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Advanced Topics on Computer Vision, Control and Robotics in Mechatronics

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Chapter 3
Mobile Augmented Reality Prototype for the Manufacturing of an All-Terrain Vehicle

Erick Daniel Nava Orihuela, Osslan Osiris Vergara Villegas, Vianey Guadalupe Cruz Sánchez, Ramón Iván Barraza Castillo and Juan Gabriel López Solorzano

Abstract In this chapter, a mobile augmented reality prototype to support the process of manufacturing an all-terrain vehicle (ATV) is presented. The main goal is assisting the automotive industry in the manufacturing process regarding vehicle design and new model's introduction; in addition, the activities of training and quality control can be supported. The prototype is composed of three main stages: (a) welding inspection, (b) measuring of critical dimensions inspection, and (c) mounting of virtual accessories in the chassis. A set of 3D models and 2D objects was used as virtual elements related to augmented reality. The prototype was tested regarding usability in a real industrial stage by measuring the scope of markers' detection and by means of a survey. The results obtained demonstrated that the prototype is useful for the manufacturing of an ATV.

Keywords Mobile augmented reality · Automotive manufacturing
All-terrain vehicle · Android OS · Unity 3D · Vuforia

3.1 Introduction

Mechatronics is the science of intelligent machines, since its dissemination has been useful for the development of several industries such as manufacturing, robotics, and automotive (Bradley et al. 2015). Particularly, most complex innovations in the automotive industry are highly integrated mechatronics systems that include electronic, mechanical, computer, and control structures (Bradley 2010).

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The automotive industry is related with the design, development, manufacturing, marketing, and selling of motor vehicles and is considered as one of the main drivers for the development of a nation's industrial economy (Schoner 2004). Companies in the automotive industry are divided into two segments: car manufacturers and car parts' manufacturers. China and USA are considered the largest automobile markets worldwide, in terms of production and sales. Only in 2017, global sales of passenger cars were estimated at 77.7 million vehicles. However, the process of manufacturing a car is complex and involves many parts and electronics (Liu et al. 2015).

A particular branch in the automotive industry is the related with the manufacturing of all-terrain vehicles (ATV) introduced in the USA in 1971 (Benham et al. 2017). In this industry, aesthetic and functional changes in the design of the existed ATVs happened frequently. The changes impact not only the design but also the manufacturing of the vehicle. All the changes are subjected to rigorous quality controls and must comply with strict security measures. Therefore, the process of personal training for design and manufacture of this kind of vehicles is complex and needs to be done rapidly.

In recent years, technologies such as virtual reality (VR) and augmented reality (AR) have been used in training scenarios with promising results (Gavish et al. 2015). VR consists of a 3D computer-generated environment updated in real time that allows human interaction through various input/output devices, while AR technology refers to the inclusion of virtual elements in views of actual physical environments, in order to create a mixed reality in real time. It supplements and enhances the perceptions humans gain through their senses in the real world (Mota et al. 2017).

With the recent studies, it has been proved that AR offers competitive advantages over VR because it offers a more natural interface and enriches the reality (Gavish et al. 2015; Westefield et al. 2015). Moreover, mobile AR (MAR) attracted interest from industry and academy because it supplements the real world of a mobile user with computer-generated virtual contents (Chatzopoulos et al. 2017). In addition to the mobility offered to the user, MAR uses the sensors included in the device such as accelerometers, gyroscope, and global positioning system (GPS), which offer additional attractive features against computer-based AR.

Based on the potential offered by MAR, in this chapter, we propose the design and the construction of a MAR prototype to support the operations of manufacturing an ATV that includes welding inspection, measuring of critical dimensions and accessories mounting.

The rest of the chapter is organized as follows. In Sect. 3.2, a brief introduction to the manufacturing of ATVs is presented. In Sect. 3.3, a literature review of the works that uses AR in manufacturing processes is showed. The proposed methodology to create the MAR prototype is presented in Sect. 3.4. In Sect. 3.5, the results obtained from experiments and its correspondent discussion are shown. Finally, Sect. 3.6 presents the conclusions obtained with this research, followed by the further works.

3.2 All-Terrain Vehicles

An ATV is a four-wheel motorized transport fueled by gasoline or diesel, which is also known as a quad-bike or four-wheeler (Azman et al. 2014). As can be observed in Fig. 3.1, an ATV is composed by an engine part, an electric system, a brake system, a power terrain (engine), a transmission, a chassis, a steering system (handlebar), a seat stride, and the tires (Aras et al. 2015).

An ATV is operated by only one people, and because of large size and low pressure of its tires, it can be driven in different terrains including sand, stony ground, road, and mud (Fleming 2010). However, the use of ATVs whether for work or recreational use continues to be major contributors to fatal and serious injuries worldwide including shocks, rollovers, and falls. Therefore, the processes of design and manufacturing an ATV including quality control and safety considerations are a very important topic (Williams et al. 2014).

The chassis is the most important structure when an ATV is manufactured; it holds the engine, bodywork, and other subsystems. The structure is composed of several components made of steel alloy that are prefab by manufacturing processes such as lamination, extrusion, die cutting, and bending to obtain the required physical characteristics. After that, the components are joined (fused) in subassemblies by means of metal inert gas (MIG) welding. The correct positioning of the components to build a subassembly with the desired specifications is achieved by means of scantlings. Posteriorly, the individual subassemblies are joined by welds to finally obtain the complete structure of the chassis.

In parallel, the steel accessories of the chassis are fabricated. After that, the accessories and the chassis obtained their aesthetic features by means of a painting process. Finally, the accessories are added to the chassis structure using screws. As aforementioned, the metal mechanic manufacturing process to create the complete chassis is complex and claimant. It is very important to ensure that the complete structural system is strong, solid, and impact resistant, so that when an accident happens to avoid breakage or detachment of chassis components.

The key aspects to review by the people in charge of quality include: (1) the critical weldings to observe the importance (critical or non-critical), trajectory type,

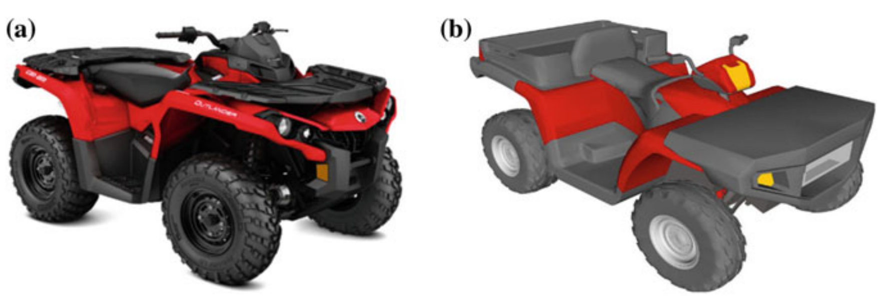


Fig. 3.1 Example of an ATV. **a** The real ATV and **b** the 3D model of an ATV

fusion, and no porosity; (2) specific dimensions, for example, the distance from one blast-hole to another, or the distance between two components; and (3) the correct mounting of the accessories to build the complete ATV structure. The measures and welding are determined by the design plans, and if they are not correct, the correspondent assembly cannot be carried out.

The difficulties encountered in the assembly lines are due to human errors or by bad weldings and out of specification dimensions, which causes that the accessories cannot be mounted properly. Therefore, it is important to create a system to support the processes of welding inspection and measure critical dimensions and accessories mounting.

3.3 Literature Review

The use of AR applications for industrial uses is increasingly common as was stated in the works of Odhental et al. (2012), Nee et al. (2012), Elia et al. (2016), Syberfeldt et al. (2017), Palmarini et al. (2018). However, in the literature, a limited number of papers have been presented which showed the ability of AR to support processes in the manufacturing industry with promising results. Following some of the papers detected in the perusal of current literature are briefly discussed.

A typical problem in operations and maintenance (O&M) practice is the collection of various types of data to locate the target equipment and facilities and to properly diagnose them at the site. In the paper of Lee and Akin (2011), an AR-based interface for improving O&M information in terms of time spent and steps taken to complete work orders was developed. The BACnet protocol was used to get sensor-derived operation data in real time from building automation system (BAS). A series of experiments was conducted to quantitatively measure improvement in equipment O&M fieldwork efficiency by using a software prototype of the application. Two research and educational facilities and their heating, ventilating, and air conditioning (HVAC) systems were used for tests: a ventilation system and a mullion system in one facility, and an air-handling unit (AHU) in the other facility. The verification tests consist of retrieval of operation data from HVAC systems in real time and superimposition of the 3D model of the mullion system. The results obtained show that with the proposal the subjects saved, on average, 51% of time spent at the task when they located target areas, and 8% of the time at task while obtaining sensor-based performance data from BAS.

The use of robots in the processes of a manufacturing plant is increasingly common for handling tasks, for example, in assembly operations. The paper of Fang et al. (2012) developed an AR system (RPAR-II) to facilitate robot programming and trajectory planning considering the dynamic constraints of the robots. The users are able to preview the simulated motion, perceive any possible overshoot, and resolve discrepancies between the planned and simulated paths prior to the execution of a task. A virtual robot model, which is a replicate of a real robot, was used to perform and simulate the task planning process. A hand-held device, which is attached with a marker-cube, was used for human–robot interaction in the task and path planning processes. By means of a pick-and-place simulation, the performance of the trajectory planning and the fitness of the selection of the robot controller model/parameters in the robot programming process can be visually evaluated.

Because maintenance and assembly tasks can be very complex, training technicians to efficiently perform new skills is challenging. Therefore, the paper of Webel et al. (2013), presented an AR platform that directly links instructions on how to perform the service tasks to the machine parts that require processing. The platform allows showing in real time the step-by-step instructions to realize a specific task and, as a result, accelerating the technician's acquisition of new maintenance procedures. The experimental task was composed of 25 steps grouped into six subtasks to assemble an electro-mechanical actuator. Twenty technicians with at least 2 years of experience on field assembly/disassembly operations served as participants. The sample was divided into two groups of ten participants: the control group executes the task by watching videos and the second group using AR. The execution time of the task was enhanced in 5%, and the affectivity rate obtained was 77% using AR.

Maintenance is crucial in prolonging the serviceability and lifespan of the equipment. The work of Ong and Zhu (2013) presented an AR real-time equipment maintenance system including: (1) context-aware information to the technicians, (2) a mobile user interface that allows the technicians to interact with the virtual information rendered, (3) a remote collaboration mechanism that allows the expert to create and provide AR-based visual instructions to the technicians, and (4) a bidirectional content creation tool that allows dynamic AR maintenance contents creation offline and on-site. The system was used to assist the machinist and maintenance engineers in conducting preventive and corrective computer maintenance activities. From the studies conducted, it was found that providing context-aware information to the technicians using AR technology can facilitate the maintenance workflow. In addition, allowing the remote expert to create and use AR-based visual interactions effectively enables more efficient and less error prone remote maintenance.

For decades, machine tools have been widely used to manufacture parts for various industries including automotive, electronics and aerospace. Due to the pursuit of mechanical precision and structural rigidity, one of the main drawbacks in machine tool industry is the use of traditional media, such as video and direct mail advertising instructional materials. In order to solve this, the machine tools augmented reality (MTAR) system for viewing machine tools from different angles with 3D demonstrations was developed by Hsien et al. (2014). Based on markerless AR, the system can integrate real and virtual spaces using different platforms, such as a webcam, smartphone, or tablet device without extra power or demonstration space. The clients can project the virtual information to a real field and learn the features of the machine form different angles and aspects. The technology also provides information for area planning.

AR is a technology that has contributed to the development of the Industry 4.0 due to its flexibility and adaptability to the production systems. The works of Gattullo et al. (2015a, b) designed a solution to the crucial problem of legibility of text observed through a head-worn display (HWD) in industrial environments. Legibility depends mainly on background, display technology (see-through optical or video HWDs), and text style (plain text, outline, or billboard). Furthermore, there are constraints to consider in industrial environments, such as standard color-coding practices and workplace lighting. The results suggest that enhancing text contrast via software, along with using the outline or billboard style, is an effective practice to improve legibility in many situations. If one text style is needed for both types of HWD, then colored billboards are effective. When color coding is not mandatory, white text and blue billboard are more effective than other styles.

The paper of Yew et al. (2016) describes an AR manufacturing system that aims to improve the information perception of the different types of workers in a manufacturing facility and to make interaction with manufacturing software natural and efficient. The traditionally paper-based and computer-based tasks are augmented to the workers' interactions in the environment. The system was distributed and modular as the different functions of CAD/CAM software are provided by individual physical or virtual objects such as CNC machines and CAD designs in the environment or by a combination of them working cooperatively. For testing purposes, a scenario following the interactions of two engineers with their AR environment was proposed obtaining good results.

AR was used in automotive industry for service training and assistance. The work of Lima et al. (2017) presented a complete markerless tracking solution to the development of AR applications for the automotive industry. The case study consists of accurate tracking of vehicle components in dynamic and sometimes noisy environments. The first scenario comprised tracking a rotating vehicle, and the second scenario involved capturing and tracking of different parts of a real Volkswagen Golf™. For both scenarios, third tasks were defined including tracking the engine part, tracking the interior from driver's seat, and tracking of the trunk (tracking from a bright into a dark environment). The proposed system allows automatic markerless model generation without the need of a CAD model, also the model covered several parts of the entire vehicle, unlike other systems that focus only on specific parts. The main positive aspect is that regular users are able to track the vehicle exterior and identify its parts.

Finally, the use of a projector-based spatial augmented reality system to highlight spot-weld locations on vehicle panels for manual welding operators was presented by Doshi et al. (2017). The goal of the work was to improve the precision and accuracy of manual spot-weld placements with the aid of visual cues in the automotive industry. Production trials were conducted, and techniques developed to analyze and validate the precision and accuracy of spot-welds both with and without the visual cues. A reduction of 52% of the standard deviation of manual spot-weld placement was observed when using AR visual cues. All welds were within the required specification, and panels evaluated in this study were used as the final product made available to consumers.

As can be observed from the literature review, most of the works use markers as the core to show the AR, only one work implemented markerless AR. None of the papers addressed the measuring of critical dimensions and mounting accessories for ATV manufacturing. However, the welding inspection for automotive purposes was addressed by the work of Doshi et al. (2017). It should be noted that the work of Doshi et al. (2017) checks the welds only in plane panels, unlike our work which checks welds even on irregular surfaces. On the other hand, none of the papers reviewed included a usability study such as the one presented in our chapter. The study is important to measure if the system complies with the initial goal and if it is ease of use.

The most observed applications focused on maintenance and training operations in different industries, including two works for automotive. It is important to note that in all the works revised the ability of AR to enhance some task is always highlighted. Motivated from the revision above, in the following section, the proposal of a methodology to create a MAR prototype to support the manufacturing of an ATV is proposed.

3.4 Proposed Methodology

The methodology for building the MAR prototype, as it is shown in Fig. 3.2, comprises five main stages: (1) selection of development tools, (2) selection and design of 3D models, (3) markers design, (4) development of the MAR application, and (5) graphical user interface (GUI) design. The individual stages of the methodology are deeply explained in the following subsections.

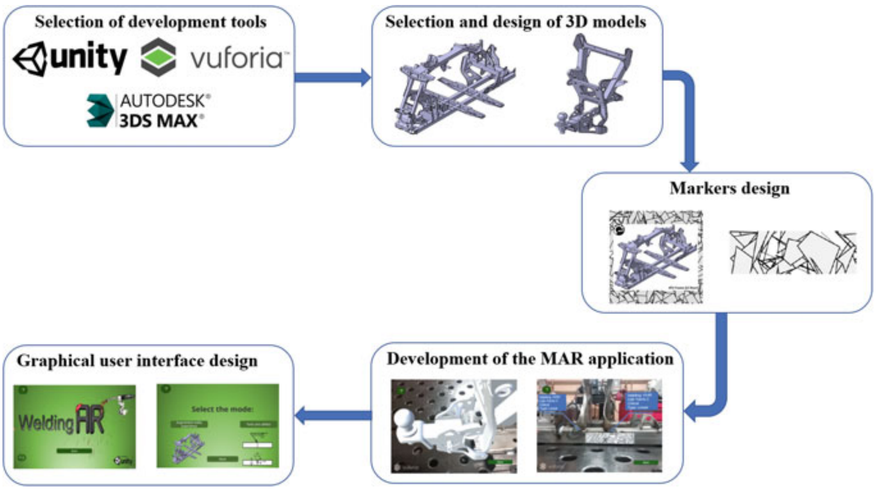


Fig. 3.2 Stages of building the MAR prototype

3.4.1 Selection of Development Tools

Three software packages were used to build the core of the MAR prototype. The selection was made by an exhaustive analysis of the commercial software for AR development. At the end, the softwares selected were Autodesk 3DS Max, Vuforia, and Unity 3D, all of them in its free or educational versions.

3DS Max is software for graphics creation and 3D modeling developed by Autodesk and contains integrating tools for 3D modeling, animation, and rendering. One of the advantages is that 3DS has an educational version that includes the same functionalities of the professional version. The software was used for the creation of all the 3D models and animations of the MAR prototype (Autodesk 2017).

Vuforia software developer kit (SDK) was selected because it is a powerful platform that contains the necessary libraries to carry out the tasks related to AR including the markers detection, recognition and tracking, and the computations for object superimposition. Nowadays, Vuforia is the world's most widely deployed AR platform (PTC Inc. 2017).

Unity is a multiplatform game engine created by Unity Technologies that offer the possibility of building 3D environments. It was selected because of the facility of having control of the content of the mobile device in a local way. In addition, the visual environment of the platform provides a transparent integration with Vuforia. The language C# was used to create script programming which includes all the logical operations of the MAR prototype Unity and includes an integrated system that allows the creation of a GUI for execution at different platforms including iPhone operating system (iOS), Android, and universal windows platform (UWP). It is compatible with 3D graphics and animations created by 3DS such as *.max, *.3ds, *.fbx, *.dae, *.obj, among others (Unity Technologies 2017).

The integration of Unity and Vuforia is explained in Fig. 3.3. The MAR application is fully designed in Unity including all the programming logic related to system navigation and 3D model's behavior. The necessary resources to create AR are taken from Vuforia that includes administration (local, remote), detection, recognition, and tracking of all the markers. Finally, the developer defines the 3D models and animations associated with each marker.

3.4.2 Selection and Design of 3D Models

Two different ATVs models known as short chassis ATV and large chassis ATV were selected as the core for 3D modeling purposes. The selection was mainly due to the associated complexity of fabrication and assembly, because both models are the most sold in the company where the MAR prototype was implemented. The short and large ATV chassis are shown in Fig. 3.4.

In addition, six different accessories, including (a) the arms of the front suspension, (b) the arms of the rear suspension, (c) the tail structure (seat support),

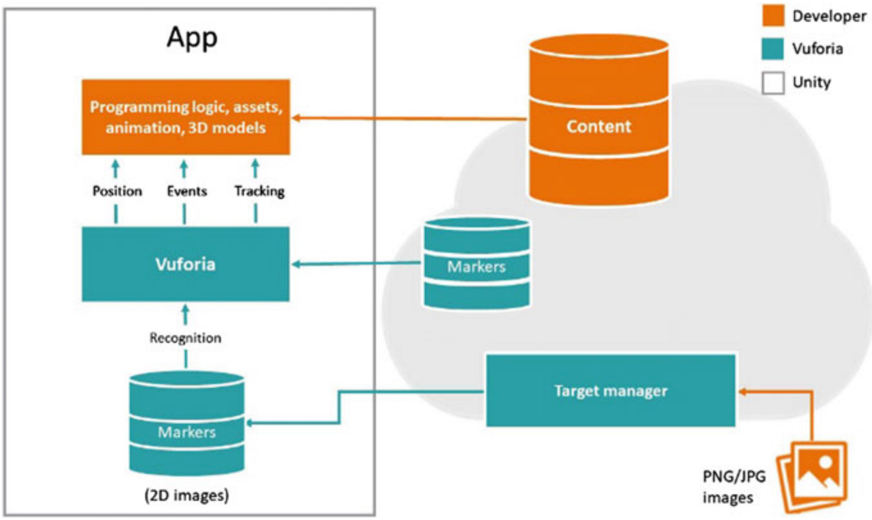


Fig. 3.3 Unity and Vuforia integration scheme to develop the MAR prototype

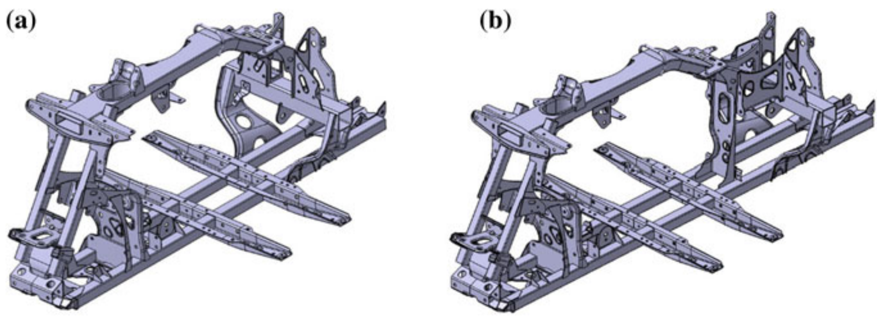


Fig. 3.4 Two versions of the ATV chassis. **a** Short, and **b** large

(d) the front bumper, (e) the rear loading structure, and (f) the steering column, were selected and 3D modeled. In the real process, the accessories are added to the chassis by means of temporal mechanical joints (screws) to shape the final ATV structure. The main idea is to make a montage of the 3D models of the accessories over the physical chassis, to observe the critical dimensions, and the weldings that will be inspected and controlled in the ATV manufacturing process. The 3D models of the six accessories selected are shown in Fig. 3.5.

The original 3D models of the chassis and the six accessories were originally designed by the manufacturing company in the computer-aided three-dimensional interactive application (CATIA) software, with a file extension *.CATPart. Therefore, the models were converted from CATPart to STEP format. Finally, STEP format was opened in 3DS Max and saved as *.max file, which is compatible with Vuforia, and

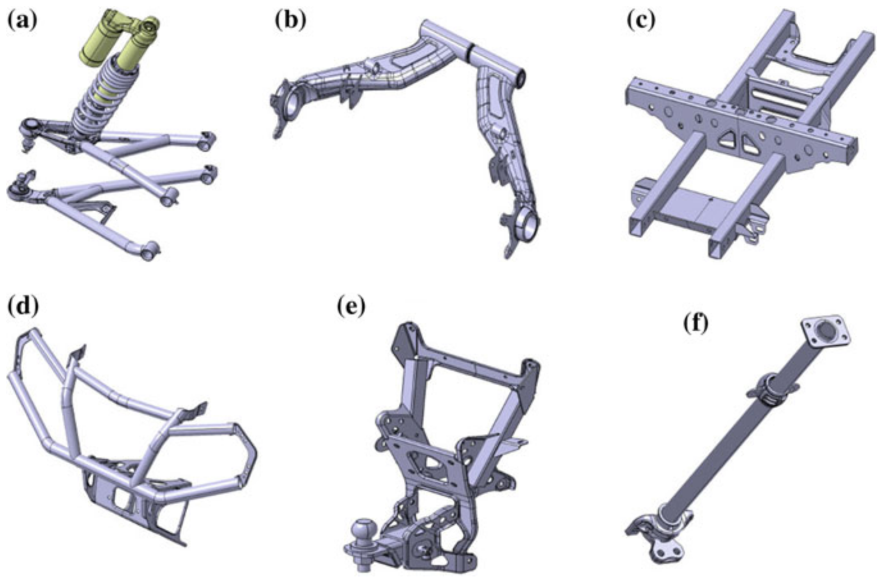


Fig. 3.5 3D models of the accessories selected. **a** The arms of the front suspension, **b** the arms of the rear suspension, **c** the tail structure, **d** the front bumper, **e** the rear loading structure, and **f** the steering column

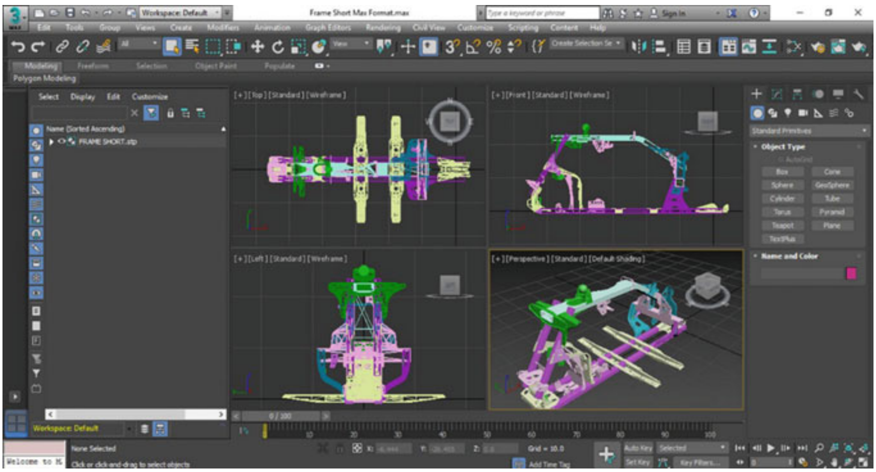


Fig. 3.6 Short chassis ATV modeled in 3DS Max

this was to allow model manipulation in the MAR prototype. The file in 3DS preserves the original model geometries and creates the necessary meshes with graphics features to be projected in an AR application. In Fig. 3.6, the model of the short chassis ATV represented in 3DS is shown.

3.4.3 Markers Design

Markers in conjunction with the programming scripts for detection and tracking are one of the main parts of the MAR prototype. The design of the markers associated with the 3D models designed was made with the AR marker generator Brosvision (2017). The generator uses an algorithm for the creation of images with predefined patterns composed of lines, triangles, and rectangles. A unique image is created randomly in full color or in gray scale.

In this stage, nine markers with different sizes were created for the MAR prototype. The size of a marker was defined in accordance with the physical space which will be located. The first two markers named Short and Max were associated with the two chassis sizes and allow to virtually observe the particular size of the chassis (short or large) as shown in Fig. 3.7.

The seven remaining markers were associated with the six selected accessories mentioned in Sect. 3.4.2 and will be mounted in the real chassis to execute the superimposition of the associated 3D models. It is important to mention that in the experimentation process, it was detected that for the case of the arms of the front suspension, the use of only one marker was not sufficient to observe the entire details. Therefore, an additional marker was created; one was used on left and the other on right side of the ATV, obtaining the total quantity of seven. The 3D model of the arms of the front suspension associated with the additional marker is just a mirror of the original ones. The set of seven markers associated with accessories are shown in Fig. 3.8.

It should be noted that markers have a scale of 1:2 and with the adequate proportion to be collocated in strategic parts of the chassis. The markers shown in Fig. 3.8a, b will be located at left and right lower tubes of the frontal suspension,

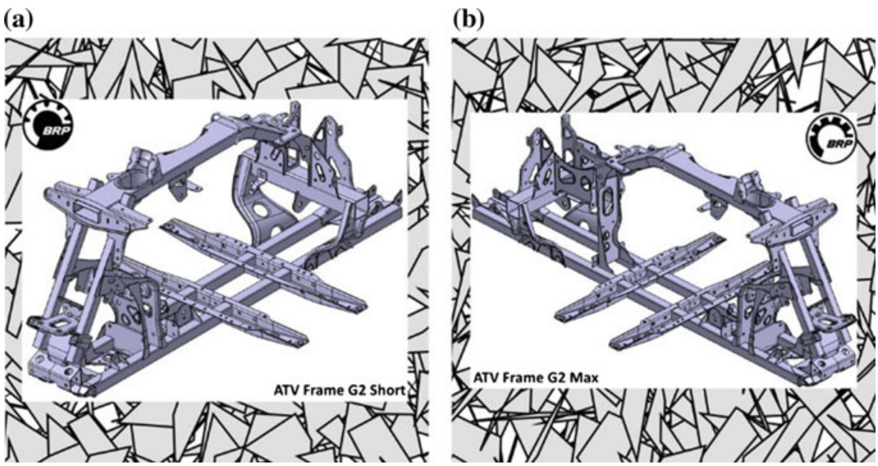


Fig. 3.7 Markers associated with ATV chassis. **a** Short, and **b** Max

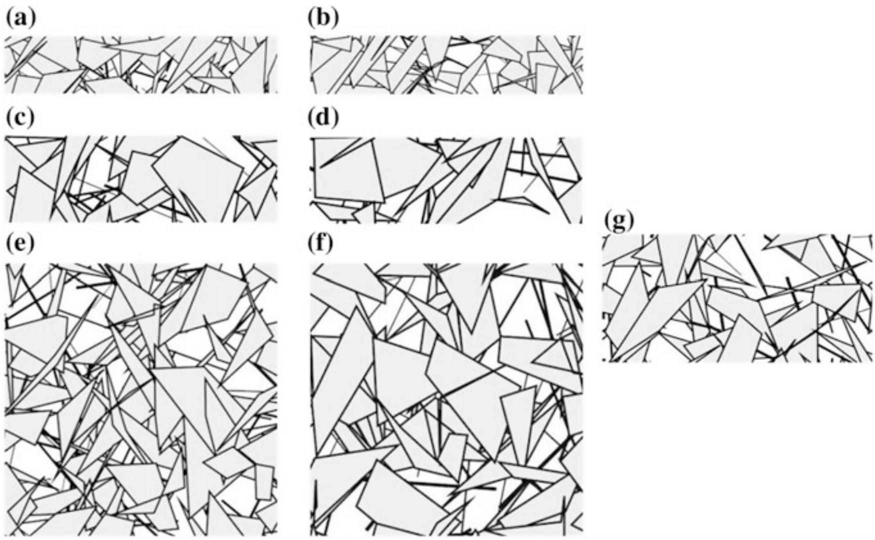


Fig. 3.8 Seven markers. **a** Front_susp_left, **b** Front_susp_right, **c** Rear_arm_suspension, **d** Rear_structure, **e** Steering_column, **f** Tail_structure, and **g** Front_bumper

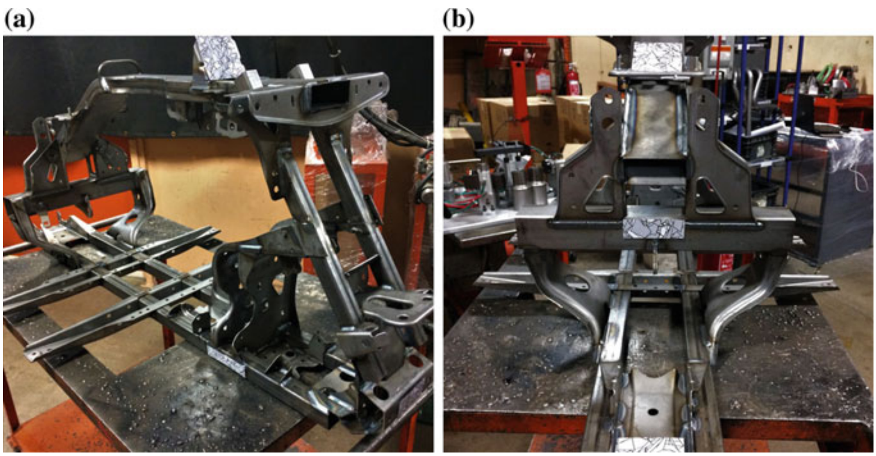


Fig. 3.9 Location of the markers in a short ATV. **a** Front section, and **b** rear section

respectively; marker shown in Fig. 3.8c will be located at the support tube of the rear suspension; marker shown in Fig. 3.8d will be located at the end of the chassis; marker shown in Fig. 3.8e will be located at the steering column bracket; marker shown in Fig. 3.8f will be located at the upper chassis beam; marker shown in Fig. 3.8g will be located at the front support. The physical location of the markers in a short chassis ATV can be observed in Fig. 3.9.

3.4.4 Development of the MAR Application

In this stage, the MAR application was developed and it is important to note that Android operating system (OS) was selected for deployment. In the first step, it is necessary to import the markers created with Brosvision to Vuforia by means of the *target manager*. To do this, a database where the markers will be stored was created. The store location can be remotely (cloud) or directly in the mobile device; for this chapter and because of facility, the last one was selected. After that, the markers were added to the database in joint photographic experts group (JPEG) format.

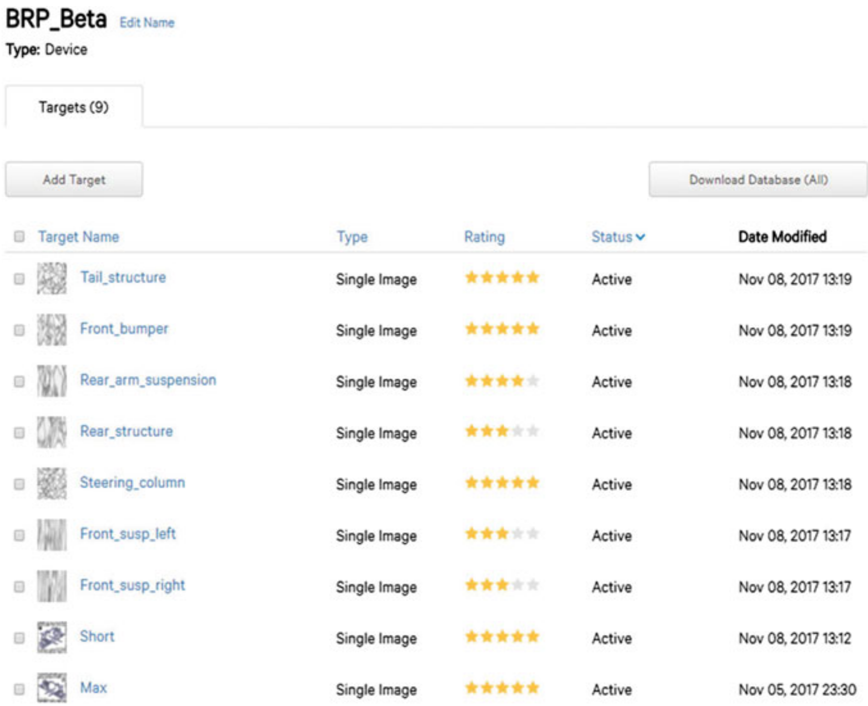
Once the database was created, each marker was subjected to an evaluation performed by Vuforia to measure the ability of detection and tracking. Vuforia uses a set of algorithms to detect and track the features that are present in an image (marker) recognizing them by comparing these features against a local database. A star rating is assigned for each image that is uploaded to the system. The star rating reflects how well the image can be detected and tracked, and can vary among 0–5. The higher rating of an image target, the stronger the detection and tracking ability it contains. A rating of zero explains that a target would not be tracked at all, while an image given a rating of 5 would be easily tracked by the AR system. The developers recommend to only using image targets that result in 3 stars an above. The rating of stars obtained for each of the nine markers used in the MAR prototype is shown in Fig. 3.10.

It should be noted from Fig. 3.10 that all the markers used in the MAR prototype obtained at least a rating of three stars, which means that are appropriate for AR purposes. In addition, every single marker was analyzed in a detailed way to observe the set of traceable points (fingerprints) as it is shown in Fig. 3.11.

After the process of marker rating, the creation of AR scenes is carried out using the AR camera prefab offered by Vuforia. The camera was included by dragging it toward the utilities tree. The configuration of the AR camera includes the license and the definition of the maximum number of markers to track and detect.

In a similar way than AR camera, the markers must be added to the utilities tree. In this part, the database that contains the markers was selected, and the respective markers to detect were defined. At this time, a Unity scene is ready and able to detect and track the markers and display the related 3D models. The 3D models also must be imported by dragging it from its location in a local directory to Unity interface. The models can be observed in the assets menu. Afterward, each model was associated with a particular marker by a dragging action similar to the previously explained.

Once that the main AR functionality was explained, the three experiences related to welding inspection, measuring of critical dimensions, and accessories mounting were developed.



Target Name	Type	Rating	Status	Date Modified
Tail_structure	Single Image	★★★★★	Active	Nov 08, 2017 13:19
Front_bumper	Single Image	★★★★★	Active	Nov 08, 2017 13:19
Rear_arm_suspension	Single Image	★★★★☆	Active	Nov 08, 2017 13:18
Rear_structure	Single Image	★★★☆☆	Active	Nov 08, 2017 13:18
Steering_column	Single Image	★★★★★	Active	Nov 08, 2017 13:18
Front_susp_left	Single Image	★★★☆☆	Active	Nov 08, 2017 13:17
Front_susp_right	Single Image	★★★☆☆	Active	Nov 08, 2017 13:17
Short	Single Image	★★★★★	Active	Nov 08, 2017 13:12
Max	Single Image	★★★★★	Active	Nov 05, 2017 23:30

Fig. 3.10 Rating of each marker obtained by Vuforia

3.4.4.1 Welding Inspection

Quality control in the manufacturing of an ATV is very important to ensure the vehicle safety. One of the most crucial stages consists on to verify the welding features against the specifications defined by the quality department. In other words, the minimum requirements that a weld must comply are established and checked.

The welding inspection AR scene contains two 2D components to show the information regarding a particular weld. The first component displays information inside a square related to the weld number assigned by the metallurgy department, the location of the workstation (cell) where the weld was made, the importance of the weld (critical or non-critical), and the weld trajectory type (linear, circular, oval). The second component consists of predefined virtual arrows that are included to the AR scene to indicate the welds that are inspected. An example of the final scene for welding inspection at different points of the ATV chassis is shown in Fig. 3.12. As can be observed, the camera of the mobile device is pointed out in front of one of the seven markers, and the information regarding weldings in that particular locations superimposed inside the real scene, generating the AR.

Fig. 3.11 Fingerprints obtained by Vuforia for short marker

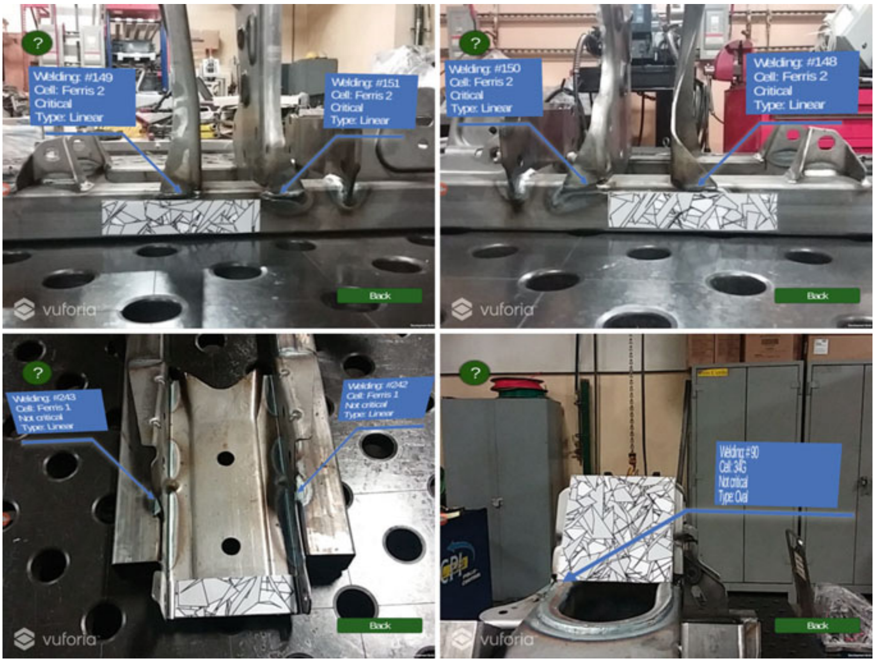


Fig. 3.12 Example of the AR scenes for welding inspection

3.4.4.2 Measuring Critical Dimensions

The possibility of reviewing the product dimensions with respect to the manufacturing plans is an important activity for the quality control and safety department. The chassis is the base component where all the accessories of the ATV will be mounted and assembled. Therefore, if the dimensions of the chassis are not according to the manufacturing plans, it cannot be assembled with other pieces.

Currently, the revision of critical dimensions and its correspondent comparison with the nominal value is carried out at the end of the production process using gauges. In addition, specialized machines such as coordinate measuring machine (CMM) are used. However, it is not easy to see full-scale measures with gauges, and the time taken by CMM to offer results of measures is quite long.

The AR tool for measuring critical dimensions offers a guide to check the measures that impact the quality of a product. In the final prototype, the dimensions from one component to another, dimensions of a manufacturing process, and dimensions from individual components were included. Also, the tool can serve for fast training of people that labor in the manufacturing of a product. In a similar way to welding inspection, 2D components for displaying information and arrows were inserted into the scene. An example of the result obtained with the measuring of the critical dimensions tool is shown in Fig. 3.13. It should be noted that information

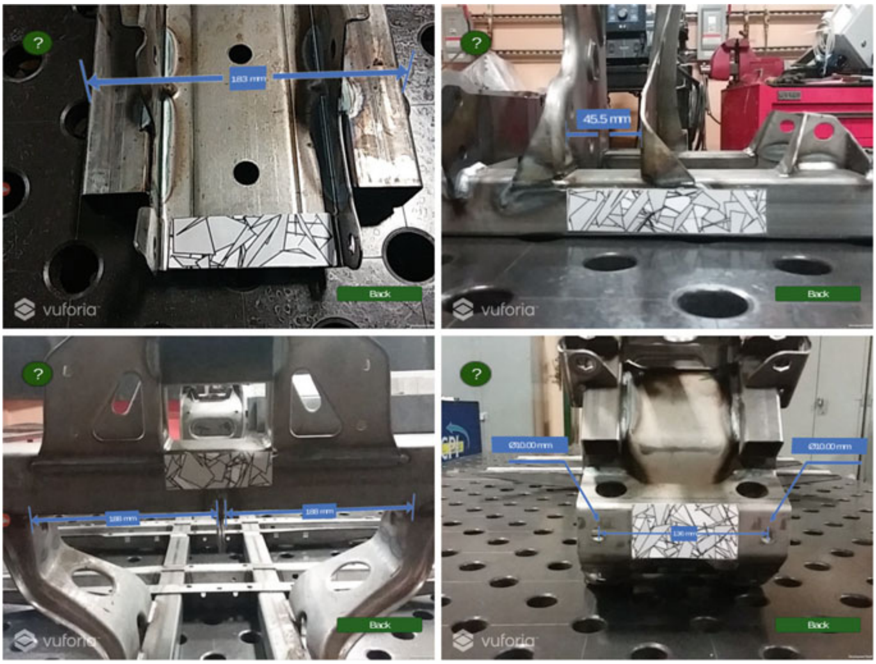


Fig. 3.13 Example of the AR scenes for measuring critical dimensions

related to a particular dimension is displayed when the camera of the mobile device is pointed out to one of the seven markers.

3.4.4.3 Accessories Mounting

The main goal of this stage is creating an AR experience to show the real place in the chassis where the accessories will be mounted. The seven markers of the accessories were placed in the chassis structure corresponding to the real location of a particular component. This tool is very important for helping in the process of training people that in the future it will construct the ATV. In this stage, unlike welding inspection and measuring of critical dimensions where only boxes and arrows were used, the transformation properties of the virtual 3D models inserted in the scene must be adjusted to determine the proper position and scale according to the size of the real accessories. The good determination of the transformation properties inside a Unity scene helps the final perspective observed by the user when the application is running on the mobile device.

The transformation properties obtained for each 3D model are shown in Table 3.1. The values obtained include the position in *X*-, *Y*-, and *Z*-axis, with the respective values in scale and orientation.

Table 3.1 Transformation properties of the 3D models

3D model	Property	*X*	*Y*	*Z*
Tail_structure	Position	−3.7	−5	0
	Rotation	−90	0	0
	Scale	0.27	0.27	0.27
Front_bumper	Position	0	−13.5	−0.4
	Rotation	0	0	90
	Scale	0.27	0.27	0.27
Rear_structure	Position	0	0	1
	Rotation	−90	−90	0
	Scale	0.27	0.27	0.27
Steering_column	Position	0	12.57	3.2
	Rotation	27.8	0	−90
	Scale	0.27	0.27	0.27
Front_susp_left	Position	0	−0.3	0.4
	Rotation	−90	0	0
	Scale	0.27	0.27	0.27
Front_susp_right	Position	0.2	0.3	0.4
	Rotation	90	0	0
	Scale	0.27	0.27	0.27
Rear_arm_suspension	Position	0	0.5	2.37
	Rotation	0	180	−90
	Scale	0.27	0.27	0.27

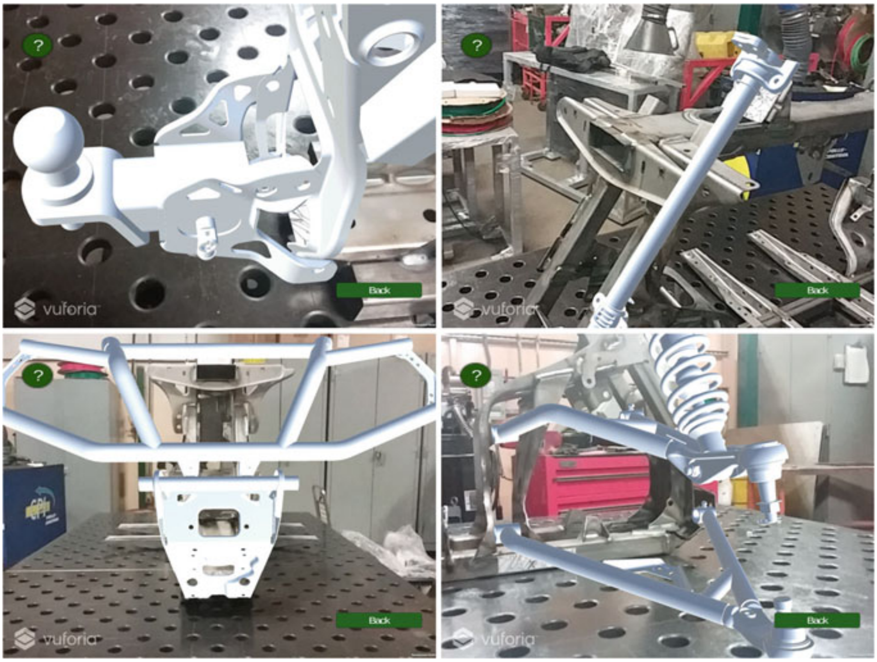


Fig. 3.14 AR scene for showing the accessories mounting

An example of the results obtained for mounting accessories AR scene is shown in Fig. 3.14.

3.4.5 GUI Design

The name of the MAR prototype is "*Welding AR*" due to the welding metalworking process for ATVs chassis manufacturing. The complete GUI structure can be observed in Fig. 3.15, and each block corresponds to one individual scene designed in Unity.

3.4.5.1 Scene Creation in Unity

The first scene created was the main screen that is displayed when the icon of the Welding AR is taped in the mobile device as shownin Fig. 3.16. The scene includes buttons to display the prototype help, for closing the application, and to start the main menu.

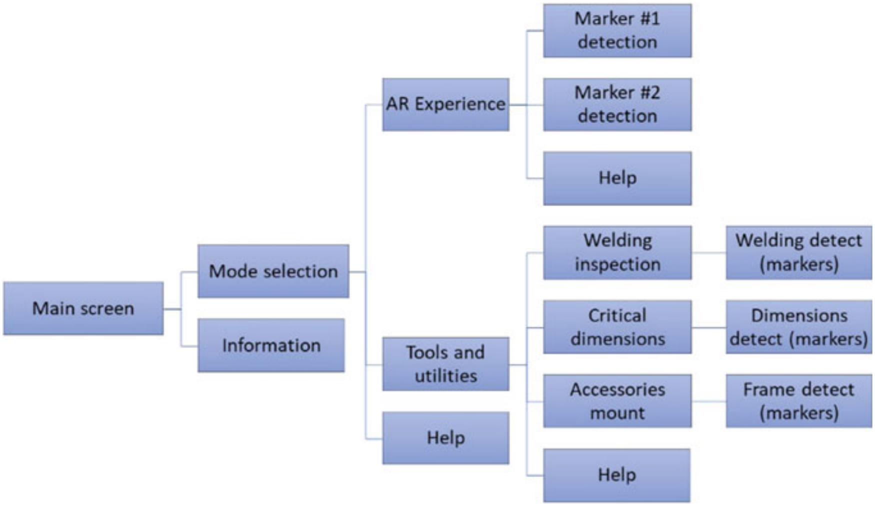


Fig. 3.15 Complete structure of the GUI

Fig. 3.16 Main scene of MAR prototype

After main scene creation, eight additional scenes were created regarding to: (1) mode selection, (2) information, (3) AR experience (observing the short and large chassis ATV), (4) tools and utilities menu, (5) Help for all the scenes, (6) welding inspection, (7) measuring critical dimensions, and (8) accessories mounting. All the scenes include buttons to follow the flow of the application and to return to the previous scene. Figure 3.17 shows the scenes of mode selection and tools and utilities.

Figure 3.18 shows the flow diagram to understand the function of the prototype regarding AR experience. The diagram was used in the MAR prototype for welding inspection, measuring critical dimensions, and accessories mounting.

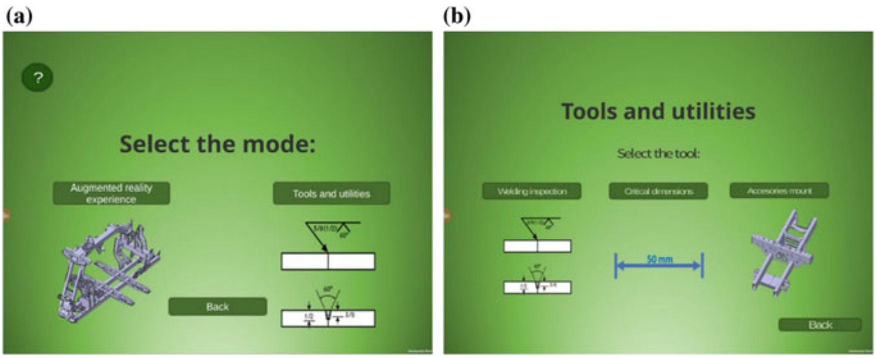
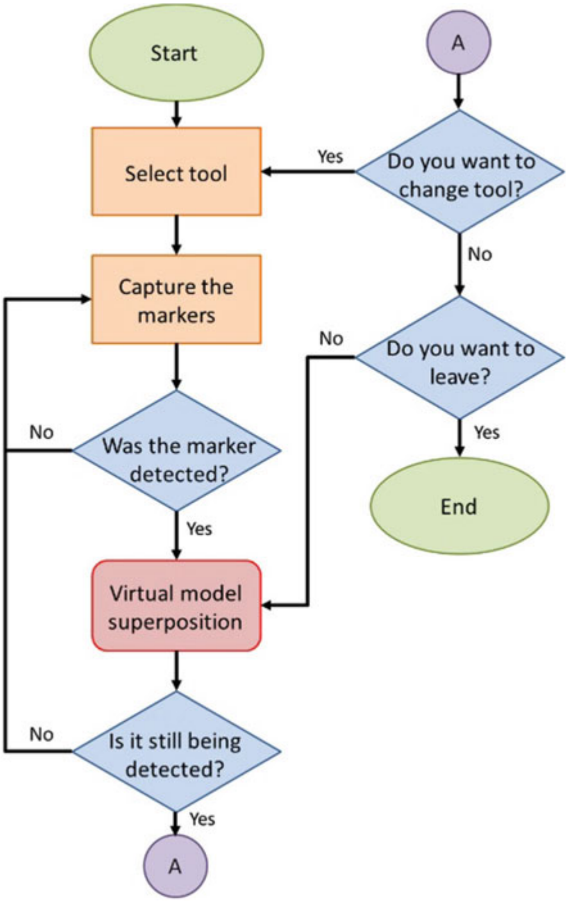


Fig. 3.17 MAR prototype scenes. **a** Mode selection, and **b** tools and utilities

Fig. 3.18 Flow diagram for AR experience



The resulting application has the *.apk extension which can be shared in a virtual store such as Google Play. Once the application is downloaded, it is deployed to the mobile device to be used.

3.5 Experimental Results

Two different tests were executed in order to measure and demonstrate the performance of the MAR prototype inside a real manufacturing industry. Both experiments are explained in the following subsections.

3.5.1 Scope of Markers Detection

The first test consists in reviewing the scope of marker detection and the behavior of the whole prototype. In this test, the measures were obtained in the real industrial environment where the ATV is manufactured, with a constant illumination of 300 lumens. By using a Bosch GLM 40 laser, and a typical flexometer, the minimal and maximal distances in centimeters to detect the 7 markers of accessories were calculated. The specifications of the two mobile devices used for testing are shown in Table 3.2.

The test was carried out by approaching the camera of the mobile device to the marker as close as possible, and after that, moving the device away until the point that the marker cannot be detected. The results obtained from the test are shown in Table 3.3.

It should be observed from Table 3.3 that the general range to detect markers is wide. In addition, even when the Galaxy S6 has better characteristics, the detection range is greater with Tab S2, concluding that this was the device with the better performance. In addition, the area covered by the marker is important for good recognition. In Table 3.4, the information about the area covered by each marker is shown.

It should be noted from Table 3.4 that the detection abilities are influenced by the area covered by the marker. For example, the marker of steering_columns is the biggest; therefore, the scope distance range is greater than the others. In conclusion,

Table 3.2 Technical specifications of the mobile devices used for tests

Brand	Model	Operating system	RAM	Camera (MP)
Samsung	Galaxy Tab S2 8.0 (SM-T713)	Android 6.0.1 (Marshmallow)	3 GB LPDDR3	8
Samsung	Galaxy S6 (SM-G920V)	Android 6.0.1 (Marshmallow)	3 GB LPDDR4	16

Table 3.3 Minimal and maximal distance to detect markers

Marker	Minimum distance (cm)		Maximum distance (cm)	
	Tab S2	Galaxy S6	Tab S2	Galaxy S6
Tail_structure	6	12.5	178	163
Steering_column	5	14	212	80
Rear_arm_suspension	9.5	17	59	48
Rear_structure	9.5	28	68	62
Front_susp_left	9.5	21.5	94	43
Front_susp_right	9.5	21.5	94	43
Front_bumper	6.5	21	147	117

Table 3.4 Area covered by the markers

Marker	Width (cm)	Height (cm)	Area (cm^2)
Tail_structure	8.8	8.8	77.44
Steering_column	8.9	8.9	79.21
Rear_arm_suspension	10.1	3.4	34.34
Rear_structure	9.1	2.8	25.48
Front_susp_left	12	2.6	31.2
Front_susp_right	12	2.6	31.2
Front_bumper	8.4	4.5	37.8

the MAR prototype allows working inside a real manufacturing scenario with different devices and different distances for pointing out the markers with good detection and tracking.

3.5.2 Survey for Users

In the second test, a questionnaire was designed for measuring the user satisfaction when using the MAR prototype inside the real manufacturing environment. Ten subjects participated in the survey, with an age ranged from 22 to 60 years. Nine subjects were men, while one was women, all of them employees of the ATV manufacturing company. In the sample, three subjects were technicians, two group chiefs, two welding engineers, one quality engineer, one supervisor, and one welder. The survey is shown in Table 3.5.

In the Likert scale used, the 1 means totally disagree, while a 10 means totally agree. Each participant received an explanation about the purpose of the survey; after that, both devices were used to test the MAR prototype. Each user takes around 15 min for testing the prototype, and after that, the survey was filled.

The results obtained for questions 1–7 are shown in Fig. 3.19, while the results obtained for question 10 are shown in Fig. 3.20. For the case of question 8, 80% of

Table 3.5 Questions of the survey

Question	Scale									
	1	2	3	4	5	6	7	8	9	10
1. Welding AR application is easy to understand and use?										
2. Welding AR application is physically or mentally demanding?										
3. Welding AR application interface is ease of use?										
4. Using Welding AR application, it's frustrating?										
5. Welding AR application will help for improving quality control?										
6. Welding AR application will be helpful to be used in manufacturing processes?										
7. Welding AR application will allow that the introduction of new chassis or modifications of current models takes less time for its manufacturing process?										
8. Welding AR application has opportunities for improvement? Which?	Yes or no, and open question									
9. Do you consider that the process of training in the department of quality control using Welding AR application will be easier and faster?	Yes or no									
10. Which kind of employees will exploit better the Welding AR application? (a) Welder, (b) trainer, (c) group chief, (d) production supervisor, (e) programmer, (f) maintenance technician, (g) quality technician, (h) engineer technician, (i) welder engineer, (j) quality engineer, (k) administrative	Multiple option selection									

the participants responded yes. The comments include augmenting the number of weldings inspected, augmenting the distance in which the prototype can detect the markers, and augmenting the number of critical dimensions measured. Most of the participants comment the benefits that could be obtained if the prototype will be installed in AR lenses such Microsoft Hololens. Finally, for the case of question 9, 100% of the participants expressed that it will be easy and fast the process of training a new employee using the MAR prototype, and this is mainly due to its visual and ease of use interface.

3.5.3 Discussion

By observing the results obtained for both experiments, it should be noted that the prototype is useful for supporting the ATV manufacturing process including the training stage. It is important to highlight that the users demonstrate interest in using the application and enthusiasm to include it in the dairy work. Effectively, the

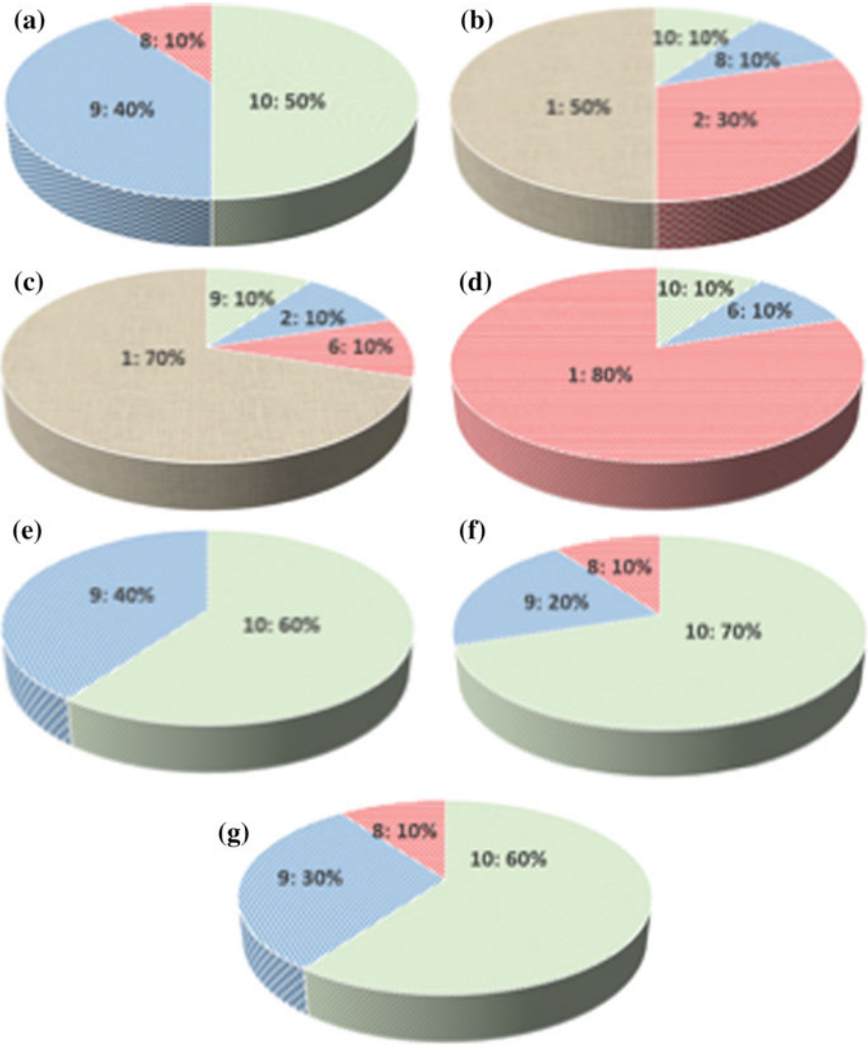


Fig. 3.19 Results obtained for questions 1–7. **a** Question 1, **b** question 2, **c** question 3, **d** question 4, **e** question 5, **f** question 6, and **g** question 7

prototype helps in the task programmed with the use of AR that includes welding inspection, measuring critical dimensions and mounting accessories.

Regarding the ability to detect the markers, it should be noted that a wide range of distances could be handled, which will help the user to observe the superimposed models at different sizes and orientations. When a detailed view is necessary, then the user approaches the device in a very short distance, if a macrovision is needed, then the user moves away from the markers.

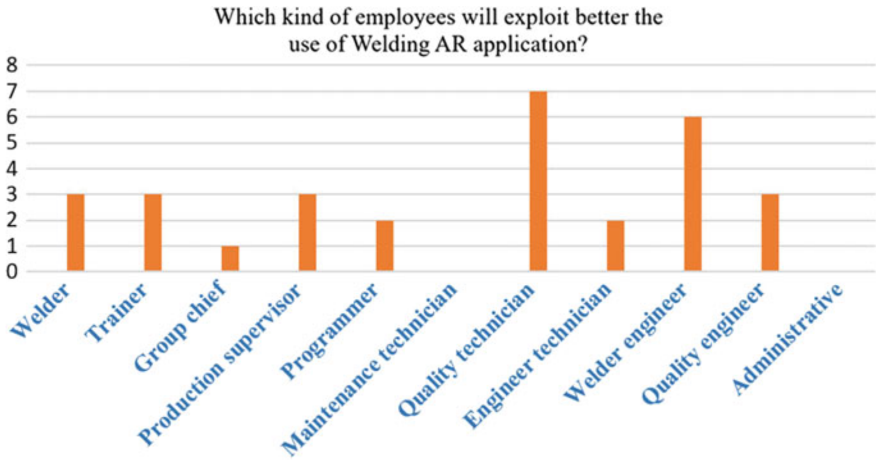


Fig. 3.20 Results obtained for question 10

It is important to highlight the ability of the prototype to be useful inside the real manufacturing environment, where changes of illumination, noisy environment, and eventually occlusions happened almost all the time.

With respect to the results obtained from the survey, we confirmed that users are interested in using the application. Nevertheless, the comments offered about improvement opportunities were very valuable to enhance the prototype in the future. At the end, the experiments allow confirming the premise that AR is a valuable technological tool that can be used to support the process of manufacturing an ATV.

3.6 Conclusions

In this chapter, a MAR prototype (Welding AR) to support the manufacturing of an ATV was presented. Particularly, the prototype serves in three crucial stages of manufacturing such as welding inspection, measuring of the critical dimensions, and accessories mounting. After the results obtained from experiments, we conclude that the prototype fully complies its function of visually showing the process of manufacturing an ATV.

The prototype can help experimented and novice users. The application executes well on mobile devices with different architectures based on Android OS. The use of this kind of technological tools is essential to finally reach the real explosion of the 4.0 industry that includes cyber-physical systems, the Internet of things (IoT), cloud computing, and cognitive computing.

Future work will be directed toward on implementing the prototype in other operating systems such as iOS. Also, it will be important to carry out a set of tests using AR glasses such as ORA Optinvent or Microsoft Hololens, which will provide the user the total mobility of the hands. It will be important to increase the number of 3D models and include more types of ATV models. It is also necessary to increase the number of welds inspected and the number of critical dimensions to measure. Finally, it will be desirable to change the functionality of the prototype from marker-based AR to a markerless system which will offer a more natural interface.

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