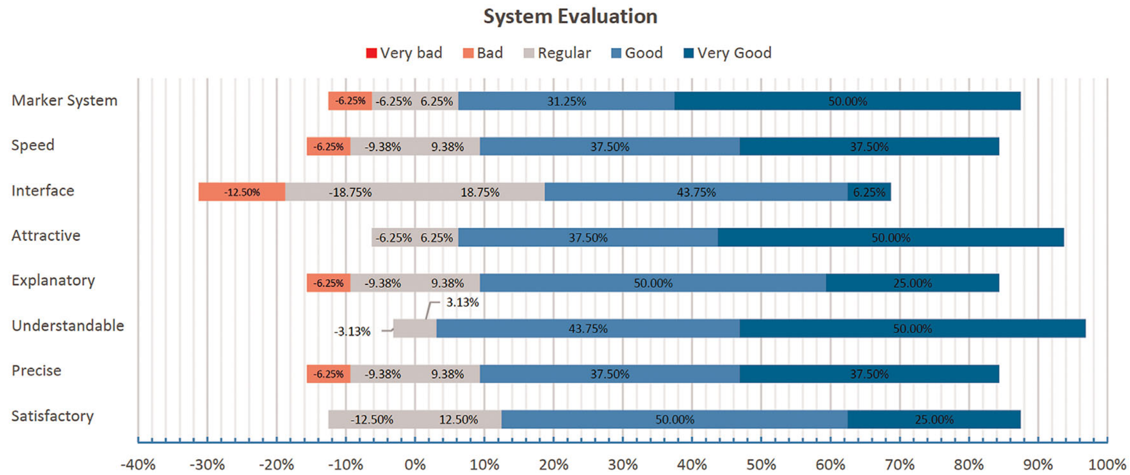


Figure 8 Survey percentage results. [Color figure can be viewed at wileyonlinelibrary.com]

AR equipment. However, introducing the application in smartphones could be a possibility to frequently use AR in the university. Obviously, this includes the restriction that at least one hand of the student will be busy manipulating the device.

Finally, we detected that students can put a lot of attention in the AR system and ignore important parts of the experience (attention tunneling effect). Also, in several occasions (which were less), students can rate the AR system more difficult to use than the classical teaching alternative.

Comparison With Other Works

As was presented in Tables 1 and 2, a number of AR works have been published in the literature over the past 5 years (2011–2016), either to support scholar, or non-scholar procedures. Typically, in scholar environments the risk of damaging an expensive equipment or dangers associated with its use, occur rarely, with the exception of works such as the presented in this research. However, in non-scholar environments, almost always a hazardous procedure is involved, and the cost of making a mistake is high. In contrast to 32 approaches discussed, the proposed technique focused on support the basic tasks to use the machinery in a manufacturing laboratory, which has not been ever presented in the literature. In fact, no studies were found covered the main features offered in our research, such as the use of MAR to carry out machining setup in a scholar environment that can be extended to non-scholar scenarios, the use of two kinds of different hardware devices (optical see-through such as ORA-1, and video see-through such as VR-Pro), the presentation of monoscopic and stereoscopic images, the participation of mechatronics

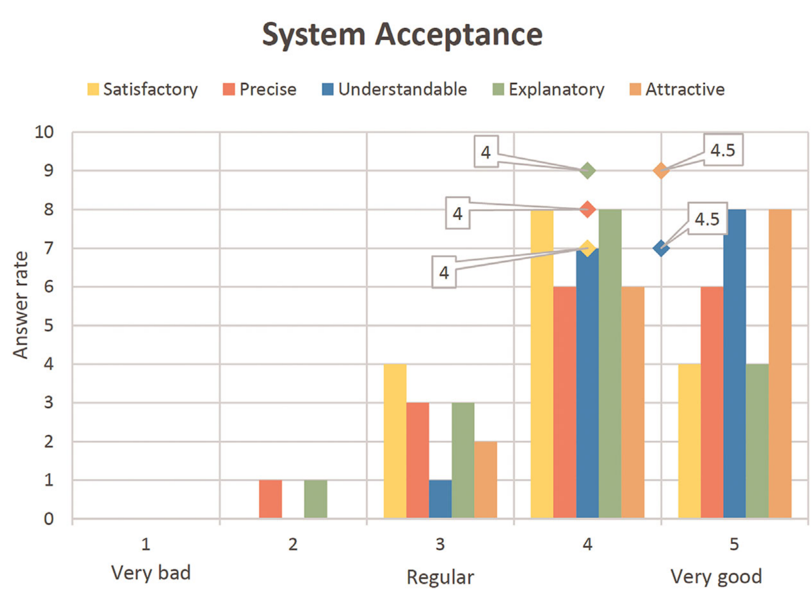


Figure 9 MAR system acceptance results. [Color figure can be viewed at wileyonlinelibrary.com]

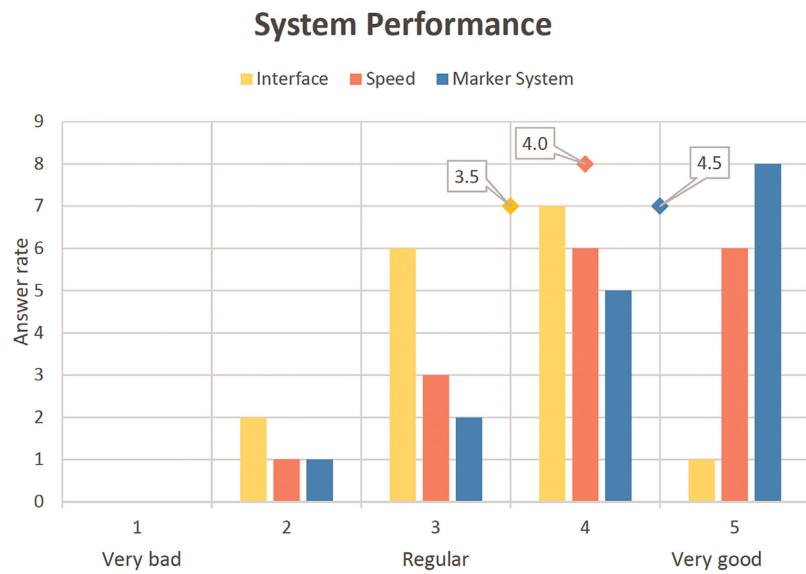


Figure 10 MAR system performance results. [Color figure can be viewed at wileyonlinelibrary.com]

students, the use of augmentation procedures based on 3D models and videos, the discussion about the details of the architecture, among others.

Regarding the level of participants, it should be noted that eight works report its experiments with undergraduates, this allows more control of the experiments due to this type of students are familiarized with the use of technological devices, in contrast to kindergarten or elementary students. However, with respect to non-scholar environments, the users typically were middle aged people ranging from 45 to 65 years, which typically refuse to use the technology. On the other hand, the sample size used for our experiment could be a drawback. As can be observed in scholar environments, the sample is typically greater than 30 participants, moreover, in some works exceeds 100 participants. The sample size in non-scholar environments is almost always smaller than 15 participants. However, using a small sample size allows us to carefully observe all the reactions of the students, and determine the drawbacks and advantages of the system discussed in Discussion section.

Besides, it should be noted that only eight of the works discussed were implemented for collaborative environments, which is a desirable feature in today scholar/training procedures. However, our proposal does not include that feature, because in manufacturing operations, only one individual interacts with the machine due to safety reasons. This does not imply that the collaborative feature cannot be easily added to our proposal. Regarding to the learning subject, it should be noted that in non-scholar environments, the applications were broadly classified in military, marine, medicine, aeronautic, and driving safety. Whereas in scholar environments, the applications were mainly focused in basic sciences such as history, chemistry, and mathematics. Hence, none of the works focused on manufacturing operations. Finally, it should be noted that all the works, including our proposal, reported the use of AR as valuable tool to display the particular operation augmented with interactive virtual models, which offers a different and engaging way of interaction than ever a user had experimented.

CONCLUSIONS

The development of a MAR system for supporting risk machinery operation at scholar manufacturing environments, and its corresponding evaluation about acceptance and performance was presented. The vision-based MAR system, can be installed in any device with Android operating system 4.2.1 and up, after that, the app presents digital media to learners when they point the camera of the device at a specific marker located in a machine. The aim of the system was to guide unexperienced students in the use of machinery, by providing them with virtual information while handling a lathe and milling machine in a university laboratory.

Based on the survey questions answered by the participants, we observed that the system had a good performance, and also a good level of acceptance between mechatronics students, laboratory technicians, and teachers. It is important to mention that teachers were very interested in using the system as a daily teaching–learning tool, and students were excited about the system, even when most of them have never used an AR system. In addition, with the results obtained, it has been proved that AR can be a technology with great potential to impact affective and cognitive learning outcomes. However, the implementation of AR in education is still at its developing stage, therefore, more work is needed to substantiate these claims.

The study presented in this paper was the first attempt to insert AR in manufacturing labs for machinery handling. Therefore, the study can be improved in several ways. Currently, the authors are performing several improvements to the system based on participant's suggestions. After that, the system could be used as an alternative to assist the manufacturing practices in the laboratory, which are an essential part of mechatronics education. Although the particular case of manufacturing processes was presented, the core of the system can be transferred/reused to tackle another kind of risk operations.

Furthermore, the authors are working with the creation of an ease of use authoring tool for creating AR. The preliminary results were reported in Ref. [47]. The authoring tool provides a visual solution for rapid AR application development. It presents to the user nodes and connection objects, and by drawing and connecting it, the interaction is defined, and the AR is created. However, the tool is still in early stages of development, due the amount of different nodes available is limited, restricting the complexity of the applications that can be created. In the future, the editor will incorporate new node definitions to extend its functionality, as well as complementary tools, to turn it into a full-fledged authoring environment.

In addition, improvements in AR glasses interaction can be added, by using speech recognition and voice navigation, instead of using the touch interface. On the other hand, the problems related to markers occlusions (when a marker is partially occluded), must be solved to offer more robustness to the system. Also, it will be interesting carry out tests in non-scholar environments, and prepare some task regarding presented knowledge and to validate the system on the base of such task. Finally, it could be desirable migrating from a marker based to a markerless AR system, in this way, augmentation can be used in difficult areas of the machinery where markers cannot be placed.

Abbreviations

AITT	augmented immersive team training
AR	augmented reality
ARL	augmented remote lab
ARLIS	augmented reality library instruction system
AROMS	augmented reality for oral and maxillofacial surgery
ARV	augmented reality vehicle
ARWILD	augmented reality wild
BARRACUDA	Bayesian assessments and real-time rider alerting and cueing for upcoming danger avoidance
CT	computerized tomography
FT	frame target
GPS	global positioning system
GUI	graphical user interface
HMD	head mounted display
HUD	head up display
HuMAR	human anatomy in mobile augmented reality
ICT	information and communication technologies
IT	image target
LPP	learning physics through play project
MAR	mobile augmented reality
MAT	motherboard assembly tutor
MMARS	marine mobile augmented reality system
MoCap	motion capture
MOUT	military operations in urban terrain
SDK	software developer kit
SSI	school scene investigators
ToSim II	tower simulators
UACJ	Universidad Autonoma de Ciudad Juarez

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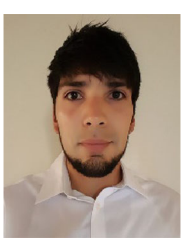
BIOGRAPHIES



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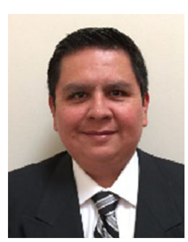

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