UNIVERSIDAD DISTRITAL FRANCISCO JOSE DE CALDAS

VISIÓN ELECTRÓNICA

A CASE-STUDY VISION

Artificial vision applied to manufacturing process

Visión artificial aplicada al proceso de manufactura

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Abstract

This article presents the results of the implementation of artificial vision and image processing projects applied to a parts manufacturing process. In a first scenario, three-dimensional computational geometric models of the parts to be manufactured were obtained from the capture and processing of thermo-graphic images. In a later stage of the manufacturing process, a direct measurement system for cutting tool wear was implemented using HD images with image processing software using NI Lab VIEW from National Instruments®. In the final stage of parts manufacturing, the development of software (UDmetaL Handbook) for the quantitative metallographic analysis of micrographs for hypoeutectoid steels is presented. The software determines the type of steel based on the percentage of carbon and finds the mechanical properties of the material in a database that is incorporated into the software. The software's basis of operation is computational analysis through digital processing of

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metallographic images obtained through experimental laboratory processes using NI Lab VIEW software from National Instruments®.

Keywords: Cyanotype, Hypoeutectoid, Robotic arm, Virtual reality environment.

Resumen

En este artículo se presentan los resultados de la implementación de proyectos de visión artificial y procesamiento de imágenes aplicados a un proceso de manufactura de piezas. En un primer escenario se obtuvieron modelos geométricos computacionales tridimensionales de las piezas a fabricar a partir de la captura y procesamiento de imágenes termográficas. En una fase posterior del proceso de fabricación se implementó un sistema de medición directo del desgaste de la herramienta de corte mediante imágenes HD con un software de procesamiento de imagen por medio de NI LabVIEW de National Instruments®. Y en una de las fases finales de manufactura de las piezas se presenta el desarrollo de un software (UDmetaL Handbook) para el análisis metalográfico cuantitativo de micrografías para aceros hipoeutectoides. El software es capaz de determinar el tipo de acero de acuerdo al porcentaje de carbono y con base a éste encontrar las propiedades mecánicas del material con una base de datos que viene incorporada al software. La base de funcionamiento del software es el análisis computacional mediante el procesamiento digital de imágenes metalográficas obtenidas mediante procesos experimentales de laboratorio por medio del software NI LabVIEW de National Instruments®.

Palabras clave: Cianotipo, Hipoeutectoide, Brazo robótico, Pinza, Entorno de realidad virtual.

1. Introduction

Machine vision systems and image processing are increasingly positioned within the productive processes of industry. Today's technology allows many of the processes in both manufacturing and control to be at the level of technologies previously thought of exclusively for robotics,

artificial intelligence and advanced production systems. The new industrial revolution 4.0 shows us a closer panorama that we can adopt to arrive with new and modern solutions to the routine activities of the industrial manufacturing sector and in general in diverse sectors [1]. Reverse engineering is a systematic approach to studying the design of existing devices or systems. It is a process in which a manufactured part is evaluated without the benefit of a cyanotype for dimensional reference. The results are then reviewed, refined and the piece is remanufactured. This is a practice frequently used, for example, in the automotive industry when a manufacturer buys a competitor's vehicle in order to dismantle it and examine the welds, seals and other components of the vehicle, with the purpose of reinforcing its vehicles with similar components. Another type of reverse engineering involves the processing of 3D images of manufactured parts to remanufacture the part when a blueprint is not available. To apply reverse engineering, the part is measured on a coordinate measuring machine (CMM) and a 3D image is generated as a point cloud and presented on a monitor. After the data collection is completed, the image of the point cloud is sized; any part can be designed inversely using this method.

Two main factors are present in the current approach, academic development and industrial development in Colombia. With respect to the educational field, one of the perceived needs is to recognize the importance of quality measurements, in this case specifically in the wear of cutting tools, this in order to achieve safe and quality machining. As for the industrial field, it is well understood that accidents are one of the most outstanding consequences when processes are not properly performed, in the case of a cutting tool if it wears out sooner than expected can generate unnecessary costs to the company, hence the importance of monitoring the status of the tool directly, so the question arises is it profitable for a company to put into operation an expensive monitoring technology and unknown in the country as the laser, which also damages human vision? Given that most Colombian companies are micro-enterprises, it is likely that very few will consider this technology, because the solution may be more expensive than the

problem. Therefore, it is not very striking for companies to implement this type of technology. Despite this, a device that can be adapted to both a lathe and a machining centre was implemented, guaranteeing a safe and affordable wear measurement system for Colombian industry.

Quantitative metallography can be defined as the sampling technique used to quantify the morphological aspects of the images obtained from a material by light microscopy, scanning microscopy or transmission microscopy [2]. These are the most widespread and effective testing methods in materials science, thanks to the breakthrough in metallographic image processing technology.

Little by little, this type of procedure has been automated, resulting in specialized equipment and programs for automated testing of different standards such as the American Society for Testing and Materials (ASTM). In fact, the same ASTM has developed a standard for automated testing, codified as ASTM E1382, which allows semi-automated grain size determination of metallographic samples [3]. Currently, the quantitative analysis of micrographs is done manually using metallographic images and their analysis requires in good measure the experience of the professional in charge of this type of study. However, this type of manual analysis is very time consuming and can generate errors on the part of personnel, due to human factors such as visual fatigue, leading to errors in the interpretation of metallographic characteristics such as type of phases, grain size, type of material, mechanical properties, among others.

In this sense, the interest on the part of the academy is the automation of these processes, for that reason applications have been developed since in the present market the cost of this type of programs is high, which for the academy and small companies results in a cost impossible to pay, making difficult the development of the investigation and limiting the use of the standards. The UDmetaL Handbook software automates the analysis of metallographic images

by simply determining the percentages present in the phases of a micrograph, using thresholding processing and digital image morphology techniques, since these meet the requirements of functionality, accuracy, time and cost when determining the metallographic phases of hypo-eutectoid steels [4]. Likewise, the application is capable of determining the type of steel of the SAE-AISI standard according to the percentage of carbon and in turn finding the mechanical properties of the material with a database that is incorporated into the software.

2. 3D scanning with thermographic artificial vision

The operating principle of the proposed system is based on the use of a single thermographic camera and the heating, controlled from the base, of an object to obtain the thermal propagation front of the entire surface of the object, from a top view (Figure 1). With a conventional camera located in the same way, only one image can be observed in X-Y coordinates; but the thermographic camera, in addition, can deliver the histogram of each of the variations of the thermographic behavior of the object's surface. These X-Y histograms can be organized in such a way that by adding up these image planes the object can be volumetrically reconstructed. That is, the speed of propagation of the temperature to be processed through thermographic images serves to obtain the third coordinate, the Z coordinate.

Figure 1. System for 3D scanning based on artificial vision by thermography.
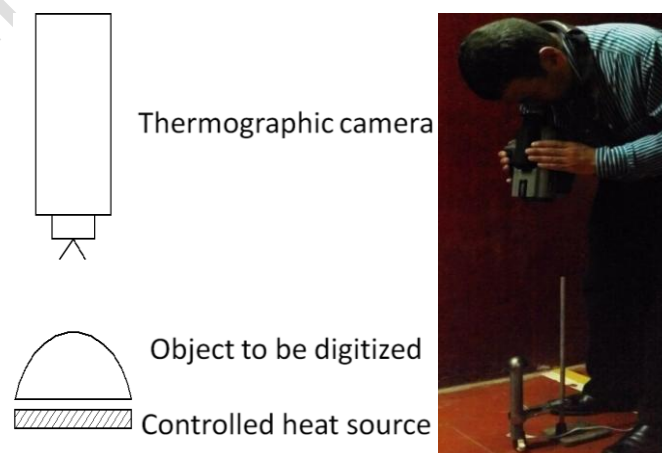
Source: own.

2.1. Methodology

The methodological process advanced to achieve the digitalization of pieces through the principle of thermography was conceived from several stages, all of them interrelated and indispensable to obtain the digitized 3D model. In the first stage of this process, the collection of information about the background related to existing image recognition systems was carried out. In order to advance the tests, the workstation for thermographic scanning in 3D was designed and manufactured. The mathematical study of heat transfer was developed in order to obtain the mathematical model that relates the speed in the heat flow with the distance in the Z coordinate. Since it was not possible to theoretically obtain the mathematical relationship to incorporate into the image processing program, a computer simulation of the heat transfer process was used to obtain the relationship curve between the distance in the Z coordinate and the heat flow. The corresponding experimental design was carried out in order to determine the number of tests to be performed to arrive at the expected response variable. The images were captured with a thermographic camera and processed in a program developed on National Instruments® NI Lab VIEW platform. Additionally, it was necessary to post-process the images in graphic modeling programs such as Rapidform® and Solidworks®.

2.2. Test design

In order to carry out the thermographic image capture tests for three-dimensional digitization purposes, it was necessary to consider important aspects such as: study piece (Figure 2), thermographic camera (Figure 3), controlled heat source (Figure 4), test environment, data storage system and computer equipment for image processing. It was decided that the material of the study piece would be a commercial AISI 1020 steel, regardless of the complications that this would bring to the project, this material being, of the three studied, the one with the lowest thermal conductivity coefficient.

Figure 2. Study objects in the initial experimentation (Aluminium, Bronze and Steel)

Source: own.

Figure 3. Thermographic camera FLIR PM 675.

Source: own.

Figure 4. Electrical resistance of the heating system.
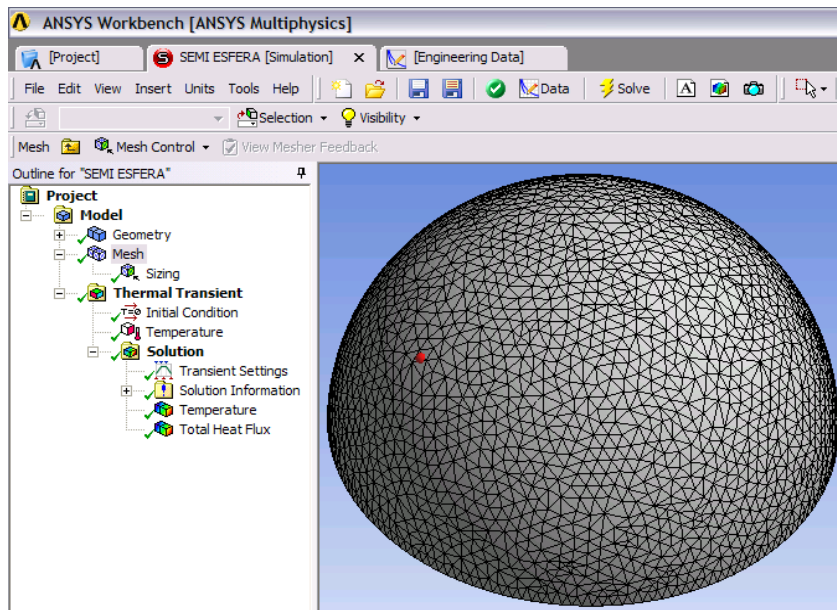

Source: own.

2.3.   Computer simulation

In order to feed the image processing algorithm, it became essential to obtain the relationship

between the speed of heat flow in the part and its correspondence in the Z coordinate of the
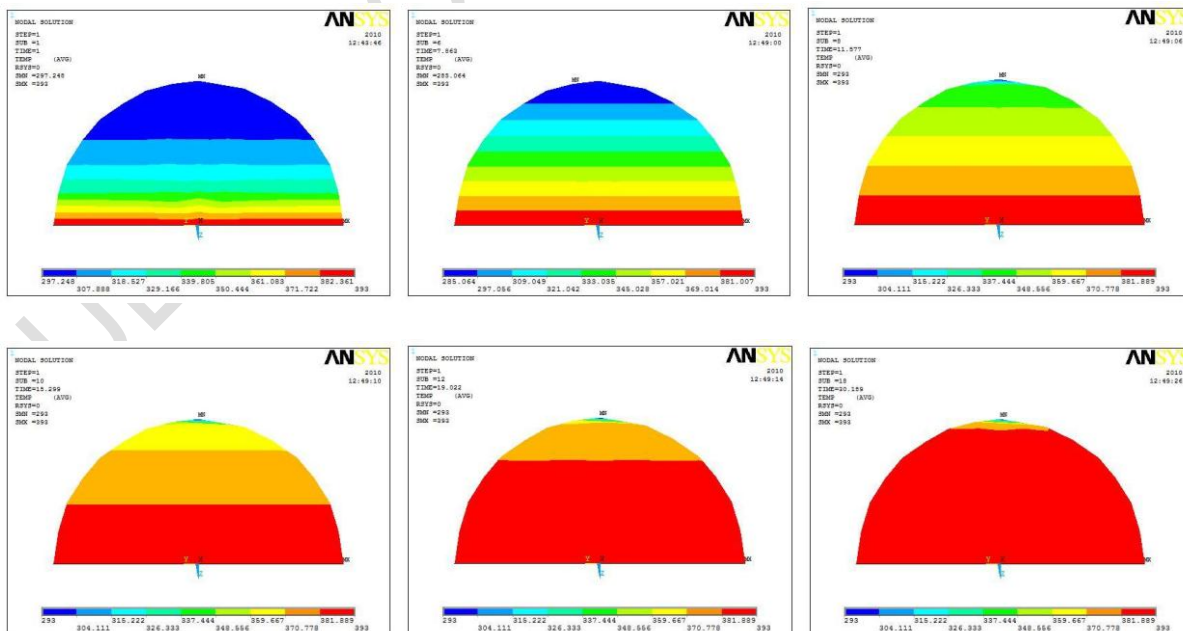
model. For this purpose, the finite element method was used through the ANSYS Workbench®

program, where the construction of the mesh of a study piece, a hemisphere (Figure 5) and the

representation of the heat flow (Figure 6) can be seen.

Figure 5. Meshing of a studio piece.

Source: own.

**Figure 6.** Graphic representation of the heat flow of the study piece.

Source: own.

2.4. Digitization software

From each experimental replica, a group of images is obtained as shown in Figure 7. In this group, the temperature behaviour during the experimental time is observed, which depends on the last temperature taken as a reference for the test. The time interval between one image and the next depends on each specific case as mentioned in the proposed experimental design.

Figure 7. Thermographic images of the hemisphere heating up from the base.
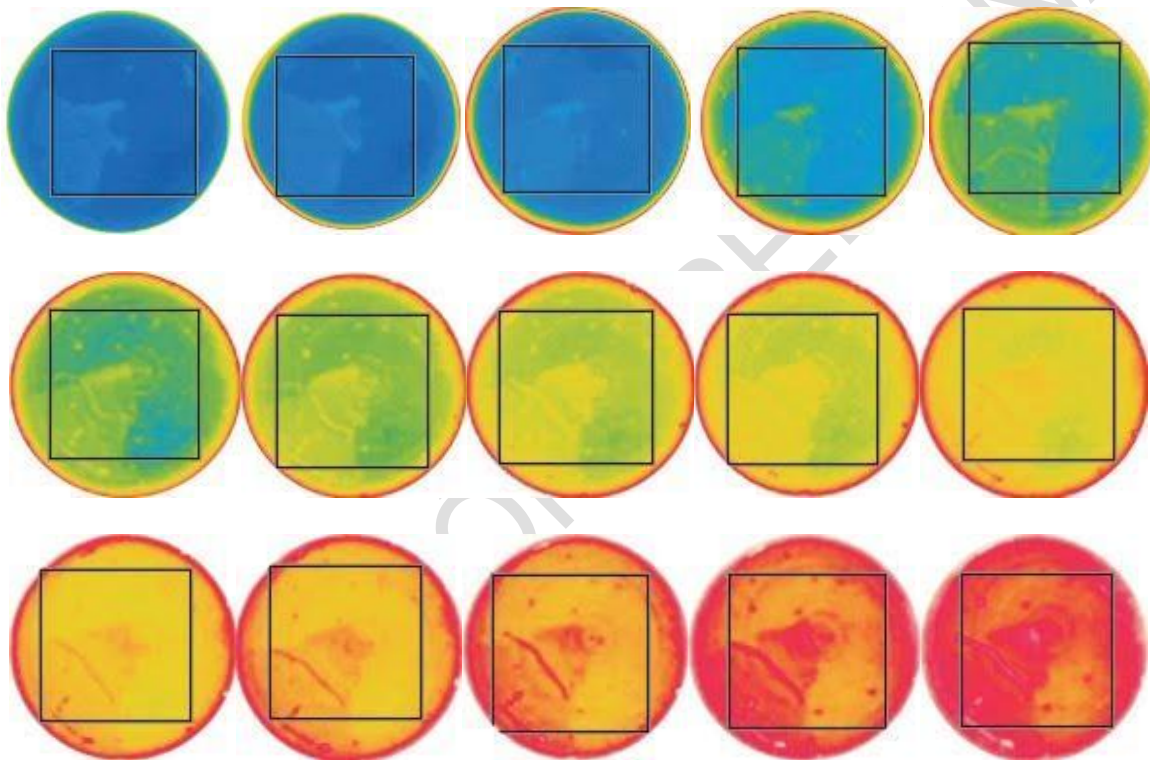
Source: own.

In order to process each of the images captured by the thermographic camera, an algorithm was developed on National Instruments® NI Lab VIEW platform, capable of transforming each of the polychromatic images into an X, Y coordinate grid. The Z coordinate is obtained as a function of time thanks to the polynomial obtained, which is included in the algorithm as shown in Figure 8.

Figure 8. Control panel of the image acquisition and processing algorithm.
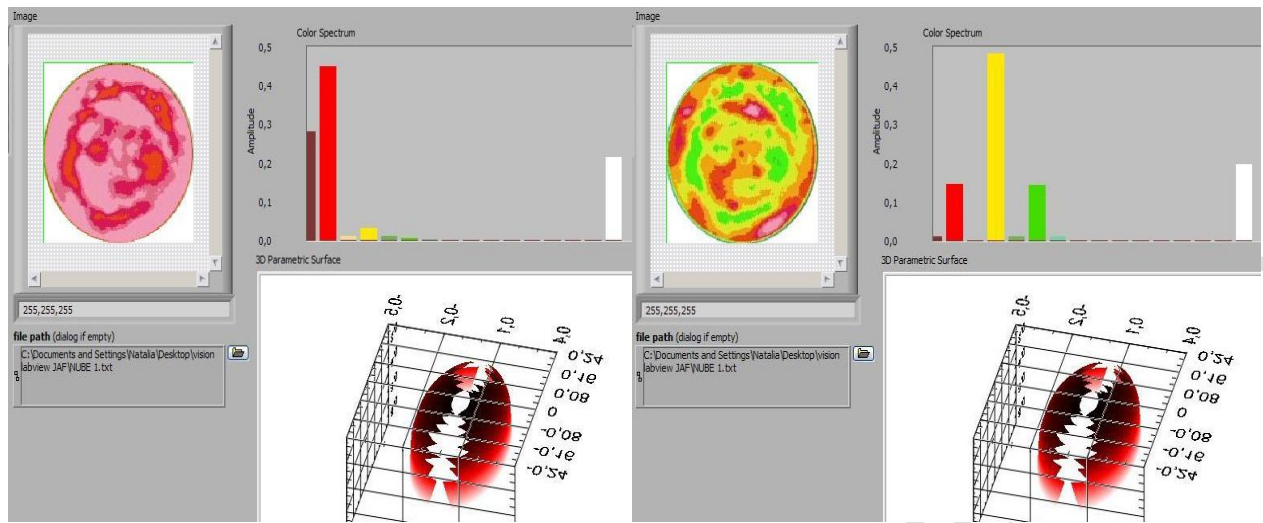
Source: own.

3. Wear measurement on cutting tools with machine vision

An artificial vision system capable of giving valid results is mainly composed of an image acquisition device, a lighting system, structure, tool support and adequate calibration. Commonly, monochromatic CCD (Charge-Coupled Device) TV cameras are used; with which resolutions of 768 x 576 pixels are obtained, for texture recognition. A manual construction of the histograms is analyzed by means of a technique known as GLCM (gray level co-occurrence matrix), and they specify the fact that there are 256 values for the gray scale and use a peripheral view of the main cutting edge (VB) in which it involves 4 views to give a two-dimensional image and thus create a 256 x 256 matrix for each of the two directions of focus [5].

Similarly, machine vision methods are useful for determining the condition of the tool with respect to each cut and thus determining the life time for replacement. What is analyzed is the area of wear, by means of three characteristics, area of wear, perimeter and compactness [6].

3.1. Image acquisition device

With a 1/4 CMOS scanning sensor and a variable focal length lens (2. 8 to 8 mm), this compact camera is capable of capturing clear and detailed images of moving objects. Thanks to H. 264 compression technology, it delivers crisp images while reducing bandwidth and storage space. The dimensions of the camera are 55 x 72 x 168 mm and the connection is made via Ethernet. The technical specifications of the camera are presented in table 1.

Table 1. Technical specifications of the Bosch NBC 265 W camera.

BOSCH NBC 265 W	
Input voltage	+12 VDC
Power consumption	4.6 W (max)
Sensor type	¼-inch CMOS
Sensor pixels	1280 x 800
Sensitivity	1.0 lux at F1.2
Video resolution	720p, 4CIF/D1, VGA, CIF, QVGA
Video compression	H.264 MP
Ethernet	10/100 Base-T, auto-sensing, RJ45
Wireless	LAN IEEE 802.11b/g
Dimensions with lens (H x W x D)	55 x 72 x 168 mm
Weight (with lens)	Approx. 255 g (0.56 lb)
Operating Temperature (Camera)	0 ℃ to +45 ℃
Operating Temperature (Power supply)	0 ℃ to +40 ℃

Source: own.

3.2. Lighting system

For the construction of the illumination system, different theories were taken into account, such as frontal illumination, which is widely used in illumination systems, consists of illuminating the piece perpendicularly, however, this method must use a background that diminishes the appearance of brightness. To measure wear on cutting inserts, 8 white 45° LEDs were placed in a ring with an internal diameter of 37 mm and an external diameter of 64 mm, concentric to the axis of the camera lens, creating a field of light that is centred and constant, and which is as perpendicular as possible to the lens, allowing the edges to be easily contrasted as shown in figure 9.

Figure 9. Lighting assembly.

Source: own.

3.3.   System structure

The design of the structure was focused on allowing the highest possible degrees of freedom in holding the camera, this allows a wide possibility of positions at the time of acquiring images, other factors were involved as dimensions of the camera, weight of the structure, ease of assembly, as well as should allow incorporate the support of the plates and lighting system. The structure was designed and manufactured in aluminium profile, the dimensions are 242 mm x 204 mm x 204 mm, with a vertical profile for the variation of the camera position in the Z axis of 450 mm in height. It has an acrylic sheet for the location of the inserts (Figure 10).

Figure 10. Camera support, lighting and inserts.
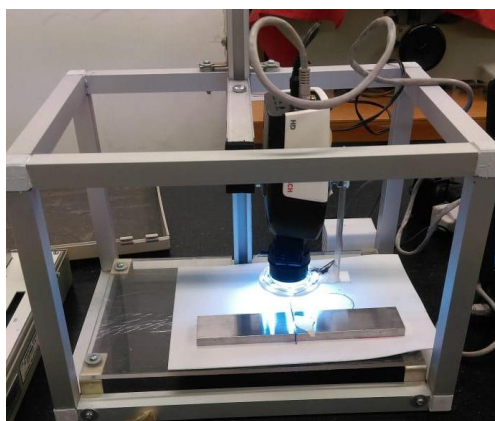
Source: own.

3.4. Software for measuring cutting tools

The Vision UD system is capable of measuring wear on cutting plates and 2D objects, through a process like any other measurement system (Figure 11). The process must have instructions specifying how to proceed, to ensure reliable and repeatable results. For this reason, an instruction protocol was constructed, explaining the steps necessary to perform reliable measurements on the new measurement system. This included the pre-installation of controllers, how to make the necessary connections for the system to start up, and instructions on how to measure.

Figure 11. User interface with green life indicator.

Source: own.

## 4. Image processing for quantitative metallographic analysis

Image processing plays an important role in the development of automated systems in the fields of medicine, biology, engineering, archaeology, among others. However, in materials science such applications are characterized by very limited and expensive licenses. For this reason and thanks to the advance of computer science and electronics, research has been developed in the creation of software with greater functionality and low cost.

At the international level, the development of these systems for material sciences is mainly concerned with the characterization of metallographic phases and the determination of the grain size index. For example, studies have been carried out on metallographic image recognition and processing systems, taking into account the characterization of the microstructure, the area and grain size, the number of pixels and the aspect ratio that identifies the ratio between the length over width of a particular grain, using pattern recognition tools, such as matching algorithms or retro-propagation (BP) neural networks [7]. Equally important is the classification based on the morphology of the graphite grain, the steels cast by means of neural networks using simple shape descriptors (SSD) or invariant moments (MI) [8].

This development is divided into three main phases: in the first one a Virtual Instrument (VI) was created exclusively for the image processing part, then another VI was developed to comply with the stage of analysis of the phases present in each image and thus be able to determine what type of steel it is according to its carbon content, finally, for each of the steels classified by the SAE-AISI standard a VI was created with representative information such as mechanical properties, chemical composition and equivalence in other standards.

## 4.1. Virtual Instrument for the image

The user interface in this image processing module consists of two displays, one for the loaded image and the other for the image with the filters already applied. Also, the drivers (red box highlighted in figure 12) choose the type of threshold and morphological filter as well as the button to view the results which will make a confirmation question initially and close the image module to move to the results phase. In the same way, the user interface for the image processing module is shown in figure 12.

Figure 12. User interface image processing module.
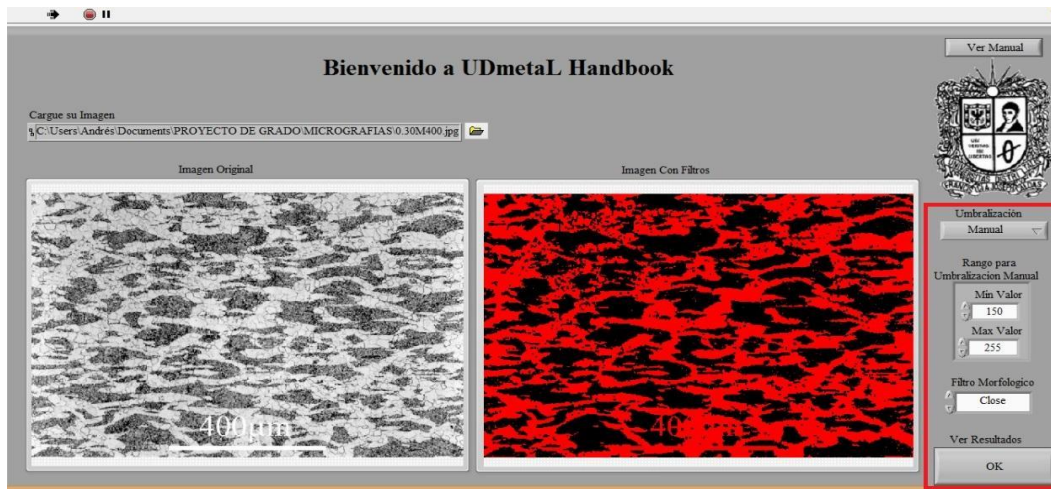
Source: own.

4.2. User interface for results analysis

The interface available to the user has three indicators (%Perlite, %Ferrite and %Carbon) with the results of the analysed metallography as shown in Figure 17. Also, buttons are available that are enabled according to the different steels that have classified among their carbon content ranges, which makes it possible for several buttons to appear on the screen as shown in figure 13. The "Exit" button allows you to close the results window to start the analysis of another new image.

Figure 13. Results analysis user interface.
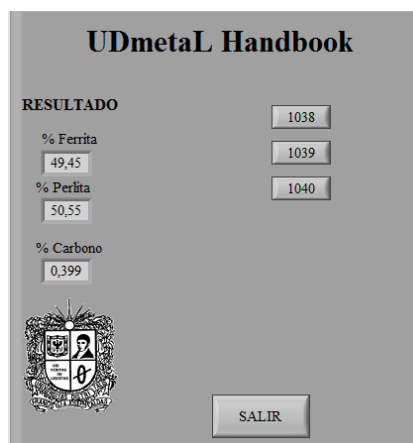
Source: own.

4.3. Virtual Instruments hypoeutectoid steels

This is the last phase of the application, which consists of creating a VI with representative information on the material for each of the 36 different hypo-eutectoid steels established in the SAE-AISI standard, specifically the 10xx series, which designates flat grain carbon steels with maximum manganese contents of 1% (ASM International, 2001). The information provided to the user by each steel is shown in figure 14, where the main mechanical properties are found, such as: modulus of elasticity, modulus of compressibility, modulus of tension, resistance to tension, Poisson's ratio, among others. These properties are for cold drawn steels and the values are in both the International System of Units and the English System of Units.

Figure 14. Interface properties of the selected steel.

ACERO		
SAE-AISI 1020		
PROPIEDADES MECÁNICAS		
PROPIEDADES MECÁNICAS	SISTEMA INTERNACIONAL	SISTEMA INGLÉS
Módulo de elasticidad	186 GPa	27000 ksi
Módulo de compresibilidad	148 GPa	21500 ksi
Relación de Poisson	0,29	0,29
Módulo de corte	72 GPa	10400 ksi
Esfuerzo último a la tensión	420 MPa	60900 psi
Esfuerzo de fluencia	350 MPa	50800 psi
Dureza, Vickers	126	126
Dureza, Rockwell B	68	68

COMPOSICIÓN QUÍMICA			
% C	% Mn	% P max	% S max
0,18-0,23	0,30-0,60	0,040	0,050

EQUIVALENCIAS OTRAS NORMAS	
ESTADOS UNIDOS (SAE)	1020
ALEMANIA (DIN)	1.0402, C22
JAPÓN (JIS)	S20C
REINO UNIDO (BS)	970 040A20
FRANCIA (AFNOR)	A35-551 XC18
ITALIA (UNI)	5598 1CD20
SUECIA (SS)	1450

Source: own.

5. Conclusions

As a result of this research work, we first have the identification of the most significant variables within the thermograph-based three-dimensional digitization process (temperature range and number of images captured) and their respective working range for each of them. Second, both the heating temperature limit and the number of images required to reproduce a 3D model are manageable variables when reproducing the experiment. And third, a software tool was

developed for the acquisition, processing and post-processing of thermographic images, aimed at the three-dimensional reconstruction of 3D geometric models.

The machine vision cutting tool measurement system put into operation is capable of measuring wear on cutting inserts, under the criteria of ISO 3685 and ISO 8688 for standardized turning and milling inserts respectively. The measurement is achieved by a direct method in a time of 200 ms, without affecting the part to be measured, this is beneficial in academia and industry, because it optimizes the machining processes in addition to not needing to remove the insert from the tool holder. We automated the processing and analysis of metallographic images for hypothecating steels by creating the UDmetaL Handbook application providing less time for the analysis of micrographs. The application developed has the function of determining the types of SAE-AISI steel even when the micrographs of the same type of material come from different types of image capture (e. g: variation in eye magnification, polychrome intensities, among others).

References

[1] Deutschland, "Hanover Fair", 2014. [online]. Available at: https://www.deutschland.de/es/topic/economia/globalizacion-comercio-mundial/industria-40-en-la-feria-de-hannover

[2] M. Velandia, "Quantitative Metallography", CITEG Referred magazine. Year 2. N°3, pp. 57-60, 2008.

[3] ASTM E1382-97. (2015). Standard Test Methods for Determining Average Grain Size Using Semiautomatic And Automatic Image Analysis. https://webstore.ansi.org/Standards/ASTM/ASTME1382972015?gclid=CjwKCAiAoOz-BRBdEiwAyuvA66bmVazawSGcOvp3QjCI0IqAtNGcpOvQFxssA-o5-r5ImgjgaoaMmBoCMVcQAvD_BwE

[4] C. C. Castañeda Agudelo, A. F. Ramírez Moreno, "Automation of the quantitative analysis of metallographic images of mortgaged steels. Mechanical engineering degree work, Universidad Distrital Francisco José de Caldas.

[5] D. Kerr, J. Pengilley, R. Garwood, "Assessment and visualisation of machine tool wear using computer vision". *Int J Adv Manuf Technol,* vol. 28, pp. 781–791, 2006. https://doi.org/10.1007/s00170-004-2420-0

[6]   Y. D. Chethan, H. V. Ravindra, Y. T. Krishne gowda, S. Bharath Kumar, "Machine Vision for Tool Status Monitoring in Turning Inconel 718 using Blob Analysis", Materials Today: Proceedings, vol. 2, no. 4–5, pp. 1841-1848, 2015.

[7]   W. Tan, C. Wu, S. Zhao and S. Li, "Study on key technology of metallographic image processing and recognition", *2008 Chinese Control and Decision Conference*, Yantai, Shandong, 2008, pp. 1832-1837. http://doi.org/10.1109/CCDC.2008.4597640

[8]   C. Prakash V. Pattan, P. Mytri, "Hiremath. Classification of cast iron based on graphite grain morphology using neural network approach. Proc. SPIE 7546, Second International Conference on Digital Image Processing, 2010, https://doi.org/10.1117/12.853286