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Machining and Dimensional Validation Training using Augmented Reality for a Lean Process

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Abstract

Quality control does not concern only to a finished product, nowadays measuring technologies control all the fabrication process in an active way. If product quality does not meet the customer specifications exists the risk of even lose projects. When multiple or complex operations are required in the fabrication process of a part and its dimensional validation is primordial and also happens that the operator has doubts about which step to follow or that the expert supervisor is not at the workshop for some reason, that is why comes the opportunity of implementing Augmented Reality (A.R.) technology in education and in a lean manufacturing process, as support for technician operators of machine-tools and coordinate-measuring machines, with the objective of helping the technician to perform, in a proper and timely manner, the step sequence of the process. It was proved that having A.R. as ally in the technician's education, the mistakes and time required to fulfill the machining and dimensioning of a part can be considerably reduced, as well as eliminate operator's dependency to the experts. At the end of the implementation, savings were found in the three stages analyzed, generating 27.36% savings in lathe process, 26.54% in milling and 45.16% in dimensional validation.

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Keywords: Augmented Reality, FARO Gage, Workshop Training, Dimensional Validation, Mobile Device, HMD Plant Managers

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1. Introduction

Nowadays, the fabrication and dimensional validation of parts in the machine-tools area are important factors for the elaboration of checking fixtures, and having the certainty that the process is being held correctly is guarantee that a job will be delivered meeting the specifications required, without risk of having to remanufacture because a wrong machining or a wrong dimensioning was held at an early stage and, at the end, it implies to reprocess the part.

Having a support tool that interacts with the operator, the machines and the measuring equipment, can stop an error before it advances more, which is why it is required to have auxiliary aids, training or guides of the right fabrication and dimensioning method.

This study evaluates the use of A.R. technology in machine-tools workshops to make the part lean machining and validation processes more efficient. Being able to dimensionally inspect a part when it is still mounted over the machine is an advantage, since it makes possible react while the part is being machined. The tools that will intervene in this evaluation study are the FARO Gage (Coordinate-Measuring Machine, CMM) and the machine-tools (lathe and milling machine).

The mind map in Fig. 1 shows some of the functionalities that Augmented Reality can have. We divide the AR applications in three main branches: *Info visualization*, *Educational*, *Real time practice*. It is important to mention that many classifications of AR have been made since the concept was coined by John Doe Boeing researchers in 1994. This mind map shows the classification that the personnel of Automated Data Systems S.A. de C.V. (ADS) uses to address the development of Augmented Reality systems.

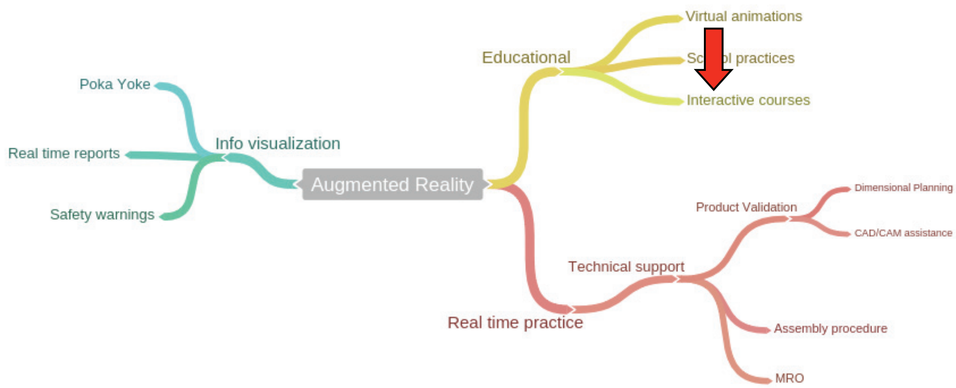


Fig. 1. Augmented Reality mind map of its principal functionalities
Source: Automated Data Systems S.A de C.V. (2015)

ADS' fabrication department, looking for making its machining and validation processes more efficient, bets on improving by educating its employees in using best practices.

Even though people knows how machine-tools works, always is good to guide the operator in the efficient manner of fulfilling the machining and validation processes. Dimensional validation is necessary to meet the customer's specified tolerances. Talking about checking fixtures and measuring devices fabrication, production criteria are very strict, requiring tolerances as small as 0.05 mm, 0.02 mm, etc., so it needs to be guaranteed that the measurements are right.

This is why the idea of creating a support system with Augmented Reality and taking advantage of the benefits this technology offers for knowledge transference emerged.

2. Technologies and Methodologies

2.1. Fabrication processes

The final objective of the mechanical fabrication is the transformation of raw material into a finished product, meeting the necessary quality and cost requirements. For that, diverse technologies are available in function of the materials to transform, product requirements, volume of parts to fabricate, etc.

Through the machining proceeding, a material is given form by the removal of material or chips. Three great machining groups will be distinguished:

- Chip removal machining
- Abrasion machining
- Special procedures machining

In the chip removal machining, fragments of materials are eliminated through tools with perfectly defined cutting edges. More habitual are: sawing, filing, drilling, threading, lathing and milling.

2.2. Lean Process

One of the key factors of a company competitiveness is their processes' cycle time and because of that, many enterprises look for doing stuff faster.

A lean process is based on Toyota Production System (TPS), developed mainly by Taiichi Ochno and Shigeo Shingo. The concepts of a lean process are focused on the processes flow and on reducing the amount of activities that do not add value and impede their flow. Any activity that generates cost but does not add value to the product is considered a waste. For achieving a Lean process one of the strategies is Just in Time (JIT), used for planning in an optimal way the production materials requirements for a process.

Another methodology is the tool changing in few minutes (SMED), which introduces the idea that generally in any preparing process should last less than ten minutes. Therefore, SMED and JIT are part of TPS.

2.3. Dimensional Metrology

Dimensional metrology is the science in charge of the measurement of geometric magnitudes: dimensions, forms and superficial finish; being a fundamental part for quality control in a mechanical fabrication company.

This specialty is of great importance in industry in general, but specially in manufacturing, since dimensions and geometry of diverse product components must be dimensionally homogeneous, so they can be interchangeable even though they are fabricated in different machines, plants, companies or countries.

2.4. Augmented Reality

Augmented Reality (A.R.) is a visualization technology that allows the user to see, in real time, virtual information added or superimposed in the real environment. This technology has the potential of "augmenting" the user's visual experience and at the same time is very useful due to the great diversity of applications it can have [1].

This concept of augmented vision may be used in different areas from the entertainment industry, marketing and architecture to the support in complex activities as production lines maintenance, automotive industry and even medicine. Augmented Reality implies a visual aid that may help reduce mistakes in critical tasks that represent a considerable risk for the user.

In recent years, A.R. research in manufacturing applications has become in a constantly growing area due to the great adaptation of the technology in tasks as assembly, disassembly, maintenance operations, design and product planning, manufacture simulation, among others [2].

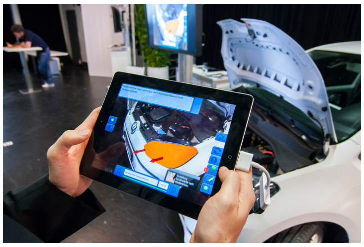


Fig. 2. Augmented Reality application for service and maintenance Source: Metaio Inc. (2014)

The term 'Augmented Reality' was first used by T.P. Caudell and David Mizell in 1992, where they limited to mention that this technology was the superposition of computed generated material over the real world and "augments" the user's field of view with information necessary to fulfill an specific task [3].

Years later, Ronald Azuma [4] defined that an A.R. system must meet three principal requirements: 1. Combine virtual elements with reality, 2. The interaction between elements is in real time, 3. The images are visualized in 3D scenarios.

In his description, Azuma also establishes that A.R. must not be hardware dependent. This allows that other technologies, besides Head Mounted Displays (HMD) used by Caudell, enter in the category of devices capable of supporting A.R.

2.5. Research delimitation

This research is developed in a Machining Workshop, using a fabrication and dimensional validation process of a part, interacting with the lathe and the milling machine and with the procedures to implement it, as well as the use of FARO Gage for the validation, so its lean process be errors-free and does not depend on the person who is carrying it out using A.R. as technology to support in these processes.

3. Equipment that use this technologies

3.1. Machine-tools

The concepts of tool and machine-tool greatly differ. Tools are thought in function of the materials (fabrication mode, material to use), while machine-tools are in function of the operation (drilling, cutting, polishing, lathing, milling, etc.).

The most known conventional machine-tools are: lathes, milling machines, saws and grinders [5]. Computerized Numeric Control arriving to any machine-tool kind optimizes its quality and security levels.

3.2. CMM

Since its beginnings, coordinate-measuring machines (CMM) capture detailed dimensioning data passing a spherical point sensor, called probe, across the surface of the part that is measured, which is how the coordinates of a point in space are determined. The accomplishment of national and international standards is of extreme importance, such way the users can verify that their parts are between tolerance limits with a high reliability level.

The precision and functionality have been improved, but what still being a disadvantage of the CMM is that they have to be in a fixed position. An alternative are portable CMMs. These provides the precision and coherence of traditional machines directly to the production zone where they allow to be moved and used as one wishes [6].

Fig. 3. Portable CMM Source: FARO Spain (2009)

3.3. *Mobile Devices*

AR applications can be processed in different devices, in PCs, laptops, tablets, smartphones and Head Mounted Display units, among others. All AR applications have a similar configuration as shown in Fig. 4: they have a *processor* or *computer* to run the software; it has a *display* to show the virtual (or augmented) information to the user and uses a *camera* to capture the environment and the triggering marker [7].

Fig. 4. Devices in an A.R. system Source: Carlos Castro, ITESM (2012)

Display: TV sets, monitors, mobile devices such as tablet-PC or mobile phones. The selection of the display device to use will depend on what kind of application we intend to give to AR, being Mobile devices' display and HMDs the types of display offering advantages such as much greater comfort, ergonomics and freedom of movement for the user. In the HMD type display the real world experience is enhanced, unlike other display types that draw user attention away from the real world and onto the screen (Billinghurst, 2002).

Camera: They can be as simple as commercial web cameras, or sophisticated like industrial-type video capturing devices. The objective of the Video Capturing Device is to get the video image of the real world, process it as necessary and finally displaying it in conjunction with the superimposed AR 3D or 2D content which "augments" the reality captured by the camera itself.

Nowadays, mobile devices like tablets and smartphones are more accessible, they are an excellent choice in for AR applications. Tablets and smartphones have been increasing its processing capability over the years allowing them to run heavier graphics and image recognition algorithms. The mobile device also has the display and the camera included; these elements get improvements over the years adding perception lenses and even thermal cameras add-ons [8].

4. Hypothesis

Augmented Reality technology makes the fabrication and dimensional validation process of a part more efficient for the operator in the machining workshop.

5. Methodological framework

The method's design is of deductive character, in which the fabrication and validation of a part sequence is followed, taking each operation times. Data of both cases: using and not using A.R., are analyzed and graphed to compare the results of implementing this technology.

The methodology to use is quantitative, analyzing collected data of times and results, using descriptive statistics through graphics for visualizing the benefits of the implementation. In the study presented, machine-tools (lathe and milling machine), portable Coordinate-Measuring Machine (FARO Gage), Mobile device (Tablet) and chronometer. All these elements intervene in this analysis and help to get the test results. Below, a description of each one is given.

Tablet: The Augmented Reality application will be processed in a Tablet mobile device, an Asus Google Nexus7. This device will be carried by the operator to view the machining and dimensional validation procedure, some of the specifications are:7" Portable Google Tablet with NVIDIA Quad-core 1.2 GHz CPU, Android 4.2 Jellybean OS, Storage of 16GB ASUS TruVivid technology and RAM Memory of 1GB, Sensors: G-Sensor, Light Sensor, Gyroscope, E-compass, GPS, NFC, Hall Sensor with Corning® Fit Glass.

Chronometer: For taking times during the implementation tests an Extech chronometer model 365510 with the following characteristics [9] is used: 12 or 24 hour mode, chronograph/chronometer mode with 1/100 s resolution, programmable alarm with sound every hour, month and day calendar.

Lathe: The oldest, most versatile and used machine global wide, is a machine-tool that makes the part turn and with a cutting tool it looks for giving the part a cylindrical shape. The tool must have an advancing movement, and depending if this movement is parallel to the turning axis, cylindrical or conical surfaces may be obtained. Characteristic jobs done on a parallel lathe are: exterior and interior cylindrical machining, facing, exterior cones lathing, chopping, slotting and threading. In this study a conventional horizontal lathe model DSL1237GH with 6 inches dump and 1.5 m bench will be used.

Milling machine: At the milling machine the process of milling is executed, which is a proceeding consistent in cutting material with a rotary tool that can have one or more cutting edges or teeth. The cutting operation is made by combining the rotary movement of the tool and the displacement either of the tool itself or of the working part. Milling machines can be classified in different ways. Depending on their axes number they optionally may have 4, 5 or more axes. Usually, additional axes refer to rotary axes. Depending on the orientation of the main spindle, there are vertical or horizontal milling machines. For this study, an Almill conventional universal vertical milling machine, model X6323A is being used.

FARO Gage measuring arm: It is a high precision 3D measuring system for small parts, differs from fixed and hard-to-use CMM, offers comparable precision levels, improves the measurements consistence, reduces the inspection time and generates automatic reports. Specifically fabricated for production personnel, it can be mounted in few seconds and allows anyone to measure unities and parts in an easy, fast and accurately way.

Fig. 5. FARO Gage Source: FARO (2011)

5.1. Data Collection

For this study, ADS Company considered using this system in a part's process at the machining workshop. The chronometer was used to obtain the time taken for every single step of the machining and dimensional validation processes of the part. The times were obtained in two stages: first without using A.R. and after, using A.R. The results are shown in Table 1.

Fig. 6. Table 1. General data capture for the study Source: Automated Data Systems S.A. de C.V. (2015)

MACHINING PROCESS PART IN LATHE				
Operation	Tiempo sin R.A. minutos	Costs without R.A. Pesos	Tiempo con R.A. minutos	Costs with R.A. Pesos
Preparation of lathe	20	$ 100.00	15	$ 75.00
Prepare tooling	15	$ 75.00	10	$ 50.00
Holding and centering piece	5	$ 25.00	3	$ 15.00
Machined face	3	$ 15.00	2	$ 10.00
Machined inner diameter and depth	20	$ 100.00	15	$ 75.00
Outside diameter machining	10	$ 50.00	7	$ 35.00
Placing and removing part	5	$ 25.00	3	$ 15.00
Machined face and thick	10	$ 50.00	8	$ 40.00
Remove piece	2	$ 10.00	2	$ 10.00
Cleaning area and part	5	$ 25.00	4	$ 20.00
Totals	95	$ 475.00	69	$ 345.00

MACHINING PROCESS PART IN MILLING				
Operation	Time without R.A. (min)	Costs without R.A. Pesos	Time with R.A. (min)	Costs with R.A. Pesos
Preparation of milling	30	$ 150.00	22	$ 110.00
Locate tools	10	$ 50.00	7	$ 35.00
Holding and centering piece	5	$ 25.00	3	$ 15.00
Machining window	20	$ 100.00	15	$ 75.00
Machining relief	5	$ 25.00	4	$ 20.00
Drilling and tapping	10	$ 50.00	7	$ 35.00
Machining two relief	5	$ 25.00	3	$ 15.00
Placing and removing part	10	$ 50.00	8	$ 40.00
Cable machined cavity	10	$ 50.00	7	$ 35.00
Machining plane	3	$ 15.00	3	$ 15.00
Cleaning area and part	5	$ 25.00	4	$ 20.00
Totals	113	$ 565.00	83	$ 415.00

MEASUREMENT PROCESS PART IN FARO GAGE				
Operation	Time without R.A. (min)	Costs without R.A. Pesos	Time with R.A. (min)	Costs with R.A. Pesos
Inner diameter	1	$ 16.67	0.5	$ 8.33
Depth	1	$ 16.67	0.5	$ 8.33
External diameter	1	$ 16.67	0.5	$ 8.33
Width of relief	2	$ 33.33	1	$ 16.67
Depth of relief	2	$ 33.33	1	$ 16.67
Cable cavity (Length and Width)	2	$ 33.33	1	$ 16.67
Diameter window	1	$ 16.67	1	$ 16.67
Depth of relief inside	1.5	$ 25.00	1	$ 16.67
Thick	1	$ 16.67	0.5	$ 8.33
height flat	2	$ 33.33	1	$ 16.67
Remove piece	1	$ 16.67	0.5	$ 8.33
Totals	15.5	$ 258.33	8.5	$ 141.67

5.2. Data Analysis

In Table 2, it is shown an analysis of the times of each process to produce a part. In this table a time reduction can be observed when implementing the A.R. application.

Fig. 7. Table 2. Time data analysis before and after using A.R. Source: Automated Data Systems S.A. de C.V. (2015)

TABLE 2.1 MACHINING PROCESS TIMES PART IN LATHE

Operation	Time without R.A. (min)	Time with R.A. (min)
Preparation of lathe	20	15
Prepare tooling	15	10
Holding and centering piece	5	3
Machined face	3	2
Machined inner diameter and depth	20	15
Outside diameter machining	10	7
Placing and removing part	5	3
Machined face and thick	10	8
Remove piece	2	2
Cleaning area and part	5	4
Totals	95	69

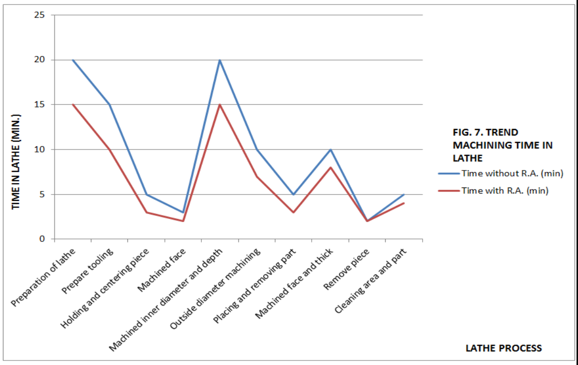


TABLE 2.2 MACHINING PROCESS TIMES PART IN MILLING

Operation	Time without R.A. (min)	Time with R.A. (min)
Preparation of milling	30	22
Locate tools	10	7
Holding and centering piece	5	3
machining window	20	15
machining relief	5	4
Drilling and tapping	10	7
machining two relief	5	3
Placing and removing part	10	8
Cable machined cavity	10	7
Machining plane	3	3
Cleaning area and part	5	4
Totals	113	83

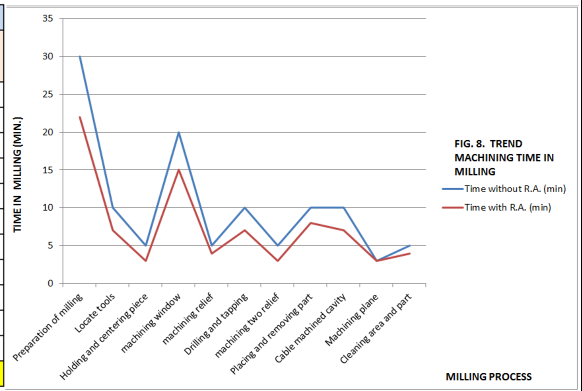
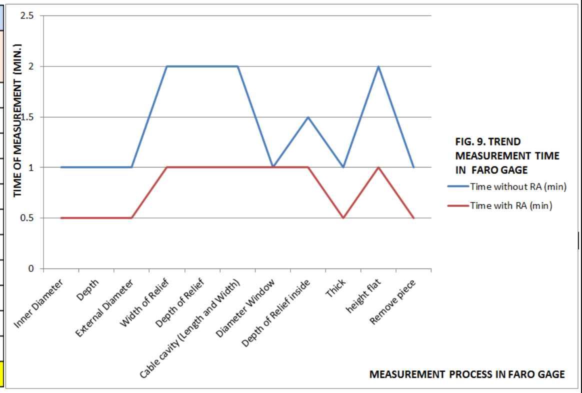


TABLE 2.3 MEASUREMENT PROCESS TIMES IN FARO GAGE

Operation	Time without RA (min)	Time with RA (min)
Inner Diameter	1	0.5
Depth	1	0.5
External Diameter	1	0.5
Width of Relief	2	1
Depth of Relief	2	1
Cable cavity (Length and Width)	2	1
Diameter Window	1	1
Depth of Relief inside	1.5	1
Thick	1	0.5
height flat	2	1
Remove piece	1	0.5
Totals	15.5	8.5



In Table 3, it is shown the total costs for a 10 parts-a-day production in ADS, i.e., 60 parts a week, 240 pieces a month

Fig. 8. Table 3. Cost data analysis, considering a 240 parts-a-month production, in each of the processes before and after using A.R. Source: Automated Data Systems S.A. de C.V. (2015)

TABLE 3.1 MACHINING PROCESS COSTS PART IN LATHE

Operation	Costs without R.A. Pesos	Costs with R.A. Pesos
Preparation of lathe	$ 6,000.00	$ 4,500.00
Prepare tooling	$ 4,500.00	$ 3,000.00
Holding and centering piece	$ 1,500.00	$ 900.00
Machined face	$ 900.00	$ 600.00
Machined inner diameter and depth	$ 6,000.00	$ 4,500.00
Outside diameter machining	$ 3,000.00	$ 2,100.00
Placing and removing part	$ 1,500.00	$ 900.00
Machined face and thick	$ 3,000.00	$ 2,400.00
Remove piece	$ 600.00	$ 600.00
Cleaning area and part	$ 1,500.00	$ 1,200.00
Totals	$ 28,500.00	$ 20,700.00

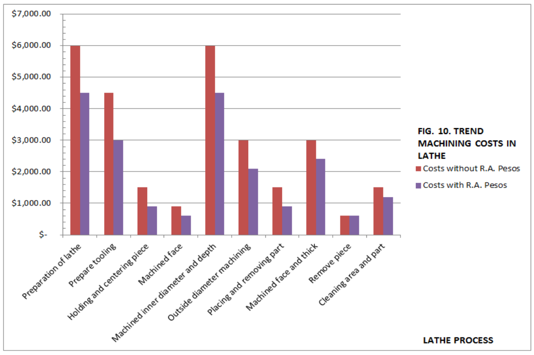


TABLE 3.2 MACHINING PROCESS COSTS PART IN MILLING

Operatión	Costs without R.A. Pesos	Costs with R.A. Pesos
Preparation of milling	$ 9,000.00	$ 6,600.00
Locate tools	$ 3,000.00	$ 2,100.00
Holding and centering piece	$ 1,500.00	$ 900.00
machining window	$ 6,000.00	$ 4,500.00
machining relief	$ 1,500.00	$ 1,200.00
Drilling and tapping	$ 3,000.00	$ 2,100.00
machining two relief	$ 1,500.00	$ 900.00
Placing and removing part	$ 3,000.00	$ 2,400.00
Cable machined cavity	$ 3,000.00	$ 2,100.00
Machining plane	$ 900.00	$ 900.00
Cleaning area and part	$ 1,500.00	$ 1,200.00
Totals	$ 33,900.00	$ 24,900.00

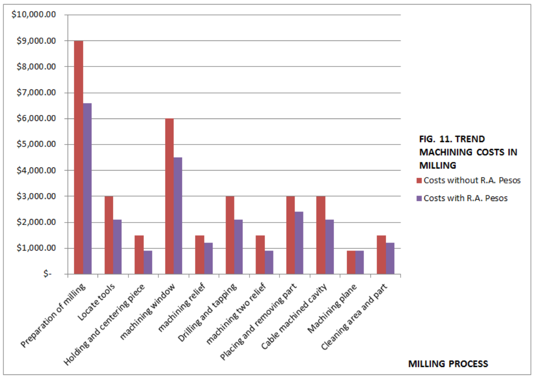
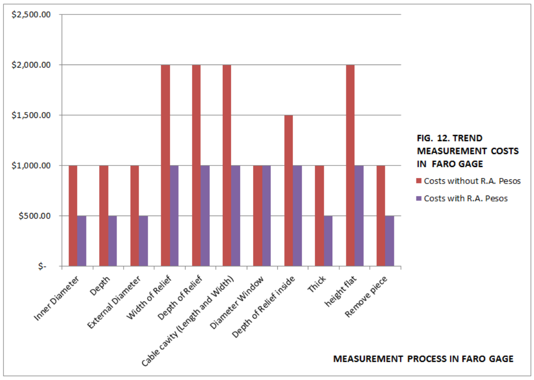


TABLE 3.3 MEASUREMENT PROCESS COSTS IN FARO GAGE

Operation	Costs without R.A. Pesos	Costs with R.A. Pesos
Inner Diameter	$ 1,000.00	$ 500.00
Depth	$ 1,000.00	$ 500.00
External Diameter	$ 1,000.00	$ 500.00
Width of Relief	$ 2,000.00	$ 1,000.00
Depth of Relief	$ 2,000.00	$ 1,000.00
Cable cavity (Length and Width)	$ 2,000.00	$ 1,000.00
Diameter Window	$ 1,000.00	$ 1,000.00
Depth of Relief inside	$ 1,500.00	$ 1,000.00
Thick	$ 1,000.00	$ 500.00
height flat	$ 2,000.00	$ 1,000.00
Remove piece	$ 1,000.00	$ 500.00
Totals	$ 15,500.00	$ 8,500.00



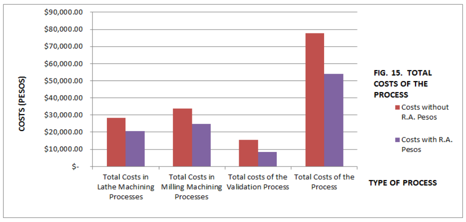
5.3. Results

Between the benefits obtained by means of this study can be mentioned the followings: time reduction in process preparation, in machining, in measurement, in validation and in decisions making during machining, reduction in the operator dependence on expert personnel, and also reducing errors possibility.

Through the research in the use of A.R. in lathe process, there was a reduction in cost from $28,500 to $27,000, achieving a 27.36% reduction. In milling process, the cost without A.R. was $33,900, and was reduced to $24,900, reflecting $9,000 in savings equivalent to 26.54%. For the dimensional validation, the reduction was from $15,500 to $8,500, getting 45.16% in savings. The results of previous graphs conclude with Table 4, which resumes the total costs of fabrication process.

Fig 9. Table 4. Total costs data analysis, considering a 240 parts-a-month production after using A.R. Source: Automated Data Systems S.A. de C.V. (2015)

TABLE 4 TOTAL COSTS OF THE PROCESS		
Operation	Costs without R.A. Pesos	Costs with R.A. Pesos
Total Costs in Lathe Machining Processes	$ 28,500.00	$ 20,700.00
Total Costs in Milling Machining Processes	$ 33,900.00	$ 24,900.00
Total costs of the Validation Process	$ 15,500.00	$ 8,500.00
Total Costs of the Process	$ 77,900.00	$ 54,100.00



6. Conclusion

Augmented Reality is, without a doubt, a technology that helps in manufacturing processes to get quality within the technical specifications required and, thus, the elaboration of a product be as expected by the client.

The fact of complementing fabrication processes augmenting the reality offers an advantage over processes that lack of this technology, due to the help that it provides to the elaboration's sequential process, guiding all the involved ones into the detail levels.

A.R. comes to eliminate error possibilities in those process, reducing execution times that favorably impact to cost reduction, besides the other benefits. That is why the growing potential is a great expectative to its developers, since the application field is very wide and gives benefits to the implementer.

The use of an application like this is useful in areas such as:

- Education (from pre-scholar to professional levels)
- Medicine (In patient treatment or for making of special studies)
- Management (for ISO certification process)

6.1. New research lines

The integration of A.R. with systems related to data acquisition and monitoring in areas such as quality, production, maintenance and manufacturing processes programming, and also that it interacts with the user in charge of these areas to show performance indicators of the process.

Acknowledgements

Thanks to the personnel of Automated Data Systems (ADS), the development of the application detailed in this paper was made possible. ADS considered the Augmented Reality technology as a highly potential tool to be applied in manufacturing and quality operations. The support, knowledge and resources provided by ADS were essential to create the application shown in this paper.

References

1. Furht B. Handbook of Augmented Reality. Springer Science & Bisiness Media. 2011.
2. Metaio website: http://www.metaio.com/customers/case-studies/ar-in-service-maintenance/
3. Caudell TP, Mizell DW. Augmented Reality: An Application of Heads-Up Display Technology to Manual Manufacturing Processes, *Proceedings of 1992 IEEE Hawaii International Conference on Systems Sciences,* 1992; pp 659-669.
4. Azuma R. A Survey of Augmented Reality. *Presence: Teleoperators and Virtual Environments* 1997; 6(4): 355–385.
5. Schvab L. Máquinas y Herramientas, Ministerio de educación Instituto Nacional deEducación Tecnologica: Argentina; 2011
6. FARO Spain, Technology White Paper, pag.1-2.
7. Castro C. A methodological framework for augmented reality technological applications in industrial field. Thesis MSM, Instituto Tecnológico y de Estudios Superiores de Monterrey, campus Monterrey, México; 2012.
8. FLIR ONE website: http://flir.com/flirone/
9. Extech Instruments. Cronómetro digital Model 365510. Available on: http://www.extech.com/instruments/resources/manuals/365510_UMsp.pdf