

## Methodology to eliminate errors in machining processes through Augmented Reality Applications

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### Abstract

Today, precision machining companies must implement new technologies to meet the requirements of the aerospace and automotive industries to maintain their competitiveness in the market and create new business opportunities. It has currently been observed that machining companies face errors in their processes that affect the quality of the products, the operation of the process, the useful life of the machines, and the tools. This research project aims to develop a methodology to reduce errors in Computerized Numerical Control machining (CNC) processes with Augmented Reality Applications (AR-Apps) that help operators interpret manufacturing drawings and assembly operations optimize Setup operations and ensure the reliability of the machining. It begins with a questionnaire applied to a sample of machining companies from Chihuahua Mexico City. To identify the factors that generate critical errors in the machining processes. The main results obtained in this paper are reduction of downtime, elimination of scrap, increment cutting tools life, optimize the machining process, increase productivity, and improved product quality. AR -apps implementation offers a low-cost alternative solution that operators and technicians can use very easily because it is a powerful tool that helps work more efficiently through virtual environments, reducing errors and optimizing the process of machining.

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**Keywords:** Manufacturing drawings, Augmented reality, Machining process, Errors

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### 1. Introduction

Currently, in Mexico, there are more than 300 companies dedicated to the machining process that offer their services to the aerospace and automotive industry [1], mainly located in Baja California, Sonora, Chihuahua, Nuevo León, Querétaro and Jalisco. Chihuahua has been classified as one of the federal entities with the greatest development and potential in the aerospace and defense sector, counting 42 aerospace companies and more than 37 certified suppliers' companies [1]. However, these companies face the challenge of manufacturing products with high quality standards and dimensional precision to stay as good suppliers of these industries. In this sense, Eldessouky [2], emphasizes that these types of companies must comply with standards such as: AS 9100 (Aerospace Standards)[3] and

the NADCAP (National Aerospace and Defense Contractors Accreditation Program)[4]. Therefore, these companies need to administer their resources through the efficient management of their available resources, which results in quality improvements, cost reduction, and intercommunication between production chains and the final consumer [5]. For this reason, machining companies have to invest in new technologies to optimize their manufacturing processes to meet the current requirements. However, to meet these requirements, companies must first identify the main errors that occur in their machining processes to implement the type of technology that would solve their problems. Recent studies show that some critical errors occur during the manufacture of products in the machining process and how they directly affect the quality of the products. In 2020, an experimental estimation study [6], determined 7 main errors that arise in the machining processes: 1. errors in the interpretation of drawings, 2. errors

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in the configuration of the work coordinate system, 3. errors in the calibration of tools, 4. error in numerical compensation, 5. programming errors, 6. errors in the design of products and 7. errors during the operation of the machine.

Today, Industry 4.0 (I4.0) offers new technologies that are transforming the production industry and are the emergence of the new digital industrial technology that can be implemented to optimize industrial processes. [7] define them such the "Nine Pillars of the I4.0" , which are: the Internet of things (IoT), Big Data, Artificial intelligence, augmented reality, additive manufacturing, collaborative robotics, simulation, cybersecurity, cloud computing, and systems integration.

Therefore, the main objective of this project is the development of a methodology to eliminate errors in CNC machining processes with the implementation of AR -Apps.

## 2. Related works

In this section we summarize the various applications of AR widely used in the industry in fields such as training, robotics, assemblies and maintenance. The fundamental approach is to use the AR as a virtual training guide support to perform work in the industry.

Chen ET AL [8] proposed a new method of human-computer interaction (HCI) for the planning of robots trajectories based on virtual reality and assembly systems offering graphics, text and animation, Figure 1 shows the result.

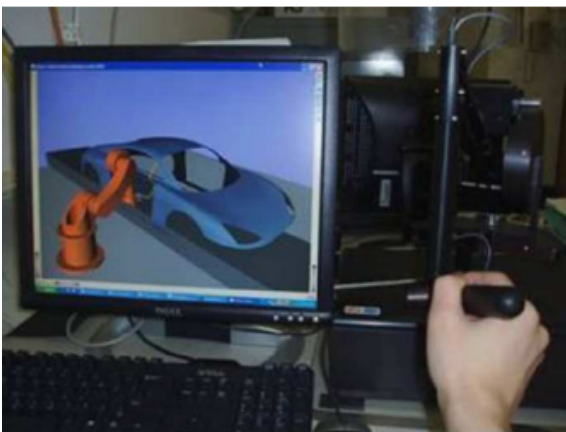


Figure 1. Haptic-aided virtual tele-operation for robot path planning. [8]

Jiang and Nee [9] presented a method of optimization and planning of design of facilities on the site, which allowed users to place virtual objects in the real environment generating an immediate visualization of the design, The Figure 2 shows the interface generated.

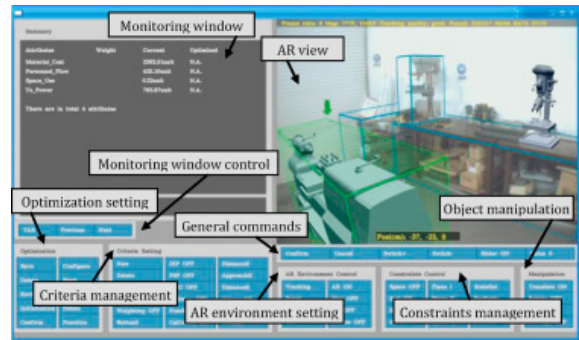


Figure 2. User interface of the AFLP system. [9]

Garza ET AL [10] used this technology to improve maintenance activities and provide a better approach for information management compared to the use of paper and computer manuals, Figure 3 shows the result of the AR animation.



Figure 3. Fuller pump animation displayed over mark. [10]

Suarez ET AL [11] presented a RA system to perform manual assemblies by admitting the recognition of online restrictions and providing a robust 3D interaction interface to allow visual feedback during assembly operations, Figure 4 shows a person performing assemblies with AR aided.



Figure 4. Display an AR aided assembly[11]

Novak AT AL[12] implemented a special virtual environment using the AR, where users can see not only visual information about an exact manufacturing process but also necessary text and audio information about workplaces, parts, work conditions etc. Figure 5 shows the environment interaction with person using AR.

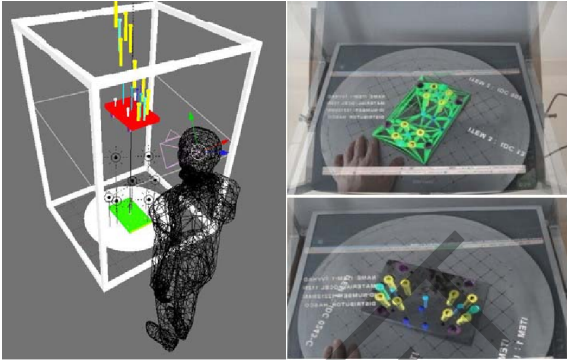


Figure 5. Worker realizing the assembly task with AR environments[12]

Amedeo Setti AT AL[13] Applied the AR as a supporting machine tool operators in setting up the machining process, simplifying and quickening the identification of setup errors and misalignments, Figure 6 shows an operator using the AR App in a machining process.



Figure 6. operator using ARTool for checking a part-program In[13]

Marinakis AT AL[14] presented a mobile Augmented Reality (AR) application to facilitate and enhance the learning processes and traditional text book material of the Mechanical Drawing course for undergraduate and postgraduate university students undertaking an engineering degree as shown in Figure 7.



Figure 7. 3D model through Augmented Reality based[14]

### 3. Experimental Method

Based on this related works a new methodology project is proposed to develop AR- Apps to eliminate errors in the machining process through the design of Apps focused on solving problems of interpretation of manufacturing drawings, assembly, and machine operating instructions. The AR-APPS will allow the company to identify, gather, store, evaluate, review and share data and information digitally at the time and place that employees require it. This information may include documents, procedures, best practices, lessons learned, and Multimedia files such as technical drawings, images, and videos.

#### 3.1. General methodology to develop AR applications for Manufacturing Drawings

As a priority, it is necessary to identify the most critical errors that arise in machining processes. First, it was determined a population of 50 companies dedicated to the CNC machining process in the City of Chihuahua Mexico [15]. From this population, a sample of 47 companies with an error level of 5 percent was calculated, giving the result as a sample size of 47 companies to be surveyed. These were invited to participate in answering a questionnaire to identify and analyze the errors that arise in the CNC machining processes. The application of the questionnaire aimed to identify and classify critical errors.

Once the errors were identified, a Pareto and the Failure Mode, Effects, Analysis (FMEA) were carried out to identify the most critical errors that cause 80% of the problems. With the results of these analyzes, the errors that are a priority to solve were presented, as well as the proposal to implement the methodology for the development of customer RA-Apps for the

AUMA company. Already identified these errors, the methodology proposed by Alan B. Craig [16] was used to apply the augmented reality to problem-solving:

1. Identify the problem.
2. Determine if there are other solutions to the problem.
3. Determine the capacities of augmented reality that would help solve the problem.
4. Design the application of augmented reality.
5. Implement the application of augmented reality.
6. Try the augmented reality application.
7. Evaluate the results of the application regarding the problem.
8. Modify design and application.
9. Test the modified application.
10. Repeat iterative from the appropriate step.

For the development of augmented reality applications focused on the reading of manufacturing drawings, the proposed methodology is illustrated in Figure 8.

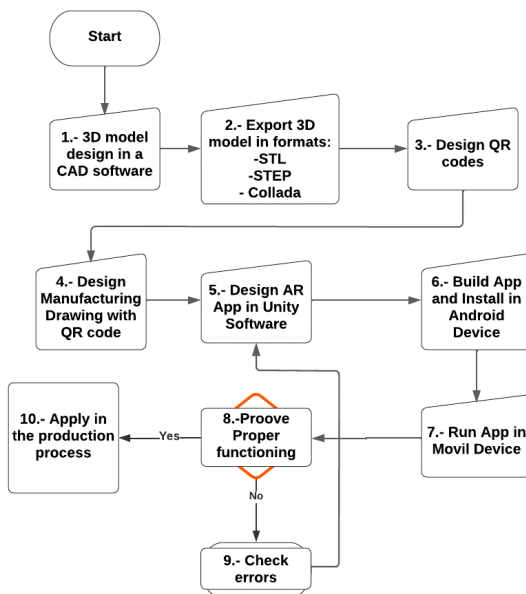


Figure 8. Methodology for AR-Apps design

**Steps description.** The following steps define the logic sequence for AR-Apps Design:

1. 3D parts design in CAD software. This step consists of designing 3D models in a CAD platform 9.

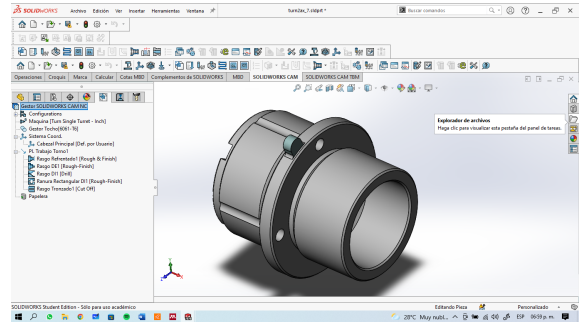


Figure 9. 3D modeling in CAD Software

2. Export models. The 3D parts must be transformed to FBX, dae, obj, dxf, 3DS STUDIO MAX or BLENDER formats before using AR software.
3. Design QR Codes. “Quick Response code” is a type of barcode (see Figure 10) that stores information as a series of pixels and can be read by a mobile device. QR codes allow connecting digital information to a digital destination through a smartphone.



Figure 10. QR code.

4. Design manufacturing drawings with QR codes. In this step design, engineers will generate manufacturing drawings with QR codes printed as shown in Figure 11, so that the app installed on the smartphone can scan the code and project the information on the screen.

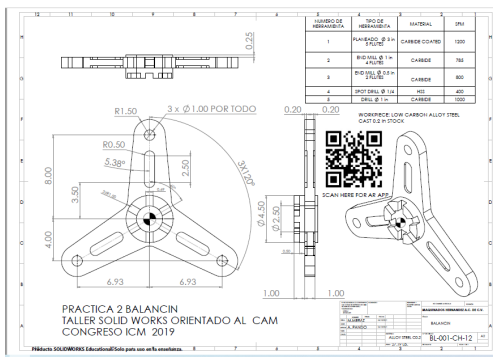


Figure 11. Manufacturing drawing with QR code

5. Design AR-Apps. In this step, the AR software Unity is used to program routines that allow the design, creation, and operation of an interactive environment as shown in Figure 12.

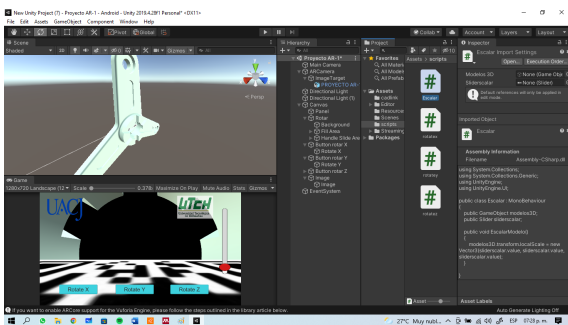


Figure 12. AR-Apps design in Unity

6. Build App and install it on an Android device. These Apps will be installed on mobile devices and ready to be used by operators and technicians in the work area. For the implementation of AR applications,[9] recommend the use of devices such as tablets or smartphones with high-definition cameras integrated for better operation of the AR program as shown in Figure 13.

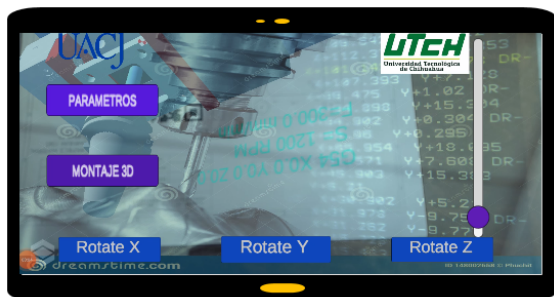


Figure 13. App installed in a mobile device

7. Run App on a mobile device. Once the Apps are installed, it needs to scan markers or QR codes placed in worksheets (Datashets) or drawings, which will show 3D objects, animations, and data in AR
8. Prove proper functioning.
9. Check errors in programming and proper functioning. If any kind of wrong functioning is detected, returned to step 5 for corrections.
10. Apply in the production process. With these Apps, the user will be able to identify the information and the type of machining process to be carried out.

The operation of this application works as follows: first, a mobile device or AR glasses with a built-in camera will be used to scan reference markers (QR codes), which through an algorithm developed in the Unity and Vuforia software will display 3D images that will show digital and detailed information over manufacturing drawings, assemblies, operations and maintenance, offering guided virtual assistance. Figure 14 shows the diagram that describes applying AR to the recognition of QR codes.

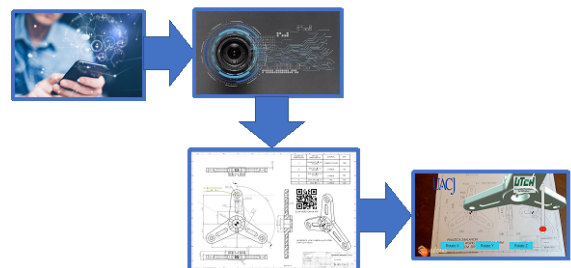


Figure 14. Applying AR to the recognition of QR codes

### 3.2. Materials

For the development of this project, it is essential to choose the hardware and software that we are going to use. For the case of the hardware, mobile phones or tablets with an android system will be used, for the software, you will work in Unity to develop apps of augmented reality of great complexity and SolidWorks 2021 for the design of 3D pieces and manufacturing drawings.

**Computer equipment and software.** The computer equipment must have sufficient capacity to support the installation of CAD/AR and programming software, Table 1 describes the characteristics of the software to be used and the computer equipment with the minimum conditions.

**Table 1.** Computer equipment specifications

<b>Computer characteristics</b>
Intel (R) Core (TM) 2 Duo CPU processor. Speed 2.3GHz. 8GB RAM. 500 GB Free Disc capacity.
<b>Required programs and licenses</b>
Unity Python 3.3.2, Matlab 2021, Visual Studio Vuforia Engine SolidWorks CAD/CAM 2021/ Onshape

**Mobile devices and accessories for RA/VA.** The requirements of mobile devices for installing AR Apps must comply with the minimum characteristics shown in Table 2:

**Table 2.** Mobile and accessories Characteristics

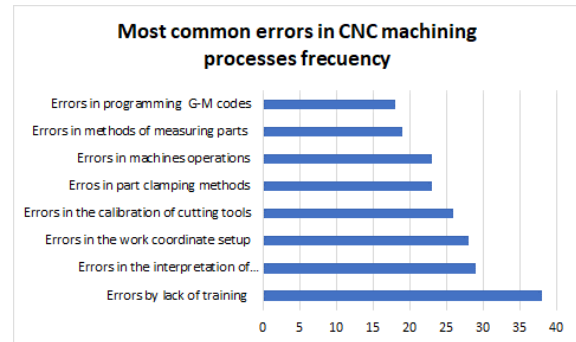
<b>Smartphone/Tablet</b>
Internal memory: 128 GB Main front camera: 16 MPX Main rear camera: 2 Mpx RAM at least 4GB 8 core processor Screen size 6.59 “
<b>RA glasses</b>
Type: Merge SO: Android/iOS Dimensions: 13.97x19.05x10.16 cm, 340.19 gr Wireless Technology:OLED/AMOLED

For the project to be successful, it is worth mentioning that it is necessary to have the necessary equipment and resources available, these being assigned by the company, in addition to administering the time for the realization of the activities, should be designing RA-APPS is arduous work.

### 4. Results

In the first phase of this project research was carried out in the city of Chihuahua Mexico to identify the companies dedicated to CNC machining parts. They were invited to participate in answering a questionnaire to identify the most critical errors that arise in their machining processes. the data obtained were classified in errors by: 1. Lack of training, 2. Drawings interpretation, 3. Setup and initial configuration, 4. Calibration of cutting tools, 5. Part clamping methods, 6. Machines operations, 7. Methods of measuring parts and 8. Errors in programming. Once these errors were identified, a methodology is proposed to develop

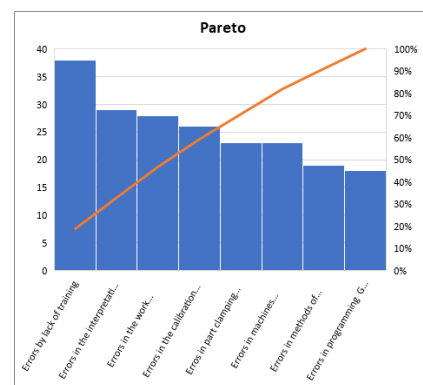
personalized AR Apps. The questionnaire was applied to 47 machining companies located in the city of Chihuahua Mexico the results obtained are shown in Figure 15.



**Figure 15.** Result of the questionnaire in determining critical errors in the machining (own source 2022).

### 4.1. Measurement Procedure

According to the analysis of the answers, a Pareto analysis was implemented to determine the most critical errors that affect the processes this analysis is carried out to determine 80 percent of the problems that are caused by 20 percent of the most vital errors, Figure 16 shows Pareto’s graph.



**Figure 16.** Pareto graph (own source 2022).

The rule says that a problem has multiple causes and that 20% of the causes count for 80% of the problem. [17] explain that reading a Pareto diagram identifies 20% of the causes and correct them means to solve 80% of the problem. From the analysis of Pareto’s chart, we determine the errors that we must attend mainly, resulting in the Table 3:

**Table 3.** Results of critical errors to attend

Errors	% accumulate
Errors due to lack of training	95
Errors in the interpretation of manufacturing drawings	78
operational errors	75

With the previous information, some errors were classified as a single category called operational errors due to the similarity: Setup and initial configuration errors, Errors in the calibration of cutting tools, Errors in part clamping methods, Errors in machines operations, and Errors in methods of measuring parts.

When using the AR-Apps, it's intended that participant who does not have experience and lack operational skill in reading manufacturing and assembly drawings achieve a faster way to identify the parameters in the process and thus avoid collisions and errors in the machining. Based on the identification of these critical errors, three types of specific AR-Apps were proposed to solve these problems:

1. Apps for interpretation of manufacturing drawings
2. Apps for assemblies and
3. Apps for machining parameters and operation data.

Due to the problem presented above, it is prioritized that these 3 errors must be eliminated, because they could cause machines collisions, increase downtimes, generate Scrap, machines malfunction, and machine cost expensive repairs. To measure the AR Apps application impact, a stay project industry was carried out at the Auma company located at Chihuahua Mex city in the period September-December 2021, obtaining specific information from a special process. Table 4 shows an FMEA analysis applied to the rear process D66 of the AUMA company, it shows the possible causes of failure of a product that was machined and that does not correctly assemble with another mechanical part.

**Table 4.** Potential failures in the machining process. Source: Auma Bocar Group (2021)

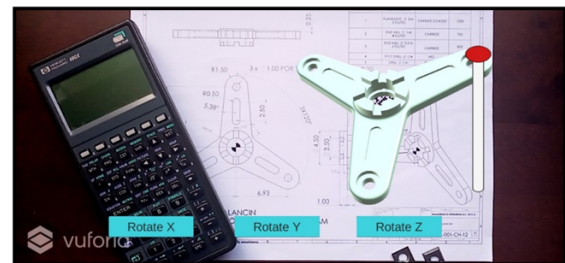
Potential effect(s) of failure	Potential cause(s) of failure	prevention
The piece will not assembly	1) tool vibration	1) parameters sheet, adjustment sheet, preventive maintenance
Auma: 100% of production scrap (8)	2) tool balance	2) adjustment sheet, hammer
OEM: portion of production scrapped/rejected (7)	3) wrong machining parameters	3) parameters sheet
end-user: degradation of primary function (7)	4) incorrect programming	4) training adjusters & engineers, chip euchner
	5) failure machine	5) preventive maintenance, TPM
	6) subjection of piece	6) training operator, preventive maintenance, air sensors
	7) damage tool	7) tool control life
	8) incorrect offset	8) adjustment sheet, or program

Due to this problem, the opportunity arises to apply the research project " Methodology to solve errors in machining processes through augmented reality applications" to solve these errors and measure their impact on the process. mainly solving the previous problem.

First, a work team must be formed by three people who will work in an integrated way in the facilities provided by the company: 1.- The platform programmer its function is to perform the videos, and the post-production effects to add to the interactive parts and will be able to optimize his work so that his insertion in the augmented reality is easy, 2.- Designer who will have the capacity to design In 3D and improve the product in addition to working hand in hand with the platform programmer and finally 3.- Leader of the project must be the general manager that everything is directed.

#### 4.2. Implementation of AR-Apps for manufacturing drawings

With the implementation of AR-Apps for manufacturing drawings, the operator will be able to rotate the part, zoomed-in, show cut sections, animate, and offer information manufacturing that helps process operators avoid misunderstandings in drawings. Figure 17.



**Figure 17.** AR-App for manufacturing drawings

**Results obtained:** Interpretation errors were reduced due to the lack of training, achieving the reduction of scrap by 2% and pieces rejected by 1%. The App consists of scanning a QR code which will project a 3D image. This helps operators to visualize 3D parts such as assemblies and digital information for manufacture.

#### 4.3. Implementation of AR-Apps for assembly drawings

With the implementation of AR-Apps for assembly drawings, the operators will be able to scan the QR code located in the drawing of the assembly sheet, then a 3D of the assembly is shown in an exploded view, as shown in Figure 18. With this application, the operator could zoom, view parts or internal details, rotate in X, Y, and

Z axes, move, view sequence assembly, and animations, and view digital information from the project.

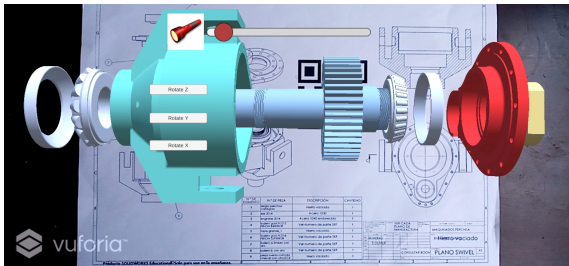


Figure 18. RA app for interpretation of assembly drawings

**Results obtained:** errors in interpretation were eliminated due to the lack of training, achieving 0%. With the implementation of this application, the operators did not make mistakes in the assembly of mechanical parts, the assembly time is shortened and the need for specialized personnel as well as training hours were eliminated.

#### 4.4. Implementation of AR-Apps for operation and setup

With the implementation of AR-Apps for operation and setup, the operators will be able to scan the QR code and digital information will be displayed such as types of tools, clamping methods, geolocation of the Work Coordinate System (WCS), configurations, and cutting parameters will be displayed as shown in Figure 19.

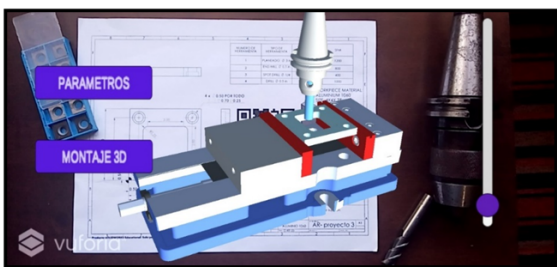


Figure 19. RA app for interpretation of assembly drawings

**Results obtained:** Elimination of tool collisions, tool vibration, tool balance, wrong machining parameters, and subsection of the piece, obtaining results such as reduction of downtime by Setup by 40%, elimination of scrap by 0%, increased life of the useful life of tools in 30%, decrease in training times (in annual review) and finally the most important thing, the quality assurance of manufactured pieces.

With the decrease of these factors mentioned above, a great benefit was obtained for CNC machining companies, since the productivity was increased by

50%, the quality of the product was improved, collisions of the tools were avoided, rewards were reduced and it was found that AR instructions are much easier to understand than classical instructions (visual aids).

When using AR-Apps, it is intended that participants who do not have experience in the interpretation of manufacturing drawings and lack operational ability achieve a simple way to identify the parameters in the process, determine values of Setup of tools and origins, interpret manufacturing and assembly drawings, all of this with the ultimate goal of avoiding errors in the machining process, ensuring the optimal functionality of machines and guaranteeing the quality of products for the benefit of their customers in addition to not generating any impact on the environment or ecological damage because it is a digital content platform.

In addition, it turns out that it is very useful to implement RA apps to visualize the information since they provide a better representation of the 3D parts so that operators that lack spatial visualization skills do not comment on errors in the interpretation. To minimize errors, a significant number of benefits will be achieved in the CNC machining process, because of the reduction of the error, companies will increase productivity, improve product quality, avoid tool collisions, and decrease Scrap and rework; in addition, it will be verified that the instructions with AR are easy to use and implement. In addition, the AR application provides better visualization of the values offering a virtual integration man -Machine so that operators who lack spatial visualization skills do not comment on errors in the process.

This result suggests that the errors in machining process cannot be eliminated for all conditions, though the overall tendencies can almost all be eliminated. The improvement of these project will be a subject of our further study.

## 5. Discussion

This paper examines the possibility of eliminating errors in CNC machining process

The project itself is technologically feasible because there is a potential market in the city of Chihuahua where the project could be applied to companies that need to innovate in their manufacturing processes through the incorporation of technologies of the I4.0. Combining Industrial Internet of Things (IIoT) and AR technologies enhances the ways that operators can interact with the world around them. But to harness that power, companies must choose where to deploy the technologies, build an ecosystem that supports IoT and AR, and develop the talent that can use both technologies. Companies that do so will be able to not only reduce costs, boost revenues, improve the



customer experience, and strengthen brands but also use contextual data in ways never before imagined.

It's recommended to present this technology to some city machining companies for assessment and recommendations, in this way it is intended to continue with the continuous improvement in the development of both the methodology and the AR app.

## 6. Conclusion

In CNC machining processes, several key factors must be considered to ensure the optimization of the manufacturing process. If these factors are not well-reviewed, errors in the process will originate, resulting in additional costs not contemplated that impact losses for the company. Implementing I4.0 technologies such as AR is a powerful tool to help CNC machine operators work more efficiently through virtual environments, reducing errors and optimizing the machining process. These technologies are helpful for modeling and manufacturing virtually as they reduce costs, increase yields, improve product quality and shorten the product development cycle. This project offers an alternative low-cost solution that can be used very easily by operators and technicians of CNC machines by developing specific AR-Apps that solve errors by implementing applications that are easy to use and economical for companies.

Finally, it is proposed as a Continuous improvement opportunity for the project to implement in the machining process a Human Interface machine (HMI), through the integration of the RA-Artificial Intelligence (AI) and IIoT with this improvement it will be achieved to send information, visualize, monitor, and control variables through the real-time apps without the need to implement expensive automation technologies. It is recommended that this integration can be used to solve problems in processes such as Validation processes, Mechanical assembly processes, Inactive time reduction (Quick Set-Up Change), Configuration checks (Critical Set Up Checks), Preventive Maintenance, and ERP administrative processes.

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