

Computer Vision system for Automatic Inspection of Automotive parts in Assembly Lines



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Abstract

The ability to automatically perform inspection and quality control in manufacturing lines, is a valuable resource, which reduces manufacturing costs and improves product quality.

This work presents a successful industrial application of the machine vision technology for the automatic inspection of half-shaft in an assembly line. The implemented system allows a 100% inspection of the parts in a reliable way, reducing time and cost, and decreasing the possibility of human errors.

The visual inspection system developed has seven cameras that were integrated into an inspection cell, which have the capacity to cover a large part of the surface of the object to be inspected. Using the data acquisition board, it is possible to send all the scenes captured by the camera to the vision software installed on the PC, where the various processing and analysis techniques will be carried out.

The development of the vision algorithms and the communication between the acquisition sensors and the control module are based on the tools provides by VisionPro software from Cognex. This software presents potential tools for image acquisition, as well as its processing and analysis. In addition, its interoperability capability with .NET facilitates the development of customizable vision software, adjusting it to the different requirements and needs of the client.

Chapter One defines the problem and gives an overview of existing systems. Chapter Two covers the state of the art and the techniques for image processing and analysis. Chapter Three describes the architecture of vision system, the elements that compose it, and functional requirements. Chapter Four mentions some results taken with the developed inspection system. Finally, the conclusions and future works are described in Chapter Five.

I dedicate this thesis to my parents, who taught me the value of hard work and that even the largest task can be accomplished if it is done one step at a time. To my sister, Maricruz, who has been a source of encouragement and inspiration. To my little brother, Angelo, whose smile illuminates our lives. To Francesco, who have actively supported me along the journey, making sense of the various challenges and providing me encouragement at those times when it seemed impossible to continue. It is also dedicated to all my family, friends, colleagues whose steadfast support were greatly needed and deeply appreciated.

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Chapter 1

Introduction

The production line has evolved from the manual process to the current Industry 4.0. Through the use of automated systems, artificial vision or collaborative robotics, the industry has increased its competitiveness. The production lines are constantly advancing and developing trying to achieve the optimization of their processes. Quality control is one of the most important aspects in industrial competitiveness. Traditionally, visual inspection is developed by human vision, which is subject to a high degree of subjectivity and whose results will depend on the experience of the inspector and his knowledge about the product. Likewise, the effectiveness of the work of inspector is subject to emotional and physic factors (Newman & Jain, 1995). These reasons have led to the search for more efficient computational solutions. As a result, several applications with computer vision have emerged. Computer vision, also called machine vision, is a technique based on recognizing, extracting and analysing quantitative information from digital images, thus verifying a specific process, activity or some task (Ma et al., 2016).

Nowadays, most large industrial production and assembly lines have an exhaustive control of the quality based on machine vision, which allows a high reliability in the inspection, reduction the production times, costs, increase of the final product quality and flexibility in the production. A very frequent problem in global industry manufacturing processes, is that, they include different manufacturing processes to reach the final product, therefore, the analysis of quality must be guaranteed throughout the different processes up to the final product. For example, the automotive manufacturing process, due to its dimension, consists of sequential processes such as body manufacturing, spraying, final assembly, and final inspections.

The automotive industry, in general, is considered a strategic sector for economic activity, due to the dynamism that it produces in the manufacturing and for many other productive activities in the areas where it is located. The automotive industry is also a huge source of investment, due to its peculiar characteristics force it to

establish numerous productive chains and to organize them in such a way that can reduce costs and take advantage of economies of scale and reach new markets.

The automotive industry is defined, according to the conventional usage, as the production and assembly of passenger cars and commercial vehicles (trucks and buses) (Lall, 1980). The production of a car requires more than 10,000 pieces, a big team people working and decades of research and development.

Although the market is dominated by relatively well-known Automotive firms or automakers in Europe, China, Japan and the United States, there is a whole network of supplier and manufacturers of auto parts and components (ACEA, 2018). The automotive firms are the responsible for the development, design, engineering and marketing of the vehicle, and it generally directly undertakes the manufacture of several components of the body as engines, transmission, frames and body parts. Nowadays, many of the Automotive firms turn to first-tier suppliers for the design and production of most components and even large sub-assemblies (Fourcade & Midler, 2005). In fact, first-tier suppliers are now as global as the vehicle manufacturers. The first-tier suppliers get subcomponents from second tier and third tier suppliers, and this chain continues down to raw material suppliers. In order to limit exposure to currency fluctuations, reduce transportation costs and minimize risks of damage in transit. First and second-tier supplier are generally located near the final assembly line, since the modules must be delivered just in time and in the required sequence at the end of the line. Similarly, the manufacturers of auto parts and components produce Original Equipment (OE) parts as close to the assembly plants as possible. The automotive parts manufacturing industry is comprised primarily of two segments: Original Equipment suppliers and aftermarket suppliers. OE suppliers design and manufacture parts required for the assembly of vehicles. OE production accounts for an estimated two-thirds to three-fourths of the total automotive parts production. Aftermarket parts are automotive parts built or remanufactured to replace OE parts as they become worn or damaged. Related to this is specialty equipment, which are the parts and tools for consumer preference vehicle modifications. Specialty equipment refers to parts made for comfort, convenience, performance, safety or customization and are designed for add-on after the original assembly of the motor vehicle (Williams, 2016).

1.1 Automotive Industry: A historical review

In the evolution of the automotive activity, Mortimore & Barron (2005) analysed two very important stages. The first one that took place at the beginning of the last century, in the United States, and that was characterized by the use of assembly lines, favouring mass production and reducing unit production costs, in particular Ford and General Motors (GM). The second important stage was developed in Japan, after the Second World War. Toyota redesigned the manufacturing process of vehicles and their parts, this innovation is called Toyota Production System or also known as lean production. This contribution allowed to raise in an extraordinary way the productivity in the Japanese automotive industry and is based on three fundamental elements: a flexible organization, emphasis on the total prevention of defects and the integral concept of the manufacturing process. With the total prevention of defects, this system seeks to eradicate at the source the possibility of generating imperfections, reducing drastically the proportion of defective units in production, which reduces operating costs and improves the quality of vehicles. Likewise, it emphasizes the workforce as a team, a lower hierarchy in the production line, fostering long-term relationships between producers and suppliers. This new integral concept of manufacturing, unlike the classic North American model, it reduced costs, improved quality, generated a better coordination and cooperation between the productive chains, produced a greater specialization through technology transfer, making them more competitive in the market.

In the decade of the nineties, as a result of the challenge imposed by Japanese automotive industry, in Europe and the United States emerged a new form of production called modular assembly. This model uses common platforms that allow for greater coordination and the use of multiple parts while maintaining the ability to adapt specific models of vehicles. In this new production, the workers handle modules already assembled by their suppliers, the modules are fully armed in the reception area of the final assembly plants, ready to be incorporated into the vehicles (Carbajal, 2010).

There has been a plethora of definitions of modularity given in the literature, Baldwin & Clark (1997) describes modularity as the process of “building a complex product or process from smaller subsystems that can be designed independently yet function together as a whole”. In an analytical framework that covering modularity in the automotive industry, Takeishi & Fujimoto (2001) proposed different approaches useful to clarify the different facets of modularization. Firstly, *Modularization in Product*, which focuses upon product architecture and the required interrelationship

between product function and structure. Secondly, *Modularization in Production* describes the manufacturing system structure where, as a result of a modular product design, the product (car) is produced from a series of modules each assembled on a sub-line before transfer to the product assembly line. Thirdly, *Modularization in Inter-firm Systems*, describes the situation where large modules are assembled by suppliers on their own assembly lines and are delivered and assembled into finished products on the main line of the automaker (Kane & Trimble, 2008).

The trend towards modularization or segmentation is linked to the consolidation of the network of suppliers, to extent that companies that sell supplies directly to assemblers they buy those companies that, in turn, provide them. Owing the larger modules are more difficult and expensive to move, the modular assembly process is placed near to the establishment of assembly plants. The modules, in turn, can be combined in different versions, so it is possible to manufacture varied products that satisfy the diverse needs of consumers (Takeishi & Fujimoto, 2001).

Producers who have been characterized by a vertical integration, have significantly increased the use of subcontracting and outsourcing to reduce costs. The recent trend towards globalization in automotive industry has led to a change in the stratification relationship between producers and their major suppliers. Tier 1 providers are dedicating themselves to the integration of modules, those of tier 2, to their production, and those of tier 3, to the manufacture of components and the provision of local content in emerging markets. The modular assembly assigns to suppliers a much more important role. The assemblers require their suppliers to invest and develop products, acquire specialized tools, improve their logistics, the modules and systems they produce, and even provide guarantees to consumers and supervise tier 2 suppliers. The modular assembly initiative in the automotive industry it has not had the same success of lean production. A central element of its issue, is mainly due to the lack of construction of strong relationships with the members and suppliers of its system, to achieve stable long-term growth and mutual benefits (CEPAL, 2003).

1.2 Robotic and Automation in the Automotive Industry

Automation has been one of the key drivers of the modern Manufacturing Industry and it has been present in various forms from the beginning of the industrial era until today passing through different evolutions responding to humans needs (Jovane et al., 2003).

Automation in automotive industry is an inclusive concept that extends from the design stage of car, crafting the body parts, building complex propulsion systems to inspecting the finished product. It improves the safety standards, ensures durability and reduces the incumbent costs. Automation helps automakers eliminate human errors and ensure precision work. The incorporation of robots in automotive manufacturing, have facilitated some complex tasks. Robots have been introduced for some processes such as spot welding, gluing and transferring windshields, battery mounting, gasoline pouring, rear seat setting, and tire feeding/mounting. In manufacturing processes, robots were introduced for the typical reasons: to move heavy parts, to handle liquids, and for precise positioning on complicated shapes (Arai, 1989). In this way, automotive manufacturers can guarantee a uniform product with a minimum of injuries to workers, a more precise global engineering, a much lower cost, shorter production time and big scale production.

In 2016, robot sales increased by 16% (with a total of 294,312 units). The main driver of the growth in 2016 was again - like in 2015 - the electrical/electronics industry (+41%). Robot sales in the automotive industry increased, like in 2015, at a rather moderate rate (by 6%). The automotive industry is still the major customer of industrial robots with a share of 35% of the total supply in 2016. The electrical/electronics industry has been catching up, specially in 2015 and 2016, reaching a share of 31% of the total supply in 2016. There are five major markets representing 74% of the total sales volume in 2016: China, the Republic of Korea, Japan, the United States, and Germany. The average global robot density is about 74 industrial robots installed per 10,000 employees in the manufacturing industry in 2016. The considerable high rate of automation of the automotive industry compared to all other sectors is demonstrated in the evaluation of the number of industrial robots in operation (“Executive Summary World Robotics 2017 Industrial Robots”, 2017).

Considering globally, 80 million passenger cars were sold in 2017 (3.2% more than 2016). The European Union remained the worlds second largest producer of passenger cars, with around 17 million passenger cars built in the EU last year (24%). Nevertheless, China maintained its leading position among global passenger car production, accounting for 29%. Demand for new commercial vehicles remained positive in the EU throughout 2017, counting 2.4 million units registered (or 3.3% more than in 2016) while for China, the commercial vehicle production ended 2017 with modest growth (+0.3%) compared to 2016, some 5.7 million units were built in total (ACEA, 2018).

Similarly, China is a strong prospect market for American-made OE auto parts. Although Mexico and Canada have historically been the largest market for the export of U.S automotive parts. In addition, Germany is the fourth largest market for U.S. auto parts and Japan is fifth. By 2015, the value of automotive parts exports from the United States was almost \$ 81 billion. For the European market, instead, Germany is the top destination for U.S. automotive parts exports, followed by the United Kingdom, Italy, the Netherlands, Belgium, France and Spain (Williams, 2016).

1.3 Trending and Challenge in Automotive Industry

The continuous restructuring and dynamics of the automotive industry have generated greater competitiveness. In addition, the pyramidal structure formed by the various suppliers that appeared in the last decade has made the production more flexible and with greater shared responsibility with all the suppliers.

Competitiveness has created a more heterogeneous market, which increasingly depends on the preferences of consumers, regarding the function and style of the vehicle. Another very important factor is the innovation technology, which has always been present in the automotive industry. Initially, the innovation technology allowed to improve and optimize the production systems as well as the operation and reliability of the units. More recently, it has been focused on the areas of safety, reduction of the impact on the environment (electric cars as an alternative environmentally friendlier), advances in navigation and electronic systems, up to the technological innovations implemented by some assembly companies as a strategy to increase the market penetration of certain particular models, such as Autonomous vehicle and full self-driving.

Bardt (2017) consider that the two fundamental technological developments that currently have the potential to substantially transform the automotive market are: electric drive technology ¹ and the digitalisation of vehicles ². Established providers are already active in these area with their innovations.

On the other hand, other important considerations in the design of the vehicles are the governmental regulations, mainly in the aspects related to safety devices such

¹Electric drive technologies, including the electric motor, inverter, boost converter, and on-board charger, are essential components of hybrid and plug-in electric vehicles (PEV) propulsion systems.

²Some researches consider ‘digitalisation’ as the application of digital technologies to realise a step change in process efficiency and decision-making. It is also referred to as “Industry 4.0”, particularly in Europe, although this term has a broader meaning. Digitalisation also encompasses the “Industrial Internet of Things”, which refers to connected devices in a manufacturing context.

as safety belts and airbags with anti-collision systems, the requirement of high levels of quality in the design of the braking system, among others (Carbajal, 2010).

The automotive industry also requires of quality and production standards very specialized because a small piece can be cause for return of a whole line of vehicles, about all when there are chances of accidents. All these innovations in vehicle production systems aimed at satisfying consumer demand and government regulations have been possible thanks to technology, these technological innovations go much further, becoming a determining factor in the course of this industry.

Chapter 2

Computer vision for automatic Inspection

The revision of the state of the art starts with the study of the general characteristics and applications of automatic inspection, to focus on those methods of processing image and vision analysis techniques. On the other hand, the most popular vision algorithms are considered in scene. Subsequently, different works have been presented that have been carried out in relation to the reduction of the noise level, improvement of contrast and improvement of sharpness in images, this in order to know different approaches that have been developed and determine among them which is the ideal alternative to be implemented.

2.1 Automatic Visual Inspection

In the last decade, computer vision systems have consolidated as a fundamental key in the production systems of the industries. In this area, Freeman (1998) has identified two major categories, in which computer vision can be applied. The first category is the one related to the visual control of robotic assembly, that is, to provide visual feedback to a robotic arm, while executing an assembly task or others. Secondly, is the automatic visual inspection, which consists of using a vision system to verify the quality of the products that have been manufactured.

Traditionally, visual inspection and quality control are performed by manual inspection, which are easily subjected to lack of attention, fatigue and subjectivity (De Oliveira et al., 2017), (Li et al., 2014). Moreover, in some environments, inspections may be difficult or dangerous, in the same way, the assembling processes with many movements in a short time, makes human visual inspection physically impossible, these reasons make an automatic inspection more interesting.

Cho et al. (2005) classified the automatic visual inspection of a three-step process: process-image acquisition, processing, and analysis.

1. Image acquisition: contains all necessary sensors for images acquisition, the vision sensors mainly includes CCD camera ¹, a focus lens, an optical filter and illumination systems (Chu et al., 2016).

Currently, many of the cameras used in artificial vision systems and image analysis are connected directly to the computer through different ports: FireWire, USB and Gigabit Ethernet. However, some cameras still require a connection to the computer through an acquisition board also called frame grabbers.

2. Processing Image: Once images have been acquired, the image processing unit removes the background noise or unwanted reflections from the illumination system and performs a variety of operations to extract the characteristics of the examined object. The processing system is usually by computer, depending on the needs of the vision algorithms to be used. This unit is responsible for receiving and analysing the images of the objects to be inspected, at a high speed necessary to be able to interact with other devices in real time.
3. Analysis: In this stage, the characteristics are analysed, a class label is assigned to the inspected regions, which depend to the default tolerance and other set parameters. The class label is usually defects or non-defects.

2.1.1 Application Domains of Automatic Visual Inspection

Although application domains of machine vision are quite broad, it is important to provide an overview of it, which allows to demonstrate the impact of machine vision in the most important industries.

- **Automotive Industry:** Mainly, it is focused in the auto parts inspection. Tornero et al. (2012) describe the design and implementation of a new inspection system based on artificial vision to detect defects in vehicle bodies or chassis. The system is based on the detection of defects by means of an illumination sweep, being the vision system fixed, like the object to inspect. Once the images have been acquired, the defects are detected as consequence of the transitions generated by the illumination sweep when the reflection pattern is deformed. The high sensitivity of the system allows to detect the millimeters damage of 0.2 mm in diameter.

¹In recent years CCD has become a major technology for digital imaging. In a CCD image sensor, pixels are represented by p-doped metal-oxide-semiconductors (MOS) capacitors.

- **Metallurgical industry:** The treatment of minerals is often exposed to difficult and rough environments. In this context, Wang & Shen (2010) designed defect detection system based on machine vision to identify some defects such as crack, scarring, roller printing, holes, scales and so on stamped on the surface of copper bar. The image processing module is developed in LABVIEW, useful for image analysis, binarization and image recognition to determine whether flawed.
- **Pharmaceutical Industry:** Jia (2009) presents an industrial application of machine vision technology for medical syringe assembly. The vision inspection station is developed with ten cameras that was integrated into an assembly line. The vision tools from Cognex allowed the easy development of vision algorithms.
- **Industry textile:** Numerous techniques have been developed to detect fabric defects or some contamination, Cho et al. (2005) proposed a real-time fabric inspection algorithm. The inspection system is PC-based system instead of the professional DSP board, and double buffer memory for a parallel process was used. Instead, Schneider et al. (2012) used important image processing and illumination techniques as node point detection, Yarn tracking and segmentation to on-line fabric defect detection. While the machine vision system proposed by W. Zhang et al. (2010) is based on the Gabor wavelet techniques, the system can automatically detect regular texture defects.

Moreover, Kumar et al. (1997) present a survey on fabric defect detection techniques presented in about 160 references. In order to evaluate the limitations and the performances of the several proposed techniques.

- **Electronic industry:** In this field, there are many applications, especially, on printed circuit boards. Moganti et al. (1996) present a survey, about the algorithms and techniques for the automated inspection of printed circuit boards. Most recently study was developed by Baygin et al. (2017), whom proposes a machine vision based noncontact defect detection algorithm for printed circuit boards (PCBs). This approach detects and controls the holes on the PCB. Firstly, a reference image is taken for training. The trained image is matched with the incoming test images and the missing holes on the PCB are precisely detected. The inspection between the trained images and the incoming test images are used in general to detect any missing component (Singh & Bharti, 2012).

Other application found on the literature was the machine vision to detect defect on the air bearing surface (ABS) of a head gimble assembly. Air Bearing Surface (ABS) is a part on HDD responsible to control the flying height during

read/write data. The proposed system is based on image segmentation techniques with generation of block matrices. Also, to determine defect in paralleled processing architecture, sub blocks and sub-ROI are allocated and employed (Kunakornvong & Sooraksa, 2016). On the other hand, Huang & Pan (2015) discusses various state of the art visual inspection algorithms and systems that have been applied in the semiconductor manufacturing industry.

- **Food Industry:** A computer vision system for automatic high-speed fruit sorting and grading is proposed by Yogitha & Sakthivel (2014). The developed work involves the dynamic capturing of image signal from camera when the objects are moving on the conveyor in real time based on synchronized trigger events. The vision algorithms were developed using OpenCV, useful open source to extract relevant information about the colour and geometry parameters. Another application that ensures automatic processing in real time and verify the proper cutting shapes of grape leaves, was developed by Richter et al. (2002). They proposed, for image processing module, a novel software application (called NtolcutPT) written in visual C++. While Benalia et al. (2016) proposed a computer vision to improve the quality control and sorting of dried figs.
- **Others industries:** In the manufacturing, was developed an automatic vision system to inspect defects of electric motor parts in assembly lines, specifically the disconnection of the stator power cables inside the electrical connector. There were applied important techniques as detection function in the threshold image and edge detection to distance measurement and determine the size. The edge detection tool uses the gradient of grey level intensity to determine if there is an edge on the image (De Oliveira et al., 2017).

Other application in industry is Tube-type bottle defects detection algorithm based on different images technique as segmentation and contour extraction, also it takes advantage the OpenCV libraries for computer vision algorithms (Liang et al., 2017).

2.1.2 Classification of Automatic Visual Inspection

Malamas et al. (2003) identified at least four types of inspection in modern industrial vision system: Inspection of dimensional quality, inspection of surface quality, inspection of structural quality and inspection of quality operation.

- 1 **Inspection of dimensional quality:** Is related to check whether the dimensions of an object are within specified tolerances or the objects have the correct shape. Such tasks involve inspection of geometrical characteristics of objects in two or three dimensions.

- 2 Inspection of surface quality:** Inspecting objects for scratches, cracks, wear, or checking surfaces for proper finish, roughness and texture, are typical tasks of surface quality inspection.
- 3 Inspection of structural quality:** Checking for missing components (e.g., screws, rivets, etc.) on assembled parts or checking for the presence of foreign or extra objects (e.g., leaves, little sticks) are typical tasks of this class of quality inspection.
- 4 Inspection of quality operation:** Inspection of operational quality is related to the verification of correct or accurate operation of the inspected products according to the manufacturing standards.

2.2 Image Processing

Image processing is the intelligent part of an automatic inspection system. Its mission is to visualize and capture a scene, to later apply the necessary transformations and extractions of the captured images. Digital image processing helps us enhance images to make them visually pleasing or accentuate regions or features of an image to better represent the content.

There is a collection of C++ libraries designed for computer vision, open source as OpenCV, VXL, IDL. There are also other more complete libraries like python, MATLAB for computer vision and many others. In these bookstores we will find a multitude of algorithms and typical operations defined of image processing that should be known and mastered.

2.2.1 Images pre-processing techniques

The images pre-processing techniques are used to enhance the quality image and some features important for further processing. It includes primitive operations to reduce noise, contrast enhancement, image smoothing and sharpening, and advanced operations such as image segmentation (Adatrao & Mittal, 2016).

2.2.1.1 Image Enhancement techniques

Image enhancement is generally divided into three categories (Ahmadi et al., 2013): spatial domain, and the Transform-domains, the frequency domain (or Fourier Transform) and the wavelet domain transform.

1. Spatial domain refers to the plane of the image itself, and the algorithms based on this approach operate directly on the pixels of the image. The most frequent techniques in this domain are also known as filters, windows or kernels. The term spatial filter is used to differentiate this process from traditional filtering in the domain of the frequency. Ahmadi et al. (2013) discuss about the two of the most common types of spatial filters: linear and non-linear filters. Both techniques go around all the pixels of an image with their corresponding neighbourhoods, but the difference is how the filters are applied to the image. The processing functions in this domain can be expressed as:

$$I_N(x, y) = T[I(x, y)] \quad (2.1)$$

where $I(x, y)$ is the input image and $I_N(x, y)$ is the new image, result of the processing. $T[]$ is an operator about $I(x, y)$ defined around a neighborhood (x, y) .

2. Frequency domain in image processing represents, at each point a particular frequency contained in the spatial domain of the image, in other words, represents the value change rate of the pixels. These change in frequency is a characteristic of change in geometry of the image (spatial distribution). For example, Edges reflect high frequency components, smooth regions have low frequency components.

The transformation operator $T[]$ now operates on frequency information contained in $I(x, y)$ and generates a new image $I_N(w1, w2)$ in the frequency domain. Finally the image of $I_N(w1, w2)$ is the antitransformada to the spatial domain.

3. Wavelet transform performs a local Fourier analysis by representing images in terms of a basis of functions localized in both space and frequency (Nowak & Baraniuk, 1999). The wavelet transform has advantages over the Fourier transform to represent functions that have discontinuities and peaks, and to destroy or reconstruct finite, non-periodic and non-stationary signals.

2.2.1.2 Noise Removal

The process of image acquisition through sensors and cameras generally contaminates the images with imperfections like noise. Defects in instruments, problems with the acquisition process, thermal noise, transmission and compression errors, they degrade the quality of the digitized images, therefore, the first step before analysing the images acquired is to apply noise removal techniques.

Z. Zhang (2015) classify noise removal techniques into three categories: spatial domain, Transform-domain, non-local approach.

Spatial domain

In general, use statistical methods. There is an extensive literature of the different techniques in spatial domain, in general, based on the use of linear and non-linear filters.

Linear filters tend to smooth the images, affecting edges, lines and fine details. An average filter is the optimal linear filter for Gaussian noise, in the sense of mean quadratic error. The idea of this filter is to replace the value of each pixel, by the average of the values of the neighbors, defined by the mask. The Gaussian filter is another linear filter, which is used to blur images, modelling Gaussian mask to reduce noise.

In non-linear filters, the noise is removed without identifying it. The median filter is an example of a non-linear filter in which the value of the pixel under study is substituted with the median of the neighbourhood defined in the mask.

Transform domain

Wavelet transform is especially useful since it enables the filtering procedure to adapt to the local variations in the signal frequency content and thereby balances the trade-off between noise removal and excessive smoothing. Fourier-domain filtering is a global operation that cannot adjust to such local variations and hence leads to excessive smoothing in regions where the image has high frequency content (Nowak & Baraniuk, 1999). The filtering in the Wavelet domain is divided mainly into two categories: linear and non-linear methods.

The most researched area of wavelet transform applied to the noise reduction or denoising ² is that of the methods based on the threshold of non-linear coefficients. This procedure takes advantage of the fact that wavelet transform maps white noise in signal domain into white noise in transform domain. Then, while the signal energy concentrates more on few coefficients in transform domain, the noise does not. This is an important principle to separate noise from the signal of interest (Donoho, 1995).

²Term defined by Dohono and colleagues (1995) in an informal way as various schemes which attempt to reject noise by damping or thresholding in the wavelet domain

Non-local approach

A nonlocal filter exploits similarities between image blocks (patches) from various spatial locations, hence the name nonlocal (Z. Zhang, 2015). Buades et al. (2005) used for the first time the term nonlocal in the context of image denoising. They proposed a new algorithm, the non local means (NL-means). The NLmeans estimates a pixel as the weighted average of all the pixels in the image, where the weights depend solely on the similarity between neighborhoods centered at these pixels and the neighborhood centered at the estimated pixel. This similarity depends on the similarity of the intensity gray level vectors.

2.2.1.3 Contrast Enhancement

Images with low contrast can result from poor lighting, lack of an adequate dynamic range in the image sensor, inadequate aperture of the lens during acquisition, or the object to be acquired has low contrast. The purpose of contrast enhancement methods is to improve visibility and details of an image. The contrast enhancement can be achieved by stretching the dynamic range of the grey-levels in the image.

They can be categorized by two approaches, global and local ones (Yoon et al., 2009).

Global Contrast

The techniques of global contrast enhancement solve problems such as excessive or poor lighting conditions in the original environment. However, these techniques do not always produce good results especially in images that have a large spatial variation in the contrast.

1 Global Histogram Equalization (GHE): It is a widely used method for contrast enhancement. Global histogram equalization uses the histogram information of the whole input image as its transformation function. This transformation function stretches the contrast of the high histogram region and compresses the contrast of the low histogram region (Kim et al., 2001).

Despite the simplicity in the histogram equalization method, there are some problems associated with it. The first, this produces a significant change in the average value of the brightness of the image. This is because the histogram equalization transforms the original histogram of the image into a uniform distribution, which has an average value in the middle of the range of grey levels regardless of the average value of the original image. Second, the histogram

equalization method can cause over-contrast or saturation of grey levels out of range.

- 2 Contrast stretching** Contrast stretching is a simple contrast enhancement technique that attempts to increase the contrast of an image by stretching its range of grey levels to a desired range of values, such as the full range of values that the type of image allows. This method differs from the histogram equalization in that it applies a linear mapping to stretch the pixel values of a low or high contrast by stretching the dynamic range across the whole image spectrum from 0-255.

Local Contrast

The global methods are appropriate for general improvement, but there are cases in which it is necessary to improve the details in small areas of the image. In terms general, local techniques present better results than global techniques.

- 1 Local Histogram Equalization:** The global histogram equalization procedure can be easily extended to local contrast enhancement called local histogram equalization (LHE), also called block-overlapped histogram equalization (Kim et al., 2001). A block-overlapped histogram equalization defines a sub-block and retrieves its histogram information. Then, a histogram equalization is performed for the center pixel of the sub-block using the cumulative distribution function of that sub-block. Next, the sub-block is moved by one pixel and sub-block histogram equalization is repeated until the end of input image is reached. Since the histogram equalization is performed with each sub-blocks local histogram, this method can adapt well to the partial light condition of the image. However, since local histogram equalization must be performed for all pixels in the entire image frame, the computation complexity is very high.

- 2 Image Segmentation:** Many contrast enhancement approaches local are based on the segmentation of images, these methods are developed in the spatial domain and domain of frequency, followed by an operator of improvement of contrast in each segment.

Image segmentation divides the image into its constituent parts up to a level of subdivision in which regions or objects of interest are isolated. Segmentation technique is used to partition an image into meaningful parts having similar features and properties.

Segmentation algorithms are based on one of these two basic categories (Kaur & Kaur, 2014): discontinuity or similarity. Discontinuity detection approach divides the image based on abrupt changes in the level of gray (e.g. edge

detection, boundary detection). Similarity detection approach, the image is segmented into regions based on similarity, the techniques that falls under this approach are: thresholding, clustering techniques.

In general, the popular techniques used for image segmentation are: thresholding, edge detection, region-based techniques, clustering, watershed, partial differential equation and artificial neural network.

3 The Gradient operator: In general, the gradient increase is associated with an increase in contrast. the gradient is used frequently in industrial inspection, either to aid humans in the detection of defects or, what is more common, as pre-processing step in automated inspection.

The derivatives of first order allow you to find places in an image where the intensity that changes rapidly is greater in magnitude than a specified threshold. There are several derivative estimators such as Sobel and Prewit.

2.2.1.4 Illumination equalization

The main objective of improving the sharpness of images is to highlight the fine details in an image or to improve the details that were blurred, either by an error or by a natural effect of the acquisition process. In general, research efforts in this area of imaging enhancement are more limited than in the case of reduction of noise and improvement of contrast.

2.2.2 Images analysis techniques for Automatic Inspection

In this section will be discuss the most popular image analysis techniques in the context of industrial visual inspection.

2.2.2.1 Histogram analysis

The histogram of an image tells a lot about the distribution of grey levels within the image. Histogram provides only statistical information, does not provides the pixel location. (See Figure 2.1).

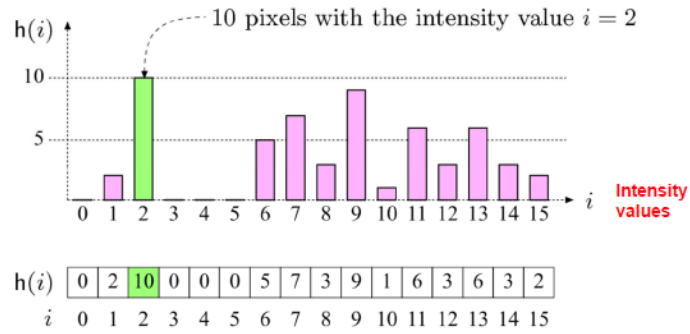


Figure 2.1: Image Histogram Analysis

The advantages of histogram are:

1. Histograms help detect image acquisition issues.
2. Problems with image can be identified (over and under exposure, brightness, contrast, dynamic range).
3. Point operations can be used to alter histogram (addition, multiplication, exp and log, intensity windowing).

Some limitations of histograms are:

1. Different images can have same histogram.
2. It is not possible reconstruct the image from histogram.

So, a histogram for a grayscale image with intensity values in range $I(x, y) \in [0, K - 1]$ would contain exactly K entries (e.g. 8-bit grayscale image, $K = 2^8 = 256$)

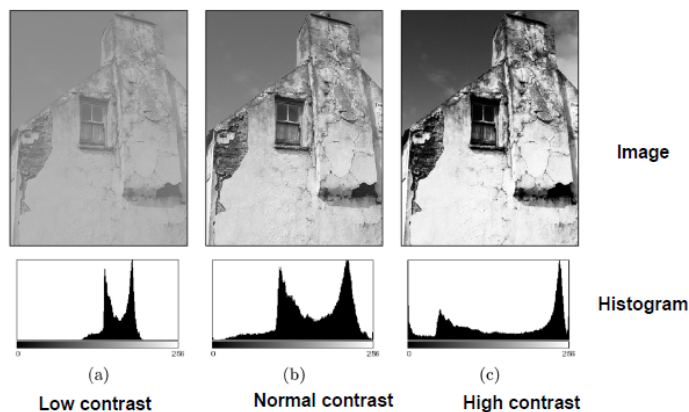


Figure 2.2: Histogram and Contrast

2.2.2.2 Image thresholding

Thresholding is an approach used for segmentation in various images processing application. An object having homogenous intensity and a background with a different intensity level could easily be differentiated with this approach. Different types of thresholding techniques are global, local and dynamic thresholding, histogram equalization and Otsu thresholding.

Global Thresholding

Thresholding operator simply selects the pixels of intensity within a predefined range. A threshold is selected that allows grouping the pixels of an image belonging to the various objects of the same image differentiating them from the background. In this way the segmentation based on the histogram is based on the choice of one or several thresholds that allow to group the points of the image in regions of similar characteristics according to their levels of gray. If the original image is $I(x, y)$, the thresholding image $g(x, y)$ and the threshold (Th) is fixed between $[0, 255]$, the threshold operation is defined by the equation:

$$g(x, y) = \begin{cases} 255, & \text{if } I(x, y) > Th \\ 0, & \text{if } I(x, y) \leq Th \end{cases} \quad (2.2)$$

If the pixels marked with 1 correspond to foreground, while the pixels marked with 0 correspond to the background, this process is known as *binarization*.

Global thresholding is global due to it evaluates each pixel of the image using the same foreground intensity range.

Dynamic Thresholding

When the lightning in the scene is uneven to the point where image foreground intensity in dark parts of the image is at the same level as the background intensity in bright sections, in other words, intensity ranges of background and foreground are overlapping (Pietrzekiewicz, 2012). Dynamic thresholding classifies the pixels of image in relation to image local brightness means ($A[x, y]$):

$$g(x, y) = \begin{cases} 1, & \text{if } minValue \leq I[x, y] - A[x, y] \leq maxValue > Th \\ 0, & \text{if } otherwise \end{cases} \quad (2.3)$$

The image of local averages may be obtained using smoothing operator. Figure 2.3 demonstrates better results for dynamic thresholding respect to global technique for uneven image.

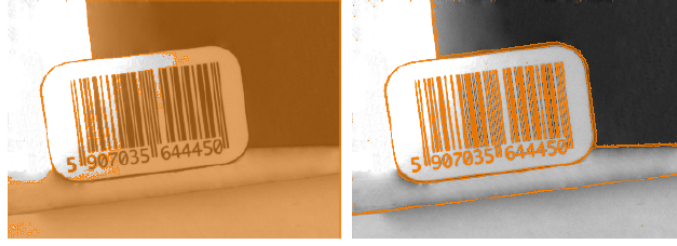


Figure 2.3: Thresholding technique: a) Global thresholding, b) Dynamic thresholding

Otsu Thresholding

Chooses the threshold to minimize the intraclass variance of the thresholded black and white pixels. Otsu technique is based on a very simple idea, find the threshold that minimizes the weighted within-class variance. This out to be the same as maximizing the between-class variance. This method operates directly on the grey level histogram.

When the distribution of histogram of an image is skew distributed, or when are noises in the grey level image, the Otsu method obtains accurate threshold and satisfactory thresholding results (Yang et al., 2012).

2.2.2.3 Edge detection

The purpose of edge detection is to identify areas of an image where a large change in intensity occurs. Edge detection is usually done using local linear gradient operators such as Sobel, Canny, zero cross edge detection and Roberts cross edge detection methods.

An edge detector accepts discrete, digitized images as input and produces an edge map as output. The edge map of some detectors includes explicit information about the position, strength of edges, their orientation and the scale.

Conceptually, the most commonly proposed schemes for edge detection include three operations: differentiation, smoothing and labelling. Differentiation consists in evaluating the desired derivatives of the image. Smoothing consists in reducing noise in the image and regularizing the numerical differentiation. Labelling involves localizing edges and increasing the signal-to-noise ratio of the edge image by suppressing false edges (Ziou & Tabbone, 1998).

1D Edge detection

Term ‘edge’ can be defined as a sharp change in brightness, ideal edge is a step function in some direction. The step edge is the point at which the grey level discontinuity occurs. In real images, step edges are localized at the inflection points of the image.

Real (non-ideal) edge is slightly blurred step function. Sharp changes in grey level of the input image correspond to “peaks” of the first derivative of the input signal. Edge can be characterized by high value first derivative. First derivative of $I(x)$ has a peak at the edge, second derivative of $I(x)$ has a zero crossing at edge (See Figure 2.4). The derivatives of first order allow you to find places in an image where the intensity that changes rapidly is greater in magnitude than a specified threshold. There are several derivative estimators such as Sobel and Prewit.

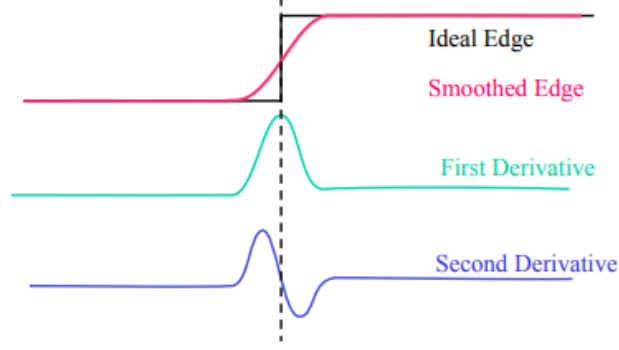


Figure 2.4: Edge detection technique

The sign transition depends on the intensity change of the image (i.e. from dark to bright or vice-versa).

2D Edge detection

In the case of derivatives of first order the gradient operator is used, while that in second-order derivatives the Laplacian operator is used. Laplacian operator that detects sudden transitions intensity of image.

Function Gradient: Let $f(x, y)$ be a 2D function, the gradient, whose direction is in direction of maximum rate of change of f and whose magnitude is maximum rate of change of f is perpendicular to edge contour.

Image is 2D discrete function, the derivatives in horizontal and vertical directions are: $\frac{\partial I}{\partial x}(x, y)$ and $\frac{\partial I}{\partial y}(x, y)$. Image gradient:

$$\nabla I(x, y) = \left[\frac{\partial I}{\partial x}(x, y), \frac{\partial I}{\partial y}(x, y) \right]^T \quad (2.4)$$

$$\begin{aligned} \text{magnitud} &= \left[\left(\frac{\partial I}{\partial x} \right)^2 + \left(\frac{\partial I}{\partial y} \right)^2 \right]^{1/2} > Th \\ &= I_x^2(x, y) + I_y^2(x, y) > Th \end{aligned} \quad (2.5)$$

$$\nabla^2 I(x, y) = [I_{xx}(x, y) + I_{yy}(x, y)] = 0 \quad (2.6)$$

There is a plethora of researches and works of edge detection methods, but the most important by their importance, accuracy and impacts are the classical method, Gaussian method, multi-resolution, nonlinear methods, machine learning based methods and many others.

1. *Classical method* the usual gradient operators include the algorithms developed by Sobel, Prewitt and Robinson. They compute an estimation of gradient for the pixels and look for local maxima to localize step edge. Typically, they are simple in computation and capable to detect the edges and their orientation, but due to lack of smoothing stage, they are very sensitive to noise (Oskoei & Hu, 2010).

Sobel edge operator applies 2D spatial gradient convolution operation in the image. Also, it used the convolution masks to compute the gradient in two directions, row and column orientations. Prewitt operator is quite similar to the Sobel with the difference that it estimates only one orientation, the horizontal (column orientation). The main advantage of Prewitt operator is that provide a better performance and higher responses for noisy images.

2. *Gaussian method* They are symmetrical along the edge, and also reduce noise by smoothing the image. The most important operator is Canny operator. Canny operator is proposed as an optimization problem. Canny detector performs firstly an image smoothing for noise removal. Then it calculates the gradient image to highlight areas with high intensity variation. Next, the algorithm goes through these areas and remove any pixel that is not a local maximum gradient direction. The gradient matrix is further reduced with hysteresis (Rusu & Voicu, 2016).
3. *Multi-resolution method* Multi-resolution methods incorporate repeating edge detection for several scales of the Gaussian filter to achieve a quality performance. The main challenges in these methods includes selection a proper range for the scales, combination of the outputs corresponding to different scales, and adaptation to level of noise in the image.

Figure 2.5 shows the difference between the most important edge detection techniques.

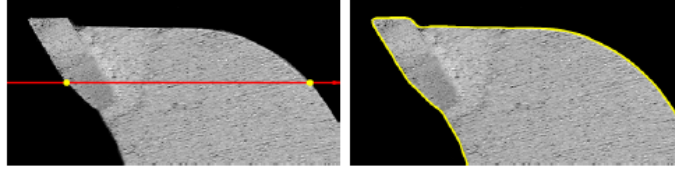


Figure 2.5: Edge detection technique: a) 1D edge Detection, b) 2D edge Detection

2.2.2.4 Blob analysis

A Blob analysis algorithm is used to find and count objects, and to make basic measurement of their characteristics. The purpose of analysis is to determine whether the results obtained from an operation are accurate, logical and true.

For image processing, a blob is defined as a region of connected pixels. The algorithm discerns pixels by their value and places them in one of two categories. Foreground (typically a pixel has a non-zero value) or the background (pixels with a zero value) (Patil et al., 2015).

Detecting Lines and simple Curves

The Hough transform find any shape that can be defined parametrically within a distribution of points, these can be lines, circles and ellipses, the geometric forms of the most objects.

Equation of a line: $y = kx + d$, if the points p_1 and p_2 are on same line, they have the same slope k and the same intercept point d . Hough transform starts with the edge point (x, y) , find the slope k and the intercept point d that passes through the most edge points. Many lines of different slope and intercept can pass through (x, y) thus it can be write in parameter space: $d = -kx + y$. Finally, after finding optimal values of k and d , is possible draw them as lines in image space.

If N lines intersect at position (k', d') in parameter space, then N image points lie on the corresponding line $y = kx + d$ in image space.

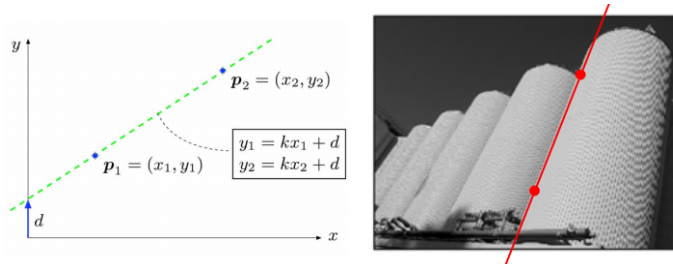


Figure 2.6: Hough Trasform: Image vs parameter space

The problem of line, it can not express vertical line ($k = \text{infinity}$). To solve this problem, alternative line representation can be expressed in terms of r and θ . Other alternative is implementing Hough transform using Hessian Normal Form of line. On the other hand, noisy image can produce bad results, so there are strategies for dealing with noise: thresholding and non-maximum suppression.

The Hough transform on circles are defined by three parameters: (\bar{x}, \bar{y}, ρ) , where \bar{x} and \bar{y} are center coordinates, ρ is radius of circle. Therefore, a point $p = (u, v)$ lies on circle when following relations holds: $(u - \bar{x})^2 + (v - \bar{y})^2 = \rho^2$. Hough transform on ellipse requires five parameters: $(\bar{x}, \bar{y}, r_a, r_b, \alpha)$, where \bar{x} and \bar{y} are center coordinates, (r_a, r_b) are two radii and α is orientation of principal axis.

Morphological Filters

Morphological filters alter local structures in an image. Originally operated in binary images. There are two important operations: translation and reflection.

1. Translation, Let A set of pixels in binary image, $w = (x, y)$ a particular coordinate point. A is set A translated in direction (x, y) if $A_w = \{(a, b) + (x, y) : (a, b) \in A\}$.
2. Reflection, Let A set of pixels. Reflections of A is given by $\hat{A} = \{(-x, -y) : (x, y) \in A\}$.

There are two basic mathematical morphology operations, built from translations and reflections: dilation and erosion. Also, several composite relations as closing, opening and conditional dilation.

1. Dilation expands connected sets of 1s of a binary image, it can be used for growing features, filling holes and gaps. Suppose A and B are set of pixels, dilation of A by B is defined by: $A \oplus B = \bigcup_{x \in B} A_x$. It means, replace every pixel in A with copy of B .

Dilation operation is commutative and associative; thus it is more efficient to apply large structuring element as sequence of smaller structuring elements.

2. Erosion shrinks connected sets of 1s in binary image, it can be used for shrinking features, removing bridges, branches and small protrusions. Given sets A and B , the erosion of A by B is given by: $A \ominus B = \{w : B_x \subseteq A\}$. Find all occurrences of B in A .

Erosion is not commutative. Dilation of foreground is equal to inverting the erosion of background. Erosion and dilation are inverses of each other, and they are useful in boundary detection applications.

Morphological filters design is based on morphological operators and contents of structuring element. The structuring element is a shape mask used in the basic morphological operations. Morphology operations can be applied to grayscale images by replacing the operations (or, and) with (max, min). For grayscale images, structuring element contains real values.

Regions

High level of vision task is to recognize objects, text on a page, objects in a picture, number and types of objects.

In binary images, each object defines a binary region, each object is found by grouping together connected groups of pixels that belong to it. There are three methods: Flood filling, sequential region labelling and combine region labelling and contour finding.

First, 4-connected (N_4) or 8-connected (N_8) pixels as neighbors must be defined. N_4 is formed by 4 pixels adjacent to given pixel in horizontal and vertical directions. N_8 is formed by 4 pixels in N_4 +4 pixels adjacent along diagonals. Once defined the connected pixel, adopt following convention in binary image:

$$I(u, v) = \begin{cases} 0, & \text{background pixel} \\ 1, & \text{foreground pixel} \\ 2, 3, \dots, & \text{region label} \end{cases} \quad (2.7)$$

Finally, select the method to find the region. The first approach, region Labelling with flood filling, searches for unmarked foreground pixel, then fill (visit and mark). There are three different versions: recursive, depth-first and breadth-first. The second approach, sequential region labelling, is based on two steps: preliminary labelling of image regions and resolving cases where more than one label occurs (collision). Although this algorithm is complex, it is preferred because it has lower memory requirements.

The third approach, region contour, after finding regions, tries to find region contours (outlines), morphological operations can be used to find boundary pixels (interior and exterior). The outer contour lies along outside of foreground (dark region) and exist only one. Inner contour, due to holes, there may be more than one

inner contour.

On the other hand, there are a lot of types of features on binary regions useful to analysis, these are: Shape properties, geometric, statistical shape, Moment-based geometrical and topological properties.

1. Shape properties, the features are numerical or qualitative value computable from values and coordinates of pixels in region. One of simplest features is size which is the total number of pixels in region.
2. Geometry features, Region R of binary image is a 2D distribution of foreground points within discrete plane. It allows to compute features as:
Perimeter: Length of outer contour of the region. Note that the region R must be connected.
Area: Simply count image pixels that make up region. $A(R) = |R| = N$
Bounding Box: Minimal axis-parallel rectangle that encloses all points in R .
Convex Hull: Smallest polygon that fits all points in R .
3. Statistical shape properties: can be applied to regions that are not connected. These are: Central moments, measure characteristic properties with respect to its midpoint or centroid. Centroid: of a binary region is the arithmetic mean of all (x, y) coordinates in the regions.
4. Moment-based Geometrical properties, several interesting features can be derived from moments, as orientation or eccentricity.
5. Topological Properties: Capture the structure of a region, these features often combined with numerical features (e.g. in Optical Character Recognition (OCR))

Figure 2.7 shows the blob analysis using labelling region:

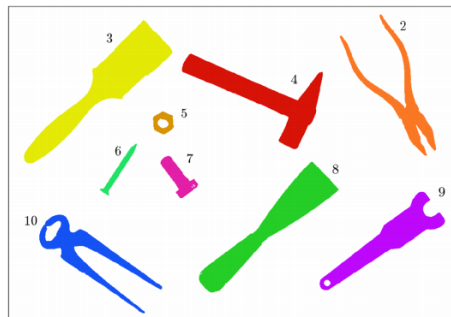


Figure 2.7: Region labelling results

2.3 Applications

In particular, there are several applications thanks to the advances of the computer vision. Computer Vision is the discipline that studies how to process, analyse and interpret images automatically. These techniques have applications in many areas, such as security, medicine, automatic inspection, or automatic navigation.

Within Computer Vision, the detection of objects is one of the hottest topics. In general, when a machine looks for an object inside an image, what it really does is look for patterns that correspond to particular object. There are many works that take advantage of the described techniques, especially to extract important information from images.

Kiadtikornthaweeyot & Tatnall (2016) propose techniques to classify objects in the satellite image by using image processing methods on high-resolution satellite images. The systems to identify the ROI focus on forests, urban and agriculture areas. The proposed system is based on histograms of the image to classify objects using thresholding. Instead, Grycuk et al. (2015) present a novel approach for image description. The method is based on two well-known algorithms: edge detection and blob extraction. In the edge detection step is used the Canny detector. This method provides a mathematical description of each object in the input image.

Vision application to monitor the machined surface in turning Nimonic75 material using coated carbide tool considering different spindle speed and feed rates. Analysis of the captured data has been processed using histogram analysis, a tool which provides the best frequency of pixels in a dominant gray level of an image. Turned surface images are acquired using machine vision camera to monitor the surface texture. The images were preprocessed to enhance the quality of the image by applying image segmentation and image enhancement techniques. The histogram distributions of an illuminated region of interest (ROI) from turned surface images were analysed to assess changes in the frequency of the histogram, which serve to quantify the surface roughness (Chethan et al., 2018).

Chapter 3

Vision System Architecture

In this chapter will be describe the design and implementation of the visual inspection system, capable to recognize and detect defects, damages, absence or incorrect sizing of the inspected object. Also, it will be focused on describing the overall process of the visual inspection system, the various elements involved and their functions.

3.1 Object to Inspection

As seen in chapter 1, automotive manufacturing is based on a modular assembly, with a large network of suppliers. In this mode, the line production coordinates better and are more efficient. This modular assembly assigns an important role to its suppliers, regarding the quality of their products, greater specialization, innovation and design. Also, due to large chain production, the quality of each component in each module need to be guarantee, from the most lower level suppliers.

An important modular assembly is the auto parts manufacturing and components. The main assembly systems can be categorized as internal, electric and electronic and chassis system. The most important, Chassis system consists main modules as engine (which have components as motor, drive shaft, transmissions), mobile chassis (composed by with suspension, drive and brake, wheels and steering systems) and front and back corners (cooling system, shock absorber, auto radiator) (CEPAL, 2003).

This study is focused to half-shaft inspection. A half shaft is essentially a drive axle, and it is so named because it does half of the job, extending from differential to one of the wheels. Its twin on the other side completes the set.

When the driving wheels of a vehicle have independent suspension, which means that each wheel can move up and down independently of the other, the differential is mounted to the frame and each half-shaft connect the differential to the driving

wheel. The usage of half shaft as a power transmitter in automotive is more convenience because it is less likely to become jammed or broken compared to chain-drives.

Half-shaft is needed to transfer the power produced by the engine to the wheels. Half-shaft is connected to the differential coupling at the inner end and to the wheel at the outer end. A driveshaft consists of the half-shaft and two constant velocity (CV) joints, used on both ends of half shaft to provide a certain degree of angular displacement. The torque is transmitted to and from the half-shaft via splines on both ends of the component (Chirag et al., 2016), (Singhal & Mandloi, 2013). Figure 3.1 shows a half shaft in typical front wheel drive:

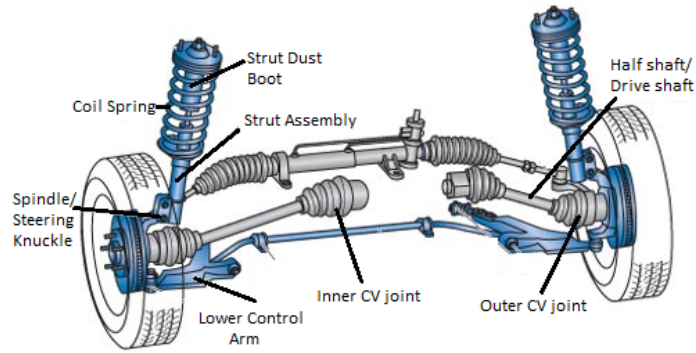


Figure 3.1: Half shaft

3.1.1 Description

Singhal & Mandloi (2013) classifies the half-shaft according the type of CV joint into three categories:

1. By Position: Inboard and Outboard
2. By Function: Fixed and Plunge
3. By Design: Ball-type or Tripod

In general, half-shaft can be classified in two families, which are the most common configuration in manufacturing:

1. Fixed Ball Joint (FBJ) with Plunging Joint (PJ)
2. Fixed Ball Joint (FBJ) with Double Offset Joint (DO)

Where, we can summarize the main components and characteristics in a general way in the fixed ball joint with plunge joint:

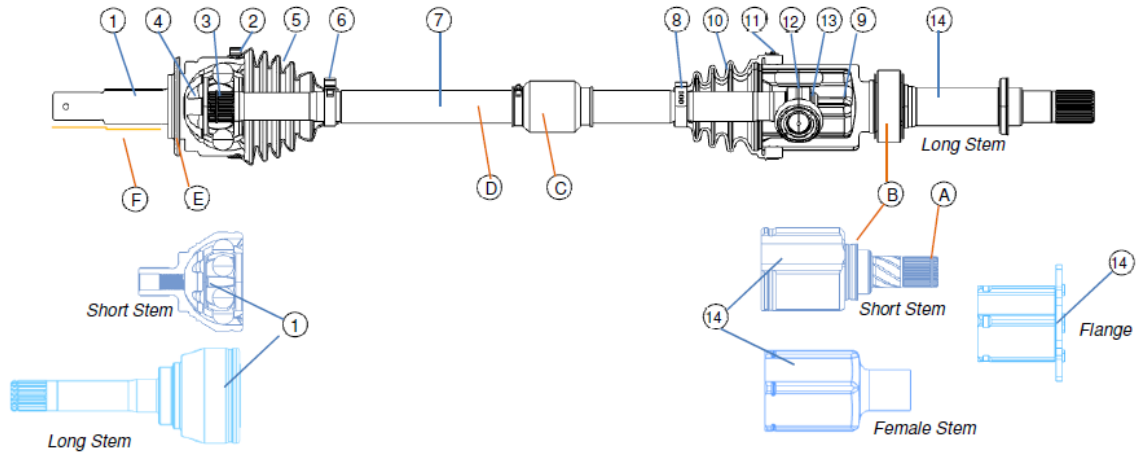


Figure 3.2: Fixed Ball Joint (FBJ) with Plunging Joint (PJ)

Standard Components	Optional Components
1 Fixed Ball joint	A Tulip ring retainer
2 FBJ ring retainer	B Dustshield/Bearing
3 Large clamp	C Damper
4 Grease	D Label
5 Boot	E Dustshield/ABS
6 Small clamp	F Rust preventive oil
7 Inner connecting shaft (ICS)	
8 Small clamp (Inboard)	
9 Grease	
10 Boot (Inboard)	
11 Large clamp (Inboard)	
12 Tripod (Inboard)	
13 Tripod ring retainer (Inboard)	
14 Plunging Joint	

Table 3.1: Components of the Half-shaft

Fixed Ball Joint

The Rzeppa joint consists of a series of ball bearings installed between two sets of channels, or races. A sheet metal cage holds the balls in place. For this reason, the Rzeppa joint is sometimes called a ball joint. The balls in this joint operate in a bisecting plane between the angles of the axle shafts. As the joint revolves, the position of the balls will change so they remain in this bisecting plane. The position of the balls is controlled by elongated openings in the cage. A typical Rzeppa joint has one race (external) and the other race is internal. The internal and external races are connected to opposite sides of the drive axle. Power flows through one race, through the balls, and into the other race.

Plunging Joint

It is located inboard joint on a constant velocity sideshaft. Its low load-to-stroke makes this joint ideal for automatic transmissions. The noise, vibration and harshness are acceptable for front-wheel drive applications with moderate running angles and output torque.

Tripod joints are also constant velocity joints. They consist of a three-pointed assembly called a spider. Trunnions on the spider allow the spider to move along internal channels in a housing. Note that the spider is splined to the axle shaft. Thin roller bearings called needle bearings are installed between the spider points and the trunnions. As the axle rotates, the spider is driven by the housing and drives the shaft. If the angle between the two sides of the joint changes, the tripod can tilt to compensate.

Double offset

For applications requiring inboard joint angles up to 30 degrees and high-axial stroke requirements, the double offset is the ideal solution. It features a low-backlash design.

Figure 3.3 shows the differences between fixed ball, plunging and double offset joint:

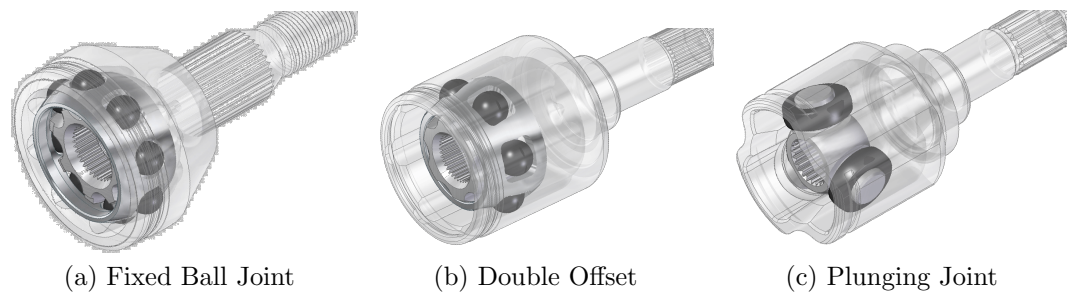


Figure 3.3: Types of CV Joints

Boot

The boots are important component in the half shaft. These protect the CV (Constant Velocity) joint from damage. Inside the boot is axle grease. This grease lubricates the joints. When the boot fails, the grease leaks out, and the joint dries out. This, in turn, causes the joint to grind and the drive shaft to fail. When this happens, you need to replace the shaft. Also, these sealing systems need to work at big angles and

continuous ambient temperatures.

There are different types of boot: Convoluted boot, Diaphragm boot and Rubber. The diaphragm boot works at limited articulation to small angles on fixed or plunge joints. The last boot type normally has a trilobed shape according to the tulip application. Figure 3.4 shows the differences boot mentioned:

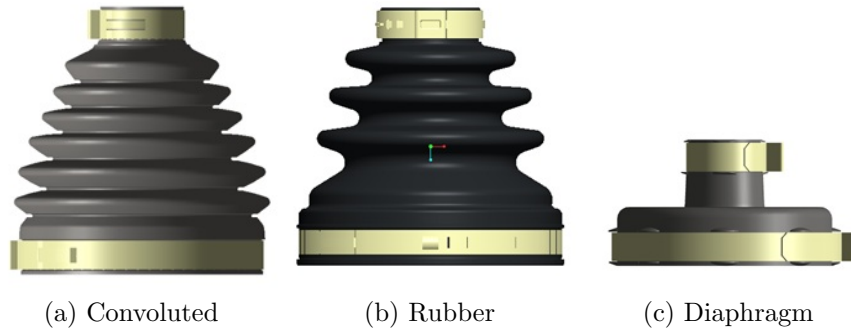


Figure 3.4: Types of Boot

Clamp

The clamp is fixed at each boot extremity to grip the boot on metal surface of the joint. The main functions are: to avoid grease leakage, to avoid debris intrusion in the boot and stabilize large end of boot at high speed. It can be categorized into stepless ear clamp (SEC), low profile clamp (LPC) and multicrimp clamp (MCR).

The term “Stepless” refers to the absence of steps or gaps on the inner circumference of the clamp. The stepless design provides uniform compression and a 360 deg seal. A Stepless Ear Clamp is a ring which allows a diameter reduction. This diameter reduction is generated by the deformation of the ear. After deformation the ear changes to an omega shape.

The name “Low Profile” is due to the reduced packaging. This has characteristics as reusability, Low installed height and Load retaining hooks, which is a visual indication that clamp is correctly installed. Instead, Multicrimp Clamps (MCR) is a ring the diameter of which could be reduced by radial crimping. The thickness gives the packaging diameter.

Other components

There are other components whose presence or model may vary according to the needs of the consumer. Among these we have the dustshield, cotter pin, damper,

ring, circlip, spline, facespline, bearing, tabslot, brackets, nuts and others.

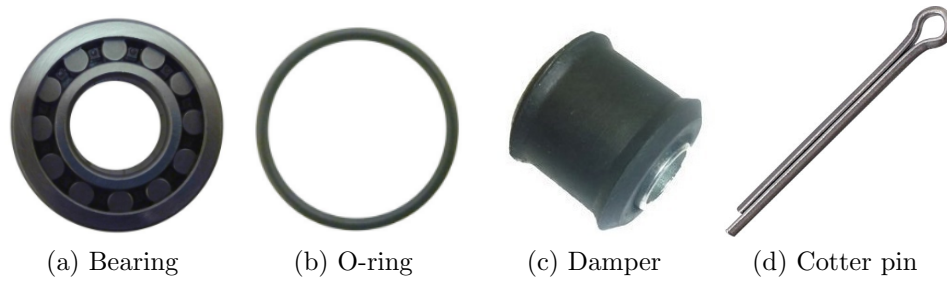


Figure 3.5: Optional Components of half-shaft

3.1.2 Features to check

We have seen that the half shaft is an important mechanical component in vehicles, and that they are constantly subjected to torsion and bending stresses, which can produce wear, fatigue and even fractural failures in the component. Robustness is one of the objectives in its design. In the study developed by Singhal & Mandloi (2013), was determined that the 21% of the common causes in service failure of half-shaft is due to manufacturing/design, which leads to a higher quality control in the manufacture of the product.

Due to the diversity of the half-shaft, the characteristics to inspection in the various components of the half-shaft, will depend on its design and function. Therefore, it is necessary to develop a list of the different parameters to be taken into account during the inspection.

Table 3.2 describes the most significant features/characteristics to be inspected of the various components that composed the half-shaft:

Component	Features	Description
FBJ	Shape	Stem length ± 0.5 mm
		Stem diameter
		Joint backface diameter
	Spline	Spline diameter
		Spline no bumps
	TabSlot	Presence
		Tab slot width ± 0.15 mm
		Tab slot length ± 0.5 mm
		No damages, no bumps
	Dustshield	Presence
		Orientation
		Position
		No damages, no bumps
	Facespline	Seal plug presence
		No damage, no bumps
	Cotter pin	Presence
	Female FJ	Short stem hole presence
		Plastic plug presence
Clamp	Clamps SEC, LPC	Presence
		Clamp diameter ± 0.2
		Right size SEC, LPC
		No damages and deformations
ICS	Damper	Position
		Type of damper
Boot	Boot	Rigth position
		No damage, no dirtyness like grease
Plunge Joint	Circlip	Presence
		Rigth diameter
	Bearing	Presence
		Position
	Brackets	Position
		Orientation

Table 3.2: Significant features to check on half-shaft

3.2 Description of Visual Inspection Process

The complete piece (half-shaft) to inspect, is composed of multiple features and components previously mentioned, therefore for a correct inspection of all them, it was necessary to develop a station, in which the piece is entered by a robot in vertical position. Inside the station, the half-shaft is held in the central shaft by a jaw and is compressed by two tailstocks on the upper and lower sides for a correct vertical positioning of the piece. Then the half-shaft is rotated around its axis, in this way, the cameras installed inside the station, start with the acquisition of the images of

the complete surface of the half-shaft. The acquired images are sent to the processing module PC-based, in this module the algorithms of capturing, processing and analysing the images is executed. After the analysis, the system will determine if the inspected object contains defects, damages, impurities or is free of them.

Finally, after finishing the complete rotation of the half-shaft around its spindle, and completing the analysis of the images, the robot executes the routines for which it was programmed. These routines consist of taking and placing the half-shaft in containers according to the result of the inspection (piece with defects or without defects). The following figure shows the general scheme of the vision system implemented.

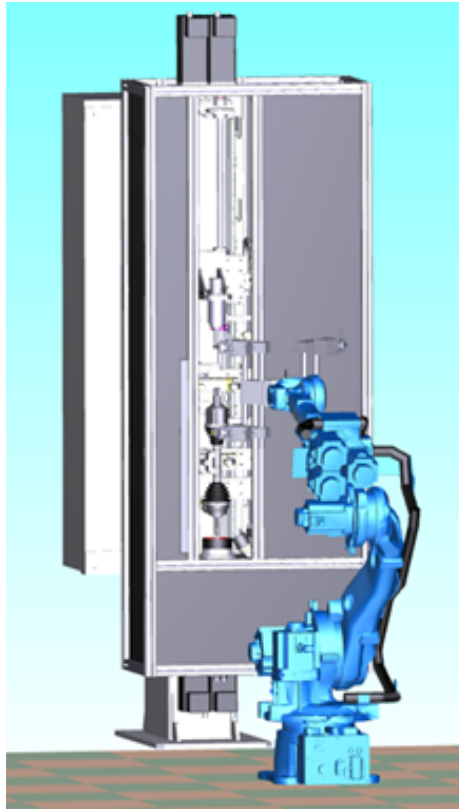


Figure 3.6: General scheme of the automated vision system

3.2.1 Constitutive Elements to automated inspection

3.2.1.1 Devices of image acquisition

The main sensors in our vision system includes cameras, focus lens and Lighting systems. The cameras based on CMOS technology capture images in real time and are transmitted to images processing unit via USB 3.1. This ability allows the cameras to communicate with other devices (specially processing module) in a way easy and quick to execute.

1. Camera DMK 38UX304, Imaging Source.
2. Xenon-TOPAZ lenses, 38mm, F # range 2.0-16.

For the acquisition system (camera-lens), it is necessary to establish the domain requirements, by means of which are established the parameters that allow to determine the environment of the image to be obtained and processed. The domain requirements to consider, are the following:

- Field of vision (FOV), is the area of the object that you want to capture and that the camera can acquire with the highest resolution.
- Working distance (WD), distance measured from the lens of the camera to the object.
- Resolution, is a measure of the ability of the vision system to reproduce the details of an object. This is defined by the characteristics of the camera and the lens to be used.
- Sensor size: dimensions of the active area of the CMOS sensor (found in the specifications of the camera to be used).

For 3D images, a last requirement is used, called depth of scene which refers to the depth of the object to be captured, determined by the front and behind area the object under study.

For the complete inspection of the half-shaft, seven cameras were used, integrated in one system. The positions of the cameras are usually fixed. In this system, the considered cameras are fixed and mobile because these are designed to inspect half-shaft pieces of different lengths and models, therefore the positions can change. Six cameras are located on the lateral side of the station, parallel and frontally to the half-shaft, while the last one was positioned at bottom of the station.

On the other hand, as seen in literature, lighting system help the cameras take the characteristics of the object clearly and accurately. If a scene under inspection is appropriately illuminated, it facilitates the reception of the image features and its posterior processing. Some types of lighting systems used are panel backlight, diffuse and directional.

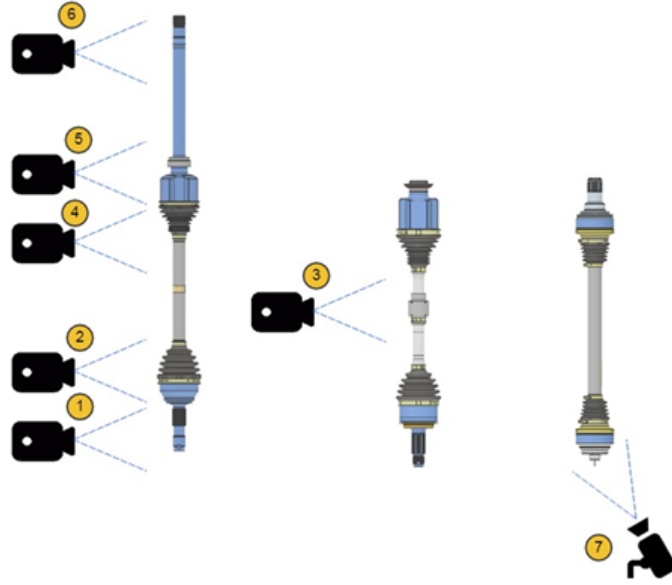


Figure 3.7: Positioning and FOV of cameras

3.2.1.2 Processing Image Module PC-based

The visual inspection software is developed on a PC. Once images have been acquired, the image processing unit removes the background noise or unwanted reflections from the lighting system and performs a variety of operations to extract the characteristics of the inspected object, according to the default tolerance and other configured parameters. Finally, after the enhancement and processing of the images, the analysis phase is developed. The analysis phase determines and labelling the half-shaft as defective or non-defective. The results be transmitted to the robot.

In addition, a report is generated with all examined components and their results. All the images are stored in a local hard disk, with labelling defective, non-defective.

3.2.1.3 Final actuator: Robot

The last element that constitutes the vision system is the robot. The sequence of the operation executed by robot will be the following:

1. Grip the half-shaft from the last stage of manufacturing and placing the half-shaft in the inspection station according to the requirement defined (correct position, orientation).
2. Leave the half-shaft to inspection and waiting for the next task.
3. Grip the half-shaft inside the inspection station, take out and place in the machine for the its label lecture.

4. Unload the half-shaft in its respective container/box according the result send by computer vision.

To properly manipulate the half-shaft, the end-effector of the robot was carefully studied. It is constituted by a clamping system of gripper-type parts, which allows it to take and manipulate the piece properly.

Also, to proper programming of the tasks to be executed by the manipulator, it is necessary to establish the parameters of the end-effector to be used. Likewise, it is necessary to carry out the modelling of the environment of robot, which refers to the representation that the robot has of the objects with which it interacts, and the trajectory to following and that is limited to geometrical characteristics: position and orientation of the objects, and sometimes shape, dimensions, weight.

3.3 Functional requirement

In order to carry out the implementation of the automatic visual inspection system it is important to establish of the system requirements. These can be classified into two: functional and non-functional- The functional requirements are those that try to determine what type of service should provide the system of automatic inspection. While non-functional requirements express limitations or restrictions on the services provided by the system (Bogarín & Murillo, 2004).

- The vision algorithms developed for the automatic inspection must be able to determine manufacturing defects, damages, absence of components, recognition of characters, verification of dimensions and tolerances of particular elements. At the end of the analysis, the defective parts will be stored in a box separated by the robot.
- The automatic inspection system must generate an *file.xml* report of all inspected parts and with detail of the found features, whether defective or not.

3.4 Non Functional requirement

- The system must be capable of operating in real time, with an user guide interface friendly, with the objective of easy handling and monitoring of the visual inspection system.
- Minimize the operation cycle of the parts to be inspected.

- Evaluate the different techniques and algorithms of computer vision, responsible for carrying out the different tasks of image processing. Each one of them must be selected according to the different characteristics or features to be inspected and trying to optimize the processing times.
- Development of an expert system that allows to give more flexibility to the vision algorithms for the inspection of new half-shaft.
- Save automatically all vision information on hard disk and on cloud.

Chapter 4

Implemented algorithms and processing image

It is important to know the techniques used in processing and analysis of industrial images. Each technique gives us specific information obtained under certain settings that help optimize the algorithms to needs very particular. There is the need to build a sequence of techniques that allow to hypothesize the ideal sequence of analysis to solve the problem.

In the development of this chapter the software used will be described, as well as the most important and outstanding techniques of vision algorithms. The different tools applied for image enhancement, processing and analysis will be evaluated. Finally, the various resources developed for easy interaction between the user and the vision system will be presented, these are the graphical user interface and the expert system.

4.1 Vision Software

A computer vision system takes useful information from a scene. Computer vision is the set of tools and methods that allow to obtain, process and analyse images. The computer vision system helps to identify the physical characteristics of an object, quantify the possible defects in the product, which allows taking the corrective measurements that seek quality excellence during production. The computer vision also allows to determine the area of the piece, its thickness, its diameter, its colour, as well as cracks in the pieces, roughness, state of the painting among other properties that the human eye cannot detect by simple inspection.

VisionPro software from Cognex is a PC-based vision software. The VisionPro tool library performs a wide range of function from geometric object location and inspection to identification and measurement. This software includes:

- Software that provides a framework for interacting with the hardware and a complete library of powerful vision tools (OCR, blob analysis, PatMax, calibration) and algorithms.
- Extensive .NET class library and user controls, users can fully integrate VisionPro software into automation equipment.
- The QuickBuild application provides an interactive environment for creating a complete vision application in the least amount of time.

QuickBuild is an interactive application builder that lets you define a job consisting of an image source, the image-processing and vision tools necessary to analyse each acquired image, and the results-analysis logic to determine the result of each inspection.

A single QuickBuild application can consist of multiple jobs for production environments where more than one camera captures images of objects to be inspected either synchronously or asynchronously. You can run the jobs interactively, using either manual, triggered, or automatic operation.

- An VisionPro Application Wizard that takes the vision application created in QuickBuild and creates a Windows application with a custom interface that is easier to use. It is also designed to make it easier or to make adjustments without having to regenerate the application.
- Advanced development capabilities for deployment and write your own custom application around the configured jobs, or to create an entire application using C# or VB.NET directly with the underlying VisionPro components: visionPro tools, objects, user-written and tool edit controls.

The algorithm that allows the automatic inspection of half-shaft is composed by three stages: the first corresponds to the visualization of the scene (Field of vision) and capture of the image in the algorithm. Second refers the vision tools applied to acquired image for its processing and analysis. This stage is also responsible for sending a signal to the controller, which depends on the results of the inspection. The signal sent will assign the task of the robot to unload the piece in containers according to the type of result (defective half-shaft and no-defective). The last stage of the algorithm generates a report in a *file.xml* of the examined half-shaft, with the respective results about their components and features to be inspected.

4.2 Image Acquisition

The process of acquiring the image from the object to its entry into the computer, is achieved through a device that must be sensitive to changes in light. The camera is composed of photosensitive elements that convert light energy into a signal. The signal is passed through the frame grabber to the PC.

The visualization of the scene in real time, is developed in a job of Quickbuild, the tool used to acquire images from a camera is the *Image source*. This tool allows to choose types of input images, image from an Image database, from camera, or from a folder of images. For input images from cameras, is necessary to specify the set-up or/and initialization of cameras, these are: Image Acquisition device/frame grabber (Device that will acquire image), the video format (select the camera and its format) and the camera port (port which camera is connected). Figure 4.1 shows the interface for image acquisition of visionPro.

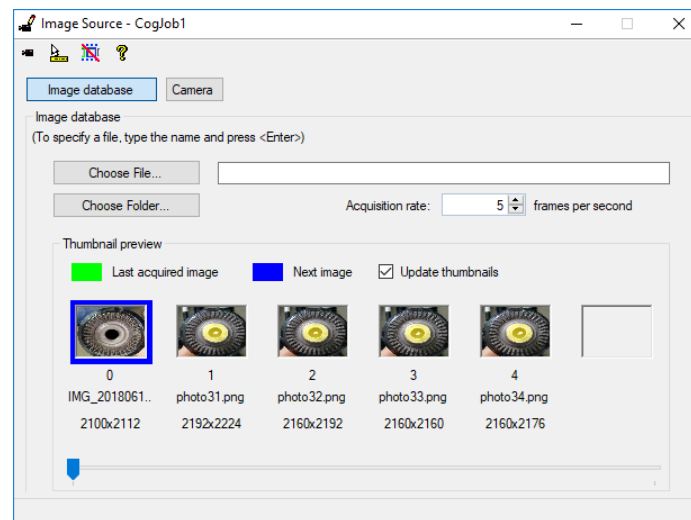


Figure 4.1: Image source Tool

Use *CogImageFile* tool to save images to file or process images from an existing files saved on the PC. The files types supported are: image database (.idb, .cdb), bitmaps (.bmp), tagged image file (.tif), JPEG and portable network graphics (.png).

4.3 Processing

The purpose of this stage is to analyse and determine if the half-shaft complies or not with the established quality parameters. In this phase the powerful vision tools are used, as well the advanced development capabilities written in vb.net (or C#) which provides an interactive and viable navigation environment to configure different functions and tools related to computer vision. The developed algorithms allow

to execute the analysis process of image and determine the quality of the half-shaft.

To make more efficient and carry out a stricter control of the analysis stage, vision algorithms is split into two sub blocks, which are placed within a sequence structure which allows sequentially execute the two sub blocks. The first sub diagram corresponds to the preparation and calibration of the image, this part is also known as system setup, and the second code corresponds to the necessary functions for the inspection to be performed.

4.3.1 Pattern Recognition

A pattern is a graphic representation that describes an object of the same class and similar features. Cognex vision system allows pattern recognition by means of several different techniques. There are *Blob* tools which identify objects by looking at size and shape properties and *PatMax* tools based on geometrical method. This category of algorithms looks at the relations between edges in an image. Edges are defined as the boundaries between regions of dissimilar grayscale values. There will be described the most useful techniques for pattern recognition:

PatMax

PatMax technology is the basis for tools as *PatQuick*, *PatFlex*, *PatInspect*, *OCVMax* and *IDMax* covering the broadest range of pattern matching and inspection in the industry. PatMax algorithm for object recognition is based on shape and not on grey-scale similarities.

The first step is to let the system know what it should look for. This is done by loading an image with the object of interest. The object is marked with a geometric shape (rectangle, circle or polygon) that encloses all the parts of the object that are important for an efficient recognition process. The training is done only once and yields a pattern which can be used to look for the specific object in any image. When searching an image, the algorithm tries to find patterns similar to the trained one. The capabilities of PatMax tool are:

- Measure position of the pattern
- Measure size and angle relative to the originally trained pattern
- Improve alignment yield, defocus, partial occlusion and unexpected features can be tolerated.

Figure 4.2 shows a training image. The rectangle defines where PatMax should look for model feature information. The rectangle makes it possible to define a model even when more than one object is present in the image. The cross marks the object reference position.

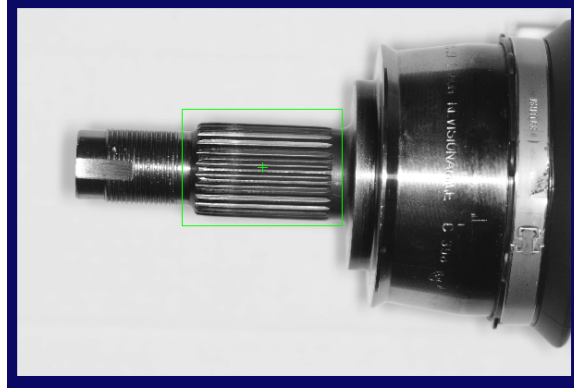


Figure 4.2: Trained image to localize spline component

PMAlignMulti

PMAlignMulti tool allows to locate instances of multiple patterns in a single runtime image. This is possible by adding different patterns, specifying a region of interest, and selecting runtime parameters. Each pattern is stored in a database, which are compared with the image transmitted by the cameras, to finally identify which class they belong to. Figure 4.3 shows a trained multiple pattern to identify the different types of damper located in the inter connecting shaft.

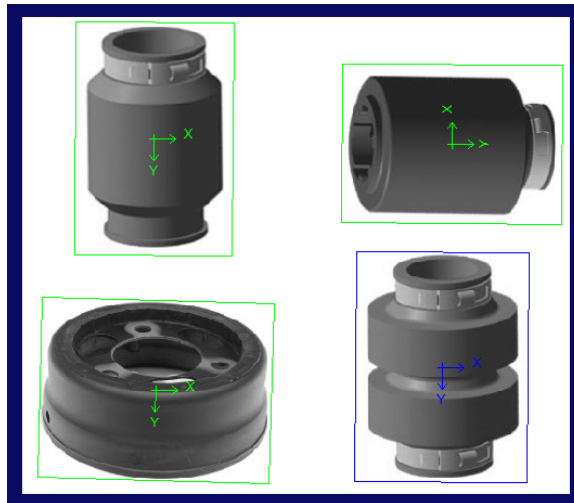


Figure 4.3: Recognizing of multiple pattern: Types of Damper

Also, the results show the position coordinates, rotation, translation and scale of each object recognized. It depends of the set degree of freedom.

ID	Pattern Name	Score	X	Y	Angle	Fit Error	Coverage
0	clamped_spline	0.883	426.72	126.06	-89.58	-1.000	-1.000
1	double_mass	0.881	416.34	347.44	0.37	-1.000	-1.000
2	wheel	0.794	132.43	370.39	1.61	-1.000	-1.000
3	barrel	0.765	130.98	121.15	0.47	-1.000	-1.000

Figure 4.4: Position coordinates and results of recognized Dampers

4.3.2 Edge Detection

The edges of a digital image can be defined as transitions between two regions of significantly different grey levels. They provide valuable information about the borders of objects and can be used to segment the image and recognize objects.

Cognex vision library offers a series of tools that facilitate the detection of edges, these tools based on geometry features that allow to find and fit lines, corners, intersection points, segments and others. Figure 4.5 presents edge detection 1D, to locate the starting coordinate of the boot component, wheel side. This facilitates the exact location of the boot position, avoiding confusion about its correct location due to the overlap of the clamp in the boot.



Figure 4.5: Edge Detection 1D in initial coordinates of boot

4.3.3 Caliper

CogCaliper tool searches for edges or edge pairs within a projection region. The Caliper edit control has two modes: Single Edge or Edge Pair, which can be set up in the Settings tab. Edge Pair mode can also measure the distance between edge pairs.

This tool is useful for measuring the width of objects, the location and spacing of pairs of edges in images. Therefore, it is ideal in inspection functions, where the verification of the sizing of certain components is required. Figure 4.6 is used to

compute the correct dimension of width and height of the *ear* of the closure of clamp, according the functional requirement defined in table 3.2



Figure 4.6: Size of Stepless Ear Clamp

4.3.4 Calibration

Calibration is a process that consists of transforming the information that contains an image into units of pixels into real units (real-world) such as millimeters, centimeters, inches. It is important to perform this procedure when accurate measurements are needed in real units.

All features located in the image such as points, lines, edges, and distances are initially expressed in camera sensor frame of reference and are scaled to the scale prevailing in this frame. The image recorded in the vision system memory is an array recording the amount of charge generated at each sensor pixel location. The process of calibration allows to specify another more useful system of coordinates and scale.

The calibration process supported by VisionPro through the tool *CogCalibNPoint-ToNPoint* allows to specify the important features of the new Calibrated coordinate system. These are:

- Location of the origin of the calibrated coordinate cystem. This is the position (0,0) in the calibrated coordinate system relative to camera sensor.
- Direction of the Major Axes of the calibrated coordinate cystem. This is the direction of X and Y in the calibrated coordinate system.
- The Angle between the calibrated coordinate system and the sensor coordinate system. The amount of rotation between the calibrated coordinate system and the camera sensor.

- Scale of the calibrated coordinate system. This is the relationship between the units of distance in the calibrated coordinate system and the pixel spacing in the camera sensor.

Figure 4.7 shows a calibrated image to measure the diameter of the fixed joint in real units (75 mm). First, the image was calibrated using the *CogCalibNPointToN-Point* tool and then this calibrated images is transmitted to the *CogCaliper* tool to measure the joint diameter.

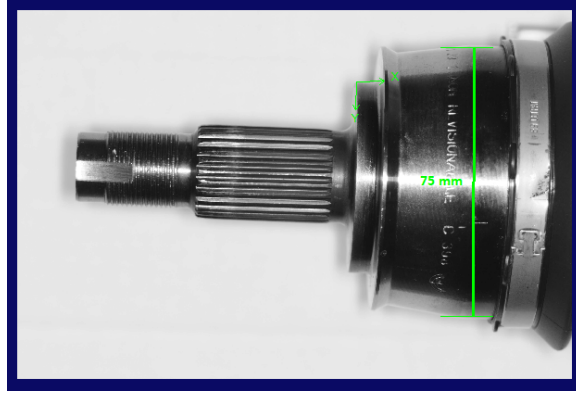


Figure 4.7: Image Calibration

4.3.5 Blob Analysis

Blob analysis allows identifying groups of pixels (known as blobs) within a grayscale image. Once these regions are identified, it is possible to carry out different types of analyses. *CogBlob* tool from Cognex can report many properties like area, perimeter, center of mass. Also, using the Blob edit control, is possible specify morphological operations (erosion, dilation, opening and closing), segmentation (dynamic, fixed and relative) and connectivity (4 -Neighborhood and 8 -Neighborhood).

As have been seen in the state of the art (chapter 2), The segmentation of an image consists in the division or partition of the image into several homogeneous and disjoint zones or regions, which depend on its contour, its connectivity, or in terms of a set of characteristics of the pixels of the image that allow discriminating other regions.

On the other hand, morphological operations help to simplify the data of an image, preserving the essential characteristics and eliminating irrelevant aspects. Considering that in the identification and decomposition of objects, the extraction of features and the location of defects are highly related to properties of form (areas, perimeters, form factors, invariant moments); the role played by morphological operations in computer vision is highlighted.

The following figure shows the analysis of the boot component, using the blob tool, to verify the correct positioning and symmetry of the component. Blob facilitates the identification of component in the image that has been segmented by means of the mentioned operations, which make possible to filter, isolate and/or soften the intensity of the pixels in an image.

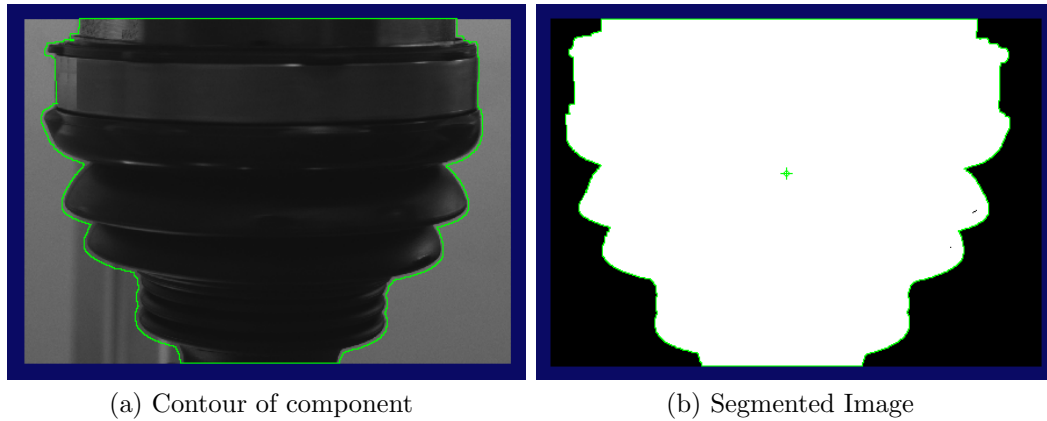


Figure 4.8: Blob analysis of Boot

4.4 Graphical User Interface (GUI)

The graphical user interfaces (GUI) in machine vision are intended to provide information of the visual inspections and quality control in the production process. The user interface is an effective way of interaction between user and vision system. It must be done in simple language, so the authorized users, whose can be vision non-expert users, can handle it adequately. The GUI for our system vision is done by means of two control panels: panel-operator and resource control panel.

Visual studio .NET makes it easy to create a user interface by providing a set of ready-to-go controls (such controls include buttons, menu, text boxes and any others) in a toolbox. To create an user interface is enough start a new project and position the controls on the form, which is the object that represents the main window of program.

VisionPro Controls Wizard populate the tool palette in Visual Studio with the latest set of VisionPro edit controls for development of .NET applications. Also, the QuickBuild environment makes it easier to create a vision application by providing you with a framework that lets you manipulate the vision tools interactively. In this mode, it is possible to create a custom user interface for our vision application. When an QuickBuild application is saved, it is stored as a VisionPro persistence *file.vpp*.

This file contains all of the information needed to recreate the QuickBuild application. At the same time, VisionPro saves it as a *CogJobManager* object.

In order to build user interface application in visual studio that loads a saved QuickBuild application. The important things to notice are:

1. Specify the assemblies that our application uses, these are mainly *Cognex.VisionPro*, *Cognex.VisionPro.Core* and *Cognex.VisionPro.QuickBuild.Core*.
2. Define class variables to refer to the QuickBuild application.
3. Use the form *Load* and *Closing* methods to load and close the QuickBuild application.
4. Handle job manager events and working with cross-thread method calls to add an user interface to application.
5. Display results and images from the application in the user interface by means *UserResult* and *CogRecordDisplay* methods.

4.4.1 Operator Panel

This panel contains a window that allows the user to visualize and monitor the scenes captured by the cameras. There is also a led indicator that allow the user to know the result of the inspection. During the processing the led indicator is yellow, if no defect was found in the components of the half-shaft, the led indicator is green, while the colour of led changes red when the half-shaft is defective.

In addition, there are window tabs, which contain an explanatory module that serves provide information about the parts and components of the half-shaft. An inspection module, which allows not only access to the database but also to see the inspected parts and their main characteristics and the last module that contains the report with summary information about the defective parts, date and the cell.

Figure 4.9 presents the monitoring module of all cameras in the visual inspection system:

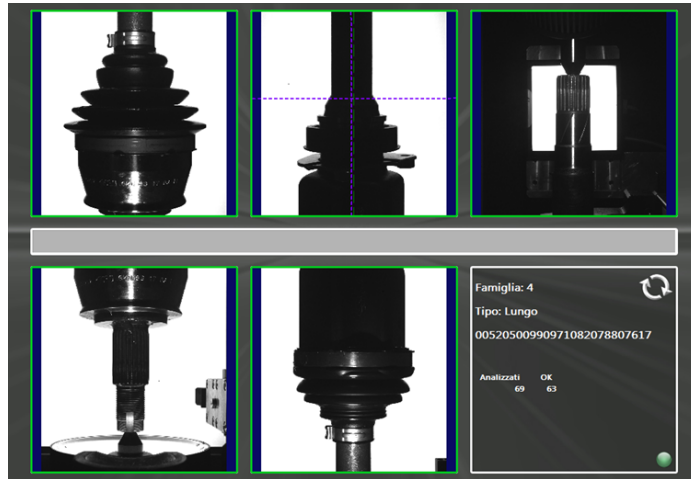


Figure 4.9: Program run, visualization of scenes and inspection results

Figure 4.10 shows the inspection module to access to local database of each examined half-shaft. At the same time, these data will be saved in the cloud.

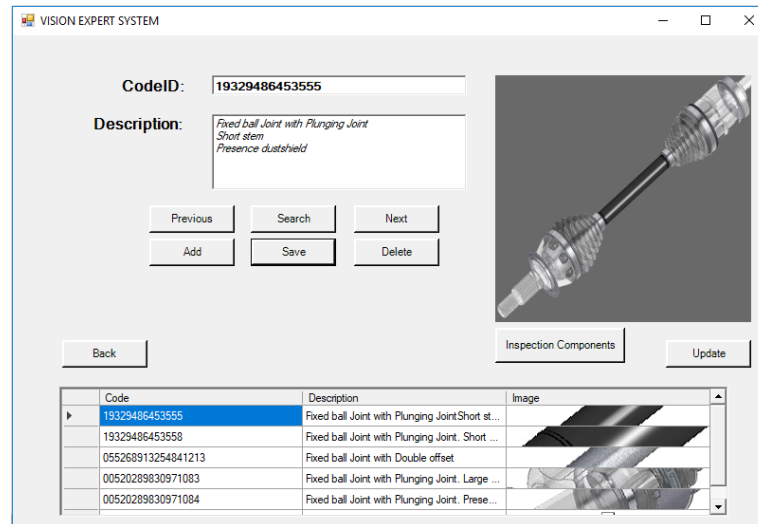


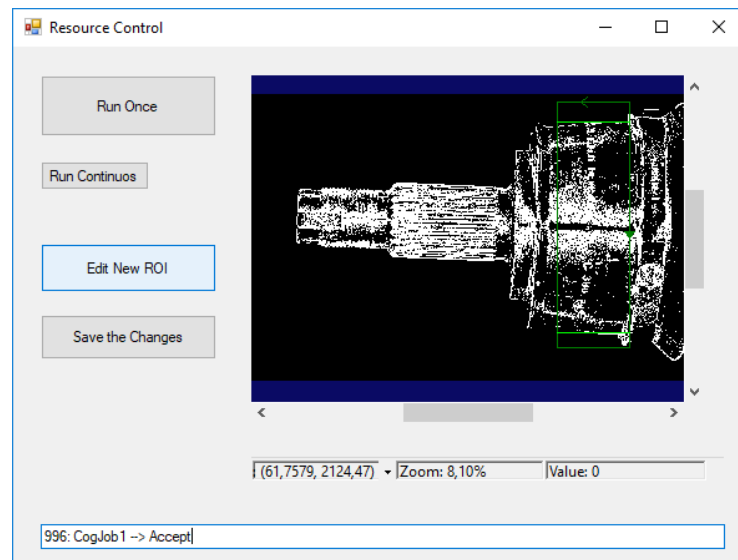
Figure 4.10: Access to local database of inspected half-shaft

4.4.2 Resource control panel

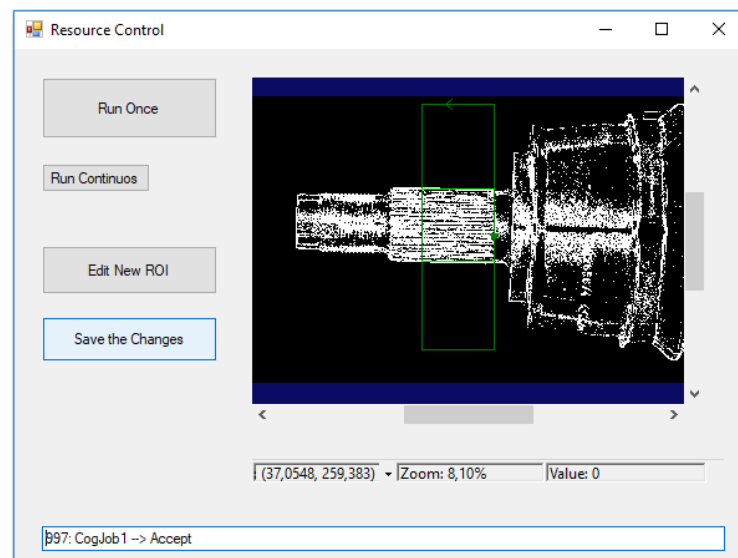
The user interface also allows the user manipulates objects in order to give commands or information to the program. Thus, the user can specify sequences of operations from the menu. This feature provides easier and faster application developments doing them a powerful re-configurable software. Since our objective is to provide flexibility to the vision software and that they adapt to the diverse needs, this will be possible through environments that develop in a short time and adjust to the modifications through the GUI.

The design and implementation of this panel, obeys the need to solve configuration tasks of vision system. The tasks controlled from this panel can be the calibration, configuration of new regions of interest, measurement of particular features, size among others.

In the following figure 4.11, is presented the resources control panel that handle and define a new region of interest (ROI) in a segmented image. Fig. (a) presents the ROI of joint to get the measurement of its diameter (using *CogCaliper* tool). Instead, in Fig. (b) a new ROI was defined in the spline component to verify its diameter. The new ROI will be defined by the user.



(a) ROI of Joint Diameter



(b) ROI of Spline Diameter

Figure 4.11: Handling the Region of Interest (ROI) of a segmented image

4.5 Data and Results Analysis with generation of Report

Cognex offers *CogDataAnalysis* tool, which allows to set tolerance ranges and perform statistical analysis on the results of vision algorithms and tools. The tolerance range can be configured for individual values or aggregate values. In the interface of data analysis edit control, it is possible to configure the number of channels and verify that each channel receives the current input value, the input values will be the results and values coming from vision algorithms. After, they will be set the range of tolerance values for each input value. The tolerance values in the channels defines one category (warn, reject and nominal) for the input value.

Obviously, the analysis is based on the predetermined requirements before the inspection, which depend on the structure and function of the components of the half-shaft to be inspected, these characteristics can be the correct sizing, tolerances, absence of elements, presence of damage in the surface and dimensions, among others.

In the same way, Cognex offers the *CogResultAnalysis* tool, which allow to define a set of expressions, in turn it will allow the most recent run of the tool group to give a passing result. Using the *CogResultAnalysis* tool, is possible to combine the results from one, several, or all the vision tools and generate a value that can be used to judge whether the tool group generates a *warn* or *reject* status. VisionPro ultimately uses this status to determine the value of the *RunStatus* property for the tool group.

The method to read all these results, visualize them and generate the report (.xml) in visual studio, it will be the same as the one described for the creation of the user interface. In the *System.Xml* assembly we have at our disposal a multitude of classes that allow us to manage, write and read XML files, for the generation of this file, this assembly will be add to our code. On the other hand, the job manager, created by visionPro, fires an *UserResultAvailable* event that allows to extract the data from the job and display it in the Form of visual studio. The job manager contains get posted to various queues. The queue, which we will work is the *Posted Items* list, also called user queue. The *UserResult* method removes and returns the oldest result record from the user queue. This record contains a subrecord for each item in the list, which include the *UserResultTag* and *Runstatus*. The last one used to show the values of the results.

The publication of the results and the information of the inspection analysis is necessary, in this way, the department of quality control issues to the department of

development and manufacture, the information compiled of the characteristics (size, type o cause of the defects) that are presented in the results, which help to analyse and determine which part of the assembly is working incorrectly.

4.6 Cloud Computing

In general, a big problem of manufacturing lines is the documentation and management of big data of information. Currently there are technologies based on cloud computing that solve this problem. Cloud computing is used due to its properties of scalability and functionality especially in complex industries.

There are three types of cloud computing model: private, public and hybrid. A public cloud is one based on the standard cloud computing model, in which a service provider makes resources, applications or storage, available to the general public over the internet. However, there is no direct control over the architecture of a public cloud. Public cloud services may be free or offered on a pay-per-usage model. Some public infrastructure platforms are Microsoft Azure, Dropbox, OneDrive or Google Cloud Platform.

The private cloud, which is a proprietary cloud computing architecture dedicated to a single organization. Private cloud differs from public cloud, as it serves as an extension of an existing data centre and is accessible only by the company. A third model, the hybrid cloud, which is a combination of public and private cloud services. In some cases, this model is attractive because it enables organizations to tap into the benefits of the public cloud, while maintaining their own private cloud for sensitive, critical or highly regulated data and applications.

In this stage, all information about the visual inspection process will be stored in a cloud to easier communication and sharing of data. This makes the system more flexible and functional with an easy data recovery, dynamic monitoring on-line, among others.

The developer platform used in this project to save visual inspection files to any server in the cloud is *.NET*. The key to create a successful stored in cloud is to select appropriately the Software Development Kits (SDK) or/and application programming interfaces (API), ensuring proper interoperability of cloud application.

To get started integrating with the Drive Cloud, it is necessary to enable the Drive API and provide configuration details. Drive API Client Library for *.NET*, manages

files in Drive including uploading, downloading, searching, detecting changes, and updating sharing permissions. For a correct integration, the following steps are needed:

- Install Google.Apis from .NET using the package manager console of NuGet. NuGet is an extension of Visual Studio that makes it easier to add, remove and update references to libraries and tools in Visual Studio projects. Write in the command console: `PM Install-Package Google.Apis.Drive.v3`. If there are other packages necessary for the application, they can be installed from this console, so for example to use files excel, install microsoft package: `PM Install-Package Microsoft.Office.Interop.Excel`.
- After install the packages, add the references in the explorer solution of visual studio project.
- Get the access credentials to be used in .NET to make cloud backups. In fact, to make an online backup to Google Drive, it is necessary to enable some specific options, then you must create an account into using the credentials provided by Google (Client ID and Client Secret). To get the credentials of Google Drive, do the following steps:
 - Go to Google Cloud Platform, sign in with your Google account
 - Select New Project
 - Create Credentials
 - Select ID client of OAuth, immediately, *client ID* and *client secret* will be shown.
- Copy these credentials and paste them into program written in .NET.
- Finally with the credentials and with the references added in .NET, it is possible to program the application that allows us to load the files automatically in the cloud.

4.7 Experimental Results

In this section we present the results that were obtained from the evaluation of the previously described algorithms. In addition, these will be categorized into the main characteristics to be analysed.

Pattern Recognition

The inspection system must be capable of performing objects recognition using templates (trained images) and comparing them with the images coming from the CMOS sensors (cameras). Each template represents a geometric model of the component to be inspected. This helps to extract object information in the captured image, invariant of the position, orientation and/or scale of the component to be inspected. These degrees of freedom that pattern recognition provides are very important for our inspection system, because the half-shaft is rotating on its axis, therefore the component of the half-shaft to be inspected, will constantly change its position and orientation. In fact, the figures 4.12 and 4.13 show that the system is able to recognize the position and orientation of the components, tabslot (component located in the outer joint of the half-shaft) and the clamp closure while the half-shaft is in rotation.

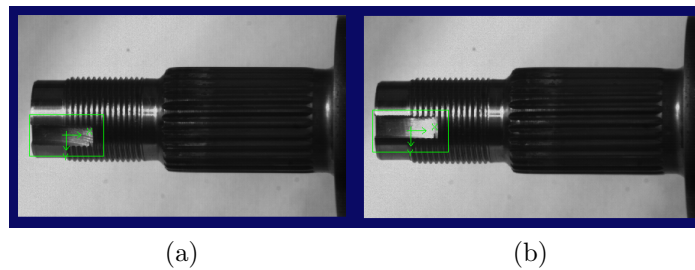


Figure 4.12: TabSlot Recognized while half-shaft rotates

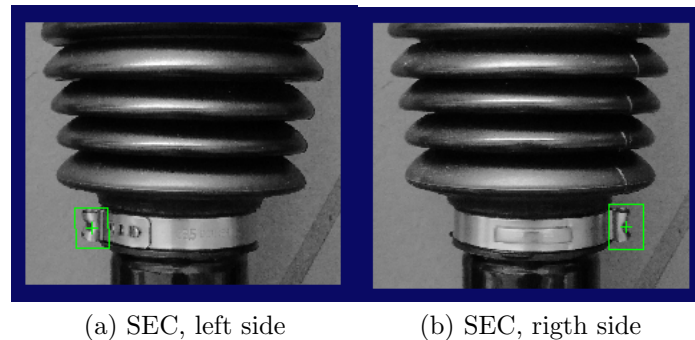


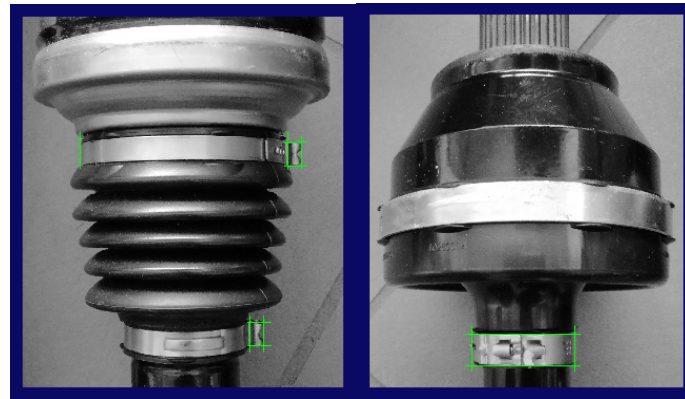
Figure 4.13: Stepless Ear Closure Recognized while half-shaft rotates

Dimensional Inspection

Some requirements of the quality control are dimensional verification of the components to be inspected, such as width, height, diameter, depth or thickness. This procedure allows knowing if the manufacturing is completely adjusted to the parameters established in the design stage and/or required by the client or, on the contrary,

an error or defect is occurring. To illustrate the dimensional inspection of our system, we will analyse in detail as an example the clamp component (component whose function is to fix the boot to the joint at one end and to the inter shaft at the other end).

Figure 4.14 presents the verification of the dimensions of the clamp, these are two types: LPC and SEC clamp. The diameter and width of both clamps must be verified, in addition, for the case of the SEC, it is necessary to verify the height of the *ear*.



(a) SEC, Convoluted boot (b) LPC, Diaphragm boot

Figure 4.14: Dimensional Inspection of clamps

According to the requirements established in Table 3.2, and according to the clamp model, it is necessary to verify the dimensions:

Clamp	Type	Minimum	Maximum	Vision System
SEC PG167	Diameter	17.8 mm	120.5 mm	37 mm
	Ear width	7.0 mm	10.0 mm	9.745 mm
	Ear height	2.1 mm	4.1 mm	2.41 mm
LPC PG168	Diameter	19.5 mm	110.0 mm	57.77 mm
	Width	7.0 mm	7.0 mm	6.97 mm

Table 4.1: Clamp Range and Dimensions

From the results we can deduce that the dimensions for both clamp models are within the established ranges. It is necessary to clarify that in the Fig. a) we have two “ears”, therefore the dimensions will be verified for both “ears”. The Table 4.1 presents only the measurements made to the upper ear, with the objective of making a comparison between the low profile and stepless ear clamp models.

Absence of elements

The absence of elements in the final product is also an indicator of defects in the quality inspection process. Many of these elements can be functional (damper, cotter pin, nuts), therefore they can create problems in the service and/or operation of the half-shaft, or they can be protection elements, such as seal plug. The following figure 4.15 shows the detection of presence of the seal plug, located in the short stem of the facespline, wheel side. When the computer vision system detects the absence of this element, it is indicated in the final results, which will provoke the rejection of the half-shaft.

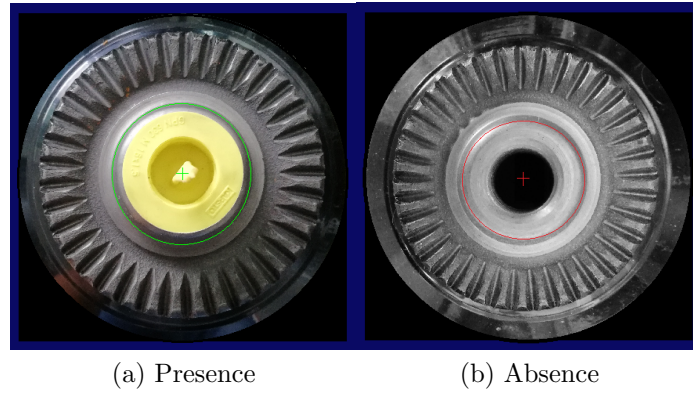


Figure 4.15: Verifying the presence of Elements: Seal Plug

The absence of the elements can have diverse origins, from faults in the assembly process, to loss of elements during the transport from one module to another.

Detection of defects

The imperfections or damages obtained in the process of half-shaft assembly, are reflected on its complete surface. As seen in chapter 2, there are several techniques to identify different types of defects, due to digital images are susceptible to different types of noise and lighting conditions, factors that can cause false alarms in the inspection result. Therefore, it is important to establish parameters to indicate to the system, under what conditions the areas or particles observed in the image are noise and brightness, which should not be recognized as defects.

Through the automatic visual inspection, it is possible to distinguish: damages, fissures, bumps or cut. The defect detection methodology begins with the segmentation process of the image using threshold (fixed or dynamic), then continue with the blob analysis, which identifies the parts in the captured image that do not belong to the object. The following figure 4.16 presents the detection of fissures and cuts

in the spline of the half-shaft. These damages and/or fissures are grouped as areas recognized by the blob analysis.

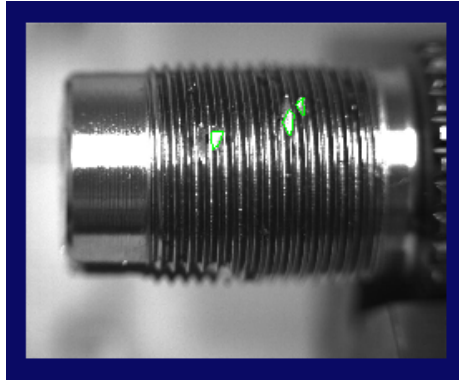


Figure 4.16: Half-shaft reject, damages presence in Spline

Likewise, the system can determine the incorrect positioning or assembly of components, by evaluating their rotation and position. In Figure 4.17, the incorrect positioning of the clamp is shown. The pattern recognition also computes the rotation angle respect to the fixed reference system, which is important to determine the correct orientation of component.

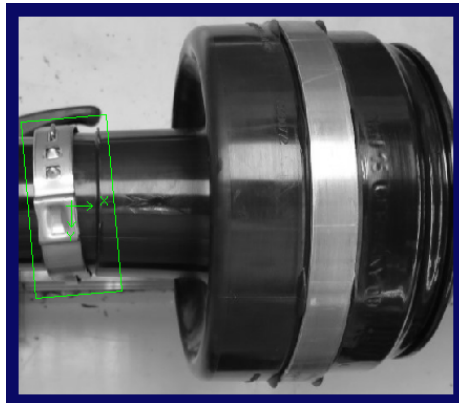


Figure 4.17: Bad positioning of the clamp

4.8 Efficiency of the inspection

The efficiency of the system is evaluated in the rate of false positives and false negatives. False positives refer to the number of products that have been classified as defective without faults (false alarm), while false negatives indicate the number of defective parts that were not detected by the automatic visual inspection system. The ideal is that both rates are 0%, however in reality this situation is hardly achieved.

In the process of visual inspection of half-shaft, it was used a sample of 60 pieces, among which were defective parts and without defects. Obtaining the following results: total number of defective parts that were reported was 19, of which 4 were false alarms (false positive); no case of failures (false negative) was recorded, so the system guarantees accuracy, and reliability.

Therefore, the rate of conforming non-defective half-shaft will be 0.91, while the rate of non-conforming defective half-shaft is 1, which guarantees an efficiency of our vision system of up 95,5%.

Chapter 5

Conclusions and Future research

5.1 Conclusions

In this work, the development of a computer vision system was presented, in order to carry out the inspection and quality control of a half-shaft. This visual inspection system was developed on VisionPro platform from Cognex. The architecture of the vision system includes: an inspection station, in which the half-shaft rotates on its axis for a complete inspection of its surface. Image acquisition sensors, 7 CMOS sensors (monochrome industrial cameras) and Schneider lenses (38 mm). A final actuator (industrial manipulator, 6 dof), and a PC for the development of specialized vision software, responsible for communicating and connecting all the components of vision architecture, and mainly for applying the vision algorithms that were developed in this work.

Through the data acquisition board and the tools provide by VisionPro, it was possible design and execute the communication from the acquisition stage to the stage of actuator/control of vision system, facilitating the interaction between the different stages through the use of digital signals of input and output, which offers a versatile solution to the problem of carrying out the inspection in real time; managing to link the result of the inspection process with the manipulator robot. In this way the manipulator executes the task of separating the defective half-shaft from those whose quality control has been overcome.

As a first step, this research begun with the identification and definition of the problem and the different solutions to solve them. There is a lot of techniques to resolve the inspection and quality control problem. Currently, computer vision for inspection present a plethora of works and researches, all of them applied to different fields. This work is focused to study of computer vision for industrial inspection. Specifically, were analysed the diverse techniques of machine vision to automatic visual inspection systems for quality control. In this sense, in the chapter related to the

state of the art, the different techniques, methodologies, development platforms and devices used in the implementation of visual inspection systems based on computer vision have been studied and evaluated.

The methodology for the development of vision algorithms and digital image processing, takes as reference, relevant aspects of vision systems with an industrial approach. However, most of the works in the literature related to the digital process of images, are commonly based on image analysis with inspection needs in scientific environments. Therefore, a selection of vision techniques was made, which provide greater flexibility, efficiency, reliability and speed in the inspection process of the various components of the half-shaft. These in turn, presenting a better solution to the analysis of the image in real time.

The algorithms for the automatic visual inspection are categorized into three modules: acquisition, processing and analysis module, and the respective documentation of half-shaft inspected. For this, the use of the Quickbuild builder of Cognex was very important, because it gives the possibility of carrying out each of the mentioned stages with great speed and flexibility. These characteristics make our vision system an effective and reliable environment. In the processing stage, there are two important aspects: processing (which includes pre-processing for image enhancement, diverse techniques of vision) and analysis. Most of the processing algorithms are based on pattern recognition of each component of the half-shaft, which in turn are based on the pattern matching theory, where a comparison is made of the acquired image with one or several trained image (templates) that characterize the class (element or component). The use of pattern recognition technique was selected due to its use provides a versatile and easy solution to adapt it to the changes of geometries and/or modification of the objects to be inspected. It was demonstrated that the proposed technique can recognize various components of the half-shaft even though they have undergone a translation, rotation and scaling on the acquired image, to which the system responds satisfactorily.

With the aim to verify the dimensions, tolerances and size of the required components, it was necessary to apply the calibration technique, which allows the algorithm to recognize the object and perform the measurements in real units (mm), which also facilitates the recognition of defects. On the other hand, the use of segmentation techniques based on thresholds (fixed, relative and dynamic) for the treatment of images in which the lighting conditions are adverse, provide the opportunity to perform a progressive attenuation of noise caused by various light sources, helping to simplify the image through the elimination of some attributes (noise and brightness) that can

cause a false alarm in the inspection system. In addition, with the application of morphological operations, local defects are enhanced, since this type of operation helps to simplify the data of an image, expanding, reducing and smoothing particles or areas; therefore, these operations, are commonly used in the detection of defects in vision systems with industrial application.

A great tool of visionPro software is its interoperability with visual studio .NET, which allows the design of a fully customized user interface, in addition to the generation of a file (.xml) and its subsequent storage in the cloud. This advantage of being able to generate a report in real time and the parallel way of communicating the results of the half-shaft inspected to the robot, for later deposit in the respective container, make the vision system very attractive and above all potential. This type of applications allows to share information of the automated inspection process to the other departments or areas involved and interested in the results of the process.

For the management of the vision system, a user interface was designed, which facilitates the use of the inspection system. The interface consists of two main panels: operator panel and resource control panel. In the first panel, the inspection parameters to be used for the monitoring and adequate tracking of the process were configured and programmed, in the same way the relevant data are configured for the presentation of the defective parts report and the access to the local database of the half-shaft examined. Also, in this panel the scenes obtained from the cameras is displayed and show the results of the inspection.

The resource panel allows the operator access to vision system to execute commands and manipulate objects of interest; with the implementation of this panel, the developed vision algorithm, can incorporate and/or handle new inspection tasks, restricting said tasks to models and/or accessories with characteristics similar to that of the defined half-shaft.

The economic viability of the system of the visual inspection system presented has been demonstrated, so that the system not only improves the quality of the half-shaft, but also increases the competitiveness of the industry at a profitable cost. It has been seen that the challenges and trends of large manufactures are directed towards the complete automation of their lines, using robots, controllers and artificial vision.

It has also demonstrated the efficiency of the inspection system, in addition to the advantages that this presents. The system has the advantage of working 24 hours a day, being able to work without having to rest, repeating identically the inspection

operation continuously, performing a safe and fast work, guaranteeing a high reliability in the quality of the inspection.

One of the disadvantages that can be found in the system is its adaptability, there are various types of half-shaft and accessories that have not been established in the algorithms of this system. For this, it will be necessary to perform a stoppage in the line and adjust or develop new vision algorithms according to the needs that each new half-shaft or accessory requires. It is important to note that in the development of a computer vision system there is no optimal or general model for all applications, so in each application should determine the appropriate techniques for an efficient extraction of the required attributes within the image.

Currently, the applications of computer vision that most predict in the industrial field are those of automatic inspection, however there are still some limitations in the visually controlled automatic manufacturing. For this to improve, it is necessary that knowledge be expanded, to produce general vision systems that can be applied in multiple domains. By doing this, their flexibility will be able to compete in costs with traditional systems that are not very versatile and incapable of facing uncertain situations or unstructured environments. Also, most of the problems of automatic inspection are reduced to a problem of two-dimensional detection, so these systems have found more acceptance in the industrial field, since there are many tasks that are performed at high speeds and on a large scale, that exceeds human capabilities. The inspector human, in most cases, is who ultimately judges the quality of a product. However, this evaluation is subjective and insufficient, in addition, some visual defects are difficult to appreciate by a human inspector, these can be small defects or whose appearance changes depending on the point from which they are observed. These reasons makes the automation of visual inspection systems very attractive in large industries.

Therefore, it has been determined that process of quality control is important, since it affects the satisfaction of the client, together with the costs involved in such event. Although there is a great literature of the vision systems applications, it is important to mention that the researches are specified at a single level of architecture implementation, or are focused in the hardware or in the inspection system software, it is not common to find the development of an integral vision system, in which both architectures are exposed. In the present work an integral architecture of a computer vision system has been exposed.

5.2 Future Research

The present development aimed to have the greatest possible scope based on the objectives set, however during its development, it was possible to observe some aspects that can complement and improve the vision system.

First, it is necessary to complement the visual inspection system with a database containing templates of all accessories or new half-shaft models that meet specifications or characteristics similar to those developed in this thesis. This will generate the possibility that the system is more flexible and that the inspection of other models or accessories can be carried out, with the similar characteristics defined in our system.

Regarding the detection of defects and vision algorithms, these can be improved through a complete integration with vision software open source, taking advantage of the functions and tools of this software that cannot be found in VisionPro. Being VisionPro a private software, it has some limitations regarding its customization.

On the other hand, it is possible to take advantage of all the information of the inspection process, especially the acquired images, which are stored in a local memory and which are also labelled with their respective information. The artificial intelligence is based mainly on the training and classification of a dataset that can be formed by tagged images or not. The supervised training (with tagged images) in artificial intelligence presents greater precision and reliability. In this way, the stored and labelled images from our inspection system can take advantage to learn and transfer knowledge.

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