Positioning of the Cutting Tool of a CNC Type Milling Machine by Means of Digital Image Processing

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Abstract. Currently, technological developments and scientific advances have driven the manufacturing industry. This allows processes to generate more quickly and efficiently. The machining process is carried out in conventional machines and tools where one or several people have different tasks. This entailed a risk for the personnel involved and the production times vary depending on the operator's experience. The numerical control machines are a solution to these problems. However, this automatic process still needs human intervention to complete some tasks. Current, research in the area of artificial vision has improved the machining processes in order to meet the demand of the industry. This article presents the implementation of an artificial vision system within a machining process, Specifically looking for the zero point or reference for a CNC milling machine. The procedure is done manually and depending on the skill of the operator could generate delays in the machining process and showing differences in measurement due to initial calibration.

Keywords: CNC · Images processing · Machines tools

1 Introduction

The demands for quality, quantity, and efficiency of the metalworking industry are high. For this reason, the research and developments such as those mentioned in [8,11] are focused on meeting this need and seeking innovation in this sector with the implementation of new technologies in these production processes. An example of this is the application of advanced control algorithms as in [12] and the use of computer vision and artificial intelligence in [3,4,10].

In the manufacturing process, the CNC (Computer Numerical Control) milling machines contribute to a great extent to the fulfillment of the quality standards. The main problem that the use of these machines has is that it is necessary to perform an initial calibration procedure in connection with the raw

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material to be machined. The coordinates of the object must be known. It must comply with the minimum dimensions for the fastening and machining of the piece. This procedure consumes part of the manufacturing time and generates loss related to downtime in the production stage.

In this work, it's proposed the implementation of an artificial vision system. The artificial vision system optimizes the positioning of the cutting tool in a CNC machine. The system makes the recognition of dimension spatial of raw material. The technique used is the segmentation of the image in the XY plane. This technique identifies: The piece, the lengths and distances with the reference axis. The artificial vision system provides the distance between the piece and the cutting tool. The new data are deposited to the software CAM that generates a new G code.

Below is a description of the following sections: In the Sect. 3 there is a description of the CNC machine implemented in the process, as well as the camera, the images, algorithms and the systems involved, in Sect. 4, the requirements are mentioned in terms of raw material, lighting conditions as well as the procedure for segmentation and extraction of the characteristics, finally in Sect. 5 some tests and results of the implemented system are illustrated. Finally, in the Sect. 6 y 7 are presented the conclusions and future work.

2 Previous Work

There is a series of works made in the last 5 years focused on technological developments in artificial vision system with CNC machines presented below. An example of these studies is the one presented in 2011 by French researchers in [2], to avoid collisions of the machine with the parts to be machined by means of digital image processing. They propose the solution of a safe trajectory based on a snake-ladder algorithm where the images of the machine are taken, go through a segmentation process to identify the important elements, their dimensions and the spatial location, and send the information to CAM software (Computer assisted manufacturing). It generates the G code corresponding to the execution of the instructions based on the results of the processing of the images and the cutting operations is generated.

The development and research related to CNC machine not only focus on the recognition or location of parts in cutting tools. In [1] uses as feedback an optical sensor for the CNC machine and for to improve the finish, two cameras are implemented that it acquires the visual information of the state of the piece during the machining process. During the execution, there are drawbacks to the acquisition of the images due to the metal chip. this causes erroneous readings of the piece. The chip aspiration of machined material in the machine uses at the moment of the reading of data in the image.

In 2014 at the science university in Tokyo presented in [9] the detection of work pieces and the location of the tool for mechaning. In the application uses an RGB-D camera to obtain a high degree of sensitivity and provide images in depth. One of the main factors in the acquisition of images or video is the alignment of the camera, without rotational component and the prevention of movements of the camera. To segment and extract the piece, it used methods for the analysis and automation of cartography and an efficient method RANSAC (Random Sample Consensus). This methods to iterate and calculate parameters of a mathematical model in order to detect the predominant plane of the image. The segmentation is not Euclidean because it also depends on the angular deviation between the camera and the spatial location of the piece. The 3D image is reconstructed, giving it width, depth, and height from a vertical and a horizontal image with one camera only.

Exist work about precision and quality as the presented by Superiore Sant'Anna of Pisa, Italy in [5]. It develops an intelligent cutting machine for marble through an artificial vision system. That system detects the defects of the plate and calculates the optimal distribution of the pieces to be cut avoiding the defective parts. These imperfections can be abrupt variations of color and texture on the surface of the marble plate or they can occur in areas of the surface with deformations that are the classic pattern presented in this type of elements. The identification and distinction of this type of patterns are commonly performed by a method of artificial intelligence and neural networks. This method requires a large database of images that can be difficult to collect and in this article, they propose a hybrid solution where the imperfections are found out manually and the cracks are automatically detected by the algorithm. These works provide the basis to start the process of detection of parts through an artificial vision system in CNC milling machines.

3 Materials and Methods

In this section is describing the characteristics of the machine in which the artificial vision system is implemented, the specifications of the image acquisition device, the main elements of the computation and processing system, the acquired images, the algorithms, methods, and software involved in the process.

3.1 Type of Machine

The Fig. 1 shows the CNC milling machine. A prototype built in the SENA (Servicio Nacional de Aprendizaje) with a structural design of type bridge. The minimum displacement per axis is of 10 μm. The servomotors AC has a resolution of 16384 steps. The ball screw has a precision of pitch of 5 mm per revolution. It has a spindle with a variation of speed (between 2000 and 23500 RPM). The working area of the machine is 300 (on axis X) x 300 (on axis Y) x 150 (on axis Z) mm.

3.2 Camera

The criteria for selection of the camera based on the parameters of precision of the machine, the artificial vision system provides the measurements and location

Fig. 1. CNC machine.

of the cutting tool with an error that is admissible for the movement of axes, the model of the camera is a Blackfly of 1.3 MP that has the following. Characteristics: Resolution 1288 * 964 px, type of CCD sensor, pixel size of 3.75 μm.

3.3 Images Description

The images were taken perpendicular to the work table. The information of the coordinates of the piece in the XY plane shows in Fig. 2, the images are taken from the same point. The variation lies in the type of material (polymer, aluminum, among others), location and orientation within the work area.

Fig. 2. Image taken from the XY plane of the work area

3.4 Software

For the integration of the entire manufacturing process used free software and an operating system Debian (Wheezy). For the mechanical design of the parts is used CAD software. This design loaded into a program CAM for the generation of G code. The CNC software is used for the execution of the instructions of the machine in real time.

- CAD (Computer Aided Design).
  The software used for the design of the desired pieces is FreeCAD (version 0.14.37). It has a portfolio of services in cover architectural designs, 2D and 3D designs, simulation of movements for robotic arms, image editor, reverse engineering, and an assembly module. So it meets the minimum requirement integrated into the manufacturing process.
- CAM (Computer Aided Manufacturing).
  After the design of the desired part, the manufacturing process is continued. The G code is generated with the trajectories and instructions that the machine must follow. For the development, it's factors taken into account as the type of material, the type of tools, travel and machining speeds, among others. The HeeksCNC CAM software is open architecture based on language programming python. The language python allows changes in the application (HeeksCNC) for manufacturing of parts. The information comes from the stage of artificial vision.
- Software CNC (Computer Numerical Control).
  To complete the process used the software LinuxCNC 2.7.11, which implements an open architecture for numerical control. It based on the RT-Linux kernel. Its function executes the G code for the piece manufacture and the calibration stage of the offset of the axis. This software is implemented in applications as in [6], where is developed the manipulation of a robotic arm for the drilling of bones.

3.5 Bag of Features

This method compares workpieces images with the 2D design. The descriptors extracted presents aspects as color changes, corners, edges, among others. The algorithm uses the SIFT to extract the key points of the images. These characteristics and point extracted for the segmented image and for the 2D design of the face to be intervened to obtain a vector of dimension $n \times 128$. Where n is the number of the key points founded.

After obtaining this vector of visual features is realized a grouping by a simple method, Euclidean distance. The number of selected conglomerates of characteristics converts in the bag of features. Once the representative points obtained, the visual features or points are compared with the workpiece image Fig. 3.

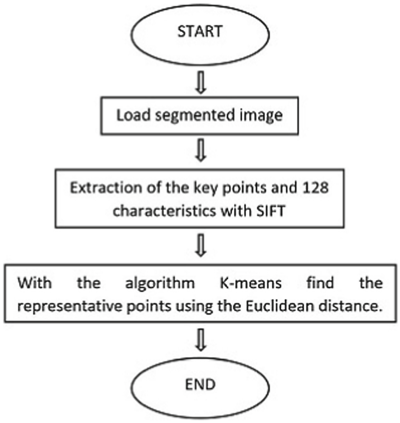


Fig. 3. Flowchart BoF.

4 Methodology

4.1 Workpiece

For the selection of the materials used in the experiments. It is necessary to take into account the limitations of the CNC milling machine, as mentioned in Sect. 3.1 CNC machine has a high-speed spindle. The materials machined are soft materials (engineering plastics and metals such as bronze and aluminum).

4.2 Illumination Conditions

In the applications where artificial vision systems are involved the lighting is a fundamental aspect because the cameras capture the light reflected in the objects. Establish adequate conditions and normalized lighting to facilitates the image processing. The most used techniques for this type of systems are front light, side light, contrast lighting and diffuse axial lighting. In this case, it is proposed to implement lateral lighting for its advantages when highlighting edges, adjusts to a degree of low inclination. In order not highlight much the reliefs of the piece because they are not of interest in the application.

4.3 Pre-processing

In the initial stage, an image of the work area is obtained without objects (initial state)to facilitate the segmentation process. The work table has grooves dark compared to the surface for the raw material subjection. For this reason, it is necessary to implement a filter of the median with a neighborhood of 50×50 pixels. So that, it is ensured that the background is normalized and delete only the unwanted surface.

The process of extraction of an object explains below. It's used a simple operation of bit by bit subtraction among the image of the piece and background filtered. The resulting image is shown in Fig. 4 where to observed that the interest object highlights in the image.

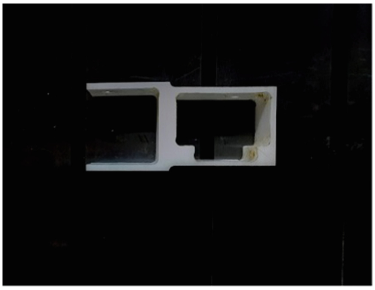


Fig. 4. Image without background for segmentation.

4.4 Segmentation

For the segmentation process, the next steps are developed. It's implemented a simple thresholding method or single thresh [7] that consists of extracting the histogram of the image. The histogram is the representation of the frequency of occurrence of the gray levels. In the Figure 5 it's found an image in a graph two-dimensional. Although several techniques of thresholding tested, the most simple give satisfactory results for this process. The histogram is separated into two parts. The Selection of the threshold is 27.45% so that the pixels corresponding to the piece exceeds the threshold. Using the structure of the Eq. 1 the new image is created.

$$I(x,y) = \begin{Bmatrix} 1 & if \;\; I(x,y) > T \\ 0 & if \;\; I(x,y) \leq T \end{Bmatrix} \tag{1}$$

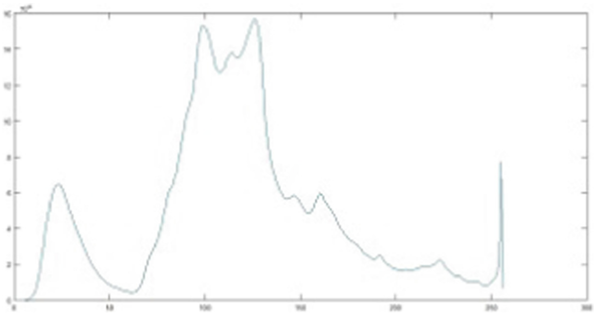


Fig. 5. Histogram.

After segmentation, a series of filters applies according to Fig. 6 to eliminate noise and undesirable elements in the image. However, some points remain in the image. The morphological operations isolate the workpiece image.

Fig. 6. Filters

- Median filter: It's one of the most commonly used non-linear filters due to its ease of attenuating noise without affecting the edges of the image, establishing a neighborhood in a pixel and extracting the value from the median. In this case, is use a rectangle of size $(20, 20)$ to delete the points and stripes that don't belong to the workpiece.
- Gaussian filter: It's a smoothing filter. It uses a neighborhood based on a Gaussian function. The Eq. (2) is a Gaussian function that to soften the noise. The weight of the central pixel is the highest and decreases according to the increment of the distance from the center. The rate of decrease depends on the assigned deviation. The size of the chosen neighborhood is 5 and the standard deviation is 1. So, the method eliminates small undesirable variations and the square edges that remain after the median filter.

$$\Phi(x) = \frac{1}{\sqrt{2\pi\sigma}} e\left(\frac{x-\mu}{2\sigma^2}\right)^2 \tag{2}$$

- Opening operation: After performing the filters, it's presented next process. It uses a morphological operation based on the theory of sets that affects the shape of the piece in the image. These are operations between sets of pixels. For this case corresponds to the Eq. 3 where A is the set and K the structural element (a disk of radius 20) used as the basis for the opening operation. This softens the outline of the objects in the image, separates the unions narrow and removes the fine projections of the remaining undesirable elements.

$$A \circ K = (A \ominus K) \oplus K \tag{3}$$

4.5 Characteristics Extraction

After obtaining a piece segmented (Fig. 7) the characteristics of the piece are extracted. This is the coordinates in X, Y and their angle of orientation about the Y-axis. The location within the work area is determined and relates to the reference of the cutting tool. The operation necessary for the extraction of a characteristic (centroid of the piece) is observed in the Eqs. 4 and 5.

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N} \tag{4}$$

$$\bar{y} = \frac{\sum_{i=1}^{y} x_i}{N} \tag{5}$$

Fig. 7. Segmented piece.

4.6 Heekscnc Intervention

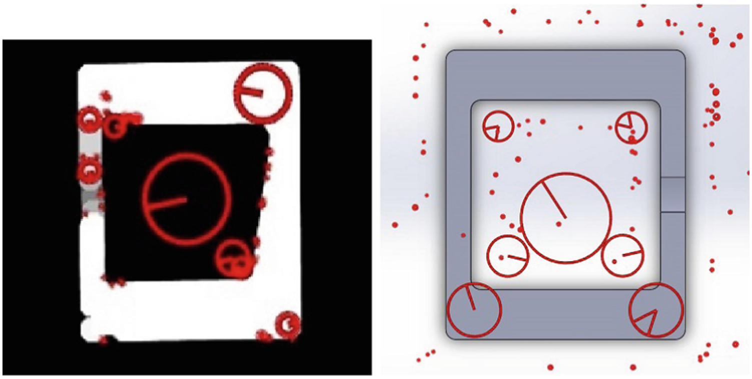
The Python programming language implements the artificial vision algorithm. An interpreted and multi-platform language, also known as multi-paradigm. It allows object-oriented programming, imperative programming, and functional programming. Python uses Mainly on the ability to be implemented in applications open source like the most of Linux application. The CAM program generates the g-code on language c/c ++ that have an open source license. Due to these features, it is possible to intervene the software and add the algorithm of the location of the piece based on the data extracted from the artificial vision module that updates the properties of the piece. Specifically its coordinate x, y, and orientation angle, this is integrated into the properties module of the software HeeksCNC. The design is loaded into the CAM software to generates the contours, profiles, and machining operations. The software receives the offset data of the stage of the image processing. The algorithm modifies the coordinates by default and updates the values with the displacements and rotation. This gives the correct position to the LinuxCNC in the G code. In this way is eliminated the process of calibration of the machine respect to the position of the piece.

5 Experiments and Results

The tests of the system of artificial vision integrated into the process of manufacture are made with the mentioned materials and simple geometrical figures (rectangle, square, among others). Other tests are made on pieces more complex. The system of artificial vision recognize the pieces and their location correcting the offset of the spindle. In the Fig. 8 is observed a test performed with a piece previously machined.

In a typical process with a CNC machine, it is necessary to rotate the piece and locate it with a lot of precision trying to keep the reference zero (0). However, with the proposed solution the piece is rotated and located randomly in the work area, the BoF algorithm is responsible for determining the points of interest in the piece by making a comparison with the 2D plane. With this it is possible to relate the position and reference the piece with the cutting tool, in the Fig. 8(a) is observed in the rotated and segmented piece with the interest points.

This process is done with an image of the 2D design of the face to be mechanized without the extrusion cut operations and the image of the segmented piece Fig. 8(b). It identifying the strongest similar points that allow the workpiece to be comparison though of a linear transformation. This stage is only possible if the design image is made at the same scale respect to the real image of the segmented piece section.



(a) Segmented piece. (b) 2D Design.

Fig. 8. Key points.

In this way it is possible to locate and perform the pertinent perforations according to Fig. 9 and mechanized in an efficient way, minimizing human intervention, and improving manufacturing times. In general, results have obtained that show a percentage of error close to 4.7% thrown by the precision of the machine and the resolution of the camera. The times measured for this process have a difference with respect to the conventional process of 10 to 17 min.

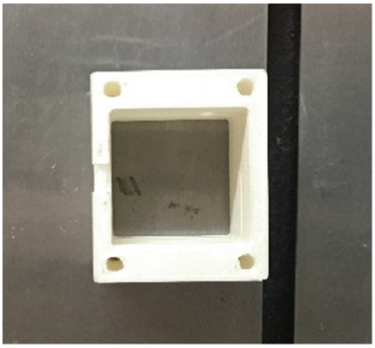


Fig. 9. Operation result.

5.1 Digital Image Processing

- Successful cases
  The system presents a good behavior when an adequate segmentation is achieved in the initial process. The method of BoF gets the key points of the piece are correctly obtained which facilitates the procedure during the comparison with the design in 2D to reference the piece with the coordinates of the CNC machine. Some of the successful cases of segmentation and localization are present in Table 1 referring to the images of the Fig. 10.
- Failed cases
  During the experiments carried out, there are mainly two cases in which the

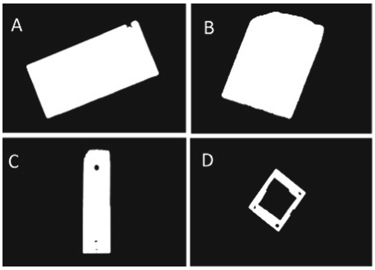


Fig. 10. Successful cases of segmented pieces.

Table 1. Tests

Coordinate	Image A	Image B	Image C	Image D
X (mm)	−52.20	−62.18	−52.72	−51.01
Y (mm)	76.59	85.98	60.25	46.47
Angle (degrees)	22.10	66.28	89.42	45.48

algorithm presents difficulties. This occurs due to inconveniences with the light and the material of the piece.

- Case I: The role of lighting in this type of process is very important. Some pieces generate shadows due to their shape or material causing different intensity levels in the pixels that correspond to the workpiece and the algorithm omits or eliminates certain parts of the image which leads to the deformation of the piece in the segmentation process. This result is evidenced in the Fig. 11.
- Case II: In some cases, the materials reflect the light so the algorithm in the thresholding process does not achieve an adequate segmentation. Additionally, it is difficult to determine what is part of the piece or work area. For this reason, and as a result, several isolated objects are obtained and it is not possible to finish the process correctly, as shown in Fig. 12.

(a) Piece of work. (b) No segmented.

Fig. 11. Piece non segmented.

(a) Piece of work. (b) Misshapen piece.

Fig. 12. Deforming on the segmenting.

6 Conclusions

During the development of the project, it was possible to demonstrate the improvement in the performance, times and simplification of the production processes through the coupling of artificial vision techniques to manufacturing chains oriented to CNC type machines and tools.

The bag of features method presents a good behavior in the extraction of the characteristics of segmented images. It is possible to obtain enough data to make the comparison.

In general, the system has maximum errors of 4.7%. It implemented for a real system. It presents satisfactory results for the manufacture of parts of medium precision.

7 Future Work

During the development of the project, the tests were carried out with different types of materials. The machine presents limitations, is necessary to use polymers and discard metallic materials. It's possible improvement of the algorithm of segmentation for different types of materials and changes in illumination.

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