NATIONAL UNIVERSITY OF ENGINEERING
COLLEGE OF MECHANICAL ENGINEERING

MECHATRONICS ENGINEERING PROGRAM

MECHATRONIC PROJECT

DESIGN OF A FAULT DETECTION SYSTEM BASED ON IMAGE RECOGNITION OF A MINERAL CONVEYOR BELT FOR ANTAMINA MINING COMPANY

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INDEX

CHAPTER I. PROBLEMATIC SITUATION

In today's Latin American mines, more and more material needs to be transported over long distances and in increasingly remote areas. New mines are now being opened in more remote areas, shafts are getting deeper and underground mines are getting bigger. Therefore, more and more material must be transported over great distances and with this new challenges appear in its handling.

Analyzing the current context of our country, mining is one of the main riches of Peru, expressed in multiple deposits whose potential has been classified as the fourth largest in the world. Peru is one of the main mineral producing countries, with a production value that reaches 22,417 million dollars according to the Mining Statistical Bulletin of the Ministry of Energy and Mines of Peru published in 2018.

In 2018, mining represented almost 10% of the national GDP and 61% of the total value of Peruvian exports, highlighting the participation of copper in more than 50% of the metal mining GDP, according to the 2018 Mining Yearbook published by the Ministry of Energy and Mines (MINEM), through its Mining Promotion and Sustainability Directorate.

According to data from the Ministry of Energy and Mines published through the 2020 Mine Construction Project Portfolio, the development of 46 mining projects with a joint investment of US $ 56,158 million is reported.

Said Portfolio is made up of mining projects whose objectives involve the construction of a mine and / or the modification or optimization of components that allow the expansion or maintenance of the productive capacity; Furthermore, all the projects are owned by private companies in the general regime stratum (large and medium mining) and cover both the production of metallic and non-metallic minerals.

Currently, the productive activity of the mining sector plays a fundamental role in the economic reactivation of the country and will be one of those that will show the greatest recovery in the next year. According to estimates by the Central Reserve Bank (BCR), Peru's gross domestic product (GDP) will advance 11% in 2021, which represents a rapid recovery due to the solidity of the Peruvian economy.

For its part, the metal mining GDP will have a growth of 14.4%, thanks to this, mining will be one of the sectors with the greatest recovery in the next year, along with construction, commerce and manufacturing.

On the other hand, the movement of mining cargo, be it abrasive material, mineral, rocks, among others, from one point to another is a critical aspect that every mining company takes into account within its costs. And although cost is a very important aspect for the mining operation, so is safety and speed during transportation. At this point, interest in using conveyor belts as a conventional means for the operating process has been growing for several years, through which mining companies manage to move large volumes of material continuously, considerably reducing transport time

between long distances. . In addition to the enormous time advantage they provide, conveyor belts have fewer staff,

With the aforementioned data, it is observed how vital mining is currently for the economic reactivation of Peru and consequently the importance of the different existing mining processes, how critical it would be for a mining company if these processes stopped working due to a failure mechanical or product of the same wear in the machines and the costs in economic losses that this would represent for the company.

From which it is proposed to analyze and design a fault detection system based on image recognition for a mineral conveyor belt for the Antamina mining company.

CHAPTER II. GENERAL PROBLEM

The constant interest in increasing the production and transformation of minerals within a mine produces the wear and subsequent mechanical failure of the equipment used in the different mining processes, which if not planned and attended in an efficient way reduce the production capacity of a mine causing millions in losses for the company.

CHAPTER III. ENGINEERING PROBLEM

What technological and engineering considerations of mechatronic design and software design must be taken into account, in order to develop the design of an image recognition-based fault detection system for a mineral conveyor belt that satisfies the requirements of the Antamina Mining Company in order to improve the preventive maintenance plan that is currently being carried out?

CHAPTER IV. STATE OF THE ART

4.1 Existing products and solutions

Among the existing solutions, the most widely used is that, in which a preventive maintenance plan is applied that consists of periodic inspections, in which possible failures are revealed before they occur, in order to avoid unscheduled plant shutdowns .

The mission of this type of maintenance is to maintain a certain level of service on the conveyor belts, scheduling the interventions of their vulnerable points at the most opportune moment. It is usually systematic, that is, it intervenes, even if the equipment has not given any symptoms of having a problem(Silva Sanhueza, 2017)

4.2 Scientific / engineering publications

4.2.1 Intelligent monitoring system of the coal conveyor belt based on machine vision technology

Zhongyi (2019), in the publication entitled "Intelligent monitoring system of coal conveyor belt based on computer vision technology", it raises the importance of the conveyor belt as a fundamental transport equipment for the extraction of coal in mining, it also warns that there are four anomalies within the process, In this document it uses technology related to computer artificial vision and statistics to monitor the operation of the conveyor in real time and inform the personnel about abnormal information within the process.

Based on computer vision technology, the author builds a set of intelligent system to monitor the abnormal situations of the belt. The main methods used are the belt conveyor operation and shutdown judgment algorithm based on local pixel difference and the YOLO object detection algorithm. Then, the output results of the two algorithms are analyzed to achieve the purpose of monitoring the four abnormal belt situations in real time.

4.2.2 Design of automatic conveyor speed control system based on image recognition.

Yongqing (2020), in the publication entitled "Design of Automatic Speed Control System of Belt Conveyor Based on Image Recognition" proposes designing a system for the dynamic measurement of the amount of carbon on a conveyor belt based on image processing, which can automatically adjust the speed of multiple conveyor belts. The system processes the real-time image of the monitoring video sequence of the conveyor belt loaded to the ground, calculates the amount of coal, and adjusts the frequency of the conveyor system according to the amount of coal in real time, to achieve The efficient and energy-saving operation effect of the whole conveyor belt system.

4.2.3 Intelligent detection system for mine belt breakage based on Machine Vision

Ming (2011)In the publication entitled “Intelligent Detection System for Mine Belt Tearing Based on Machine Vision”, it raises the existing problem in the processes that are carried out with conveyor belts within mining companies, which is the breakage of the belts, generated by the continuous use of the themselves. The solution he proposes is the early detection for the breakage of the belts used in mining based on artificial vision. Using the

artificial vision methodology, such as dynamic, fast, non-contact and high precision measurement repeatability, an efficient belt break detection method was developed. The experimental results obtained show that this method can effectively identify the tear region, but is not good for the scrape or deformation regions.

The system is just a fledgling investigation for belt break detection. More studies are needed to improve the failure recognition rate to detect future belt breaks.

4.2.4 Investigation on the reliability of a conveyor belt system for coal mines

Huanzhong & Jing-xia (2011)In the publication entitled “Research on the Reliability of Underground Coal Mine Belt Conveyor System”, it proposes determining the reliability of the conveyor belt of an underground coal mine. Based on the reliability theory and in terms of the computer simulation method, the article calculates the system reliability index and identifies the weak links in the mine's transportation system. According to the reliability model, it is concluded from the computational results that it is applicable to analyze the reliability of the transport system of an underground mine, using the reliability simulation test method.

CHAPTER V. JUSTIFICATION

In mining one of the main challenges is to efficiently move the processed materials. For this, the growing trend is to use conveyor belts, which in many cases can even replace conventional transport: trucks and forklifts, since it implies a continuous load and a reduced cost in operation, precisely due to the continuous operation of the belts Conveyors failures occur throughout their useful life as a result of the continuous wear of the machine and the abrasive material that is used to transport.

The present investigation proposes to design a fault detection system for mineral conveyor belts, which will solve the problematic situation posed because it will allow early detection of possible wear symptoms produced in the conveyor belts. This will allow the development of a better maintenance plan, increasing its efficiency and considerably reducing the risks of unplanned plant shutdowns in the company.

The development of the proposed solution implies solving different engineering problems that arise within the mining processes related to conveyor belts such as vibration, motor torque, shock, fatigue failure, contraction and thermal expansion, they are all external forces that directly affect the proper functioning of the conveyor belts.

Although the solution of designing a predictive maintenance plan is much more expensive in the first instance than the current solution used in

mining, it provides a much greater benefit due to the fact that it considerably reduces the risk to a company compared to the other. Unscheduled plant stoppage, said plant stoppage produces losses for the mining company which would amount to more than $ 55,000,000.00 money that could be invested in the development of the problem raised.

Silva Sanhueza (2017) presents and analyzes the economic losses that are produced by a failure in a conveyor belt showing the following table:

Table 1. Economic indicators

Precio del dólar año 2014		
máximo valor	621,41	CLP
mínimo valor	524,61	CLP
valor promedio	570,37	CLP
Precio del cobre año 2014		
mayor	3,3 Dólares	libras
menor	3 Dólares	libras
promedio	3,15 Dólares	libras
Equivalencias		
1 libra	0,453592	kg
Ley de cobre andina		
promedio ley de cobre de 2014		0,7 % de cobre fino
2000 ton/h promedio de mineral traspasado a molinos		14 ton/h de cobre fino

The table above shows the main parameter with which an economic cost can be established, since it shows the amount of fine copper that is transferred per hour to the next process, through a conveyor belt.

I know analyzes the indicators of the process before and after, of the preventive maintenance plan, focusing mainly on the economic losses of the company.

The author concludes the following:

- The hours of unscheduled detention before the proposed maintenance plan are: 491 h

- The hourly earnings that the corporation ceases to receive amount to $ 55,453,537.03.
- The hours of unscheduled stoppage after the proposed maintenance plan are: 179.8 h

The proposed product presents a large potential sales market because predictive maintenance is not widely applied in mining companies in the country. In addition, this is a necessary tool to be able to lower costs and considerably increase the reliability of the equipment.

Table 2 shows all the potential clients for this project.

Table 2. Potential customers

	Potential customers	Location
1	Antamina	Ancash
two	Southern	Ilo
3	green Hill	Arequipa
4	The Bambas	Apurimac
5	Antapaccay	Cusco
6	Chinalco	Junin
7	Hudbay	Cusco
8	The Brocal	Pasco
9	Others	In some region of

Figure 1 shows all the mining companies according to the copper production that they extract in Peru according to the Ministry of Energy and Mines, all these companies represent the market to which this research project can reach.

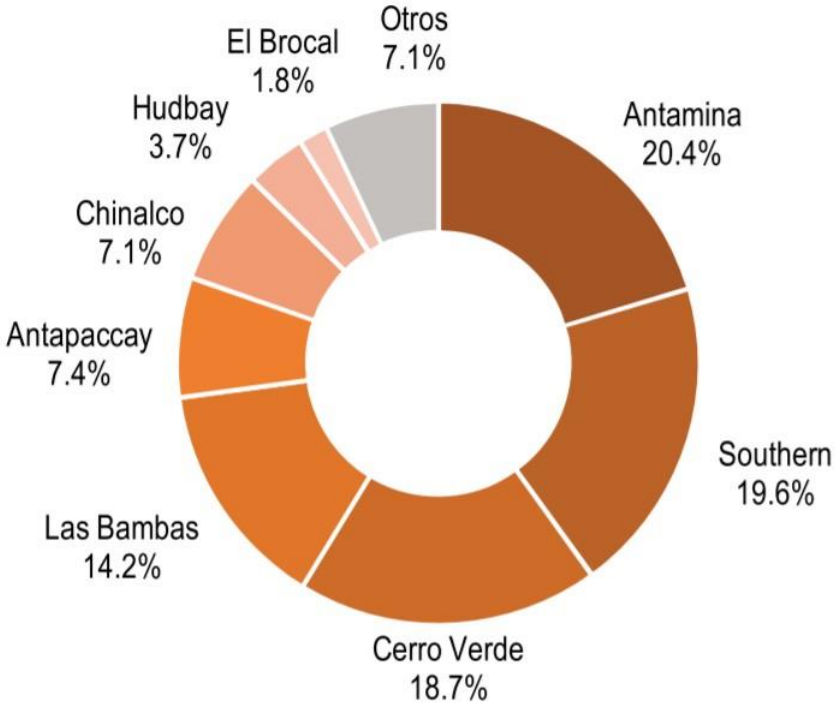

Figure 1. Copper producing companies and quantity of production between January and March 2020.

The proposed solution is aimed at thefuture of mining operations, which aim to be fully automated. What was once seen as an industry with dangerous and challenging environments and operations, thanks to the technological revolution is ready to dramatically change that perception that was maintained for decades, all this is due to the advancement of technologies and the innovation of new applications for the mining company. The main reason for this change is the need for the industry to be more efficient, productive, safe and resourceful to face adversity, especially considering the climatic difficulties and the increasing energy costs that the industry faces every day.

This project also seeks drive innovations that create a safer and more comfortable work environment for miners; This added to the automation of processes will make the mines safer by removing miners from danger zones.

CHAPTER VI. OBJECTIVES

6.1 General objective

Design an image recognition-based fault detection system for a mineral conveyor belt for the Antamina Mining Company.

6.2 Specific objectives

- Study the state of the art of mining processes related to conveyor belts and identify the failures that may occur within them.
- Design an image acquisition system to detect variations due to wear on conveyor belts.
- Develop an algorithm that allows the maintenance area to be alerted to a possible failure that may occur in the conveyor belts, which allows planning and carrying out the necessary repairs in order to reduce the risk of an unscheduled plant shutdown.
- Develop efficiency indicators that allow to compare the effectiveness of the proposed algorithm and identify possible points of improvement.
- Simulate the operation of the fault detection system.

CHAPTER VII. DESCRIPTION OF THE PROPOSED SOLUTION

7.1 Description

7.1.1 Pictorial block diagram

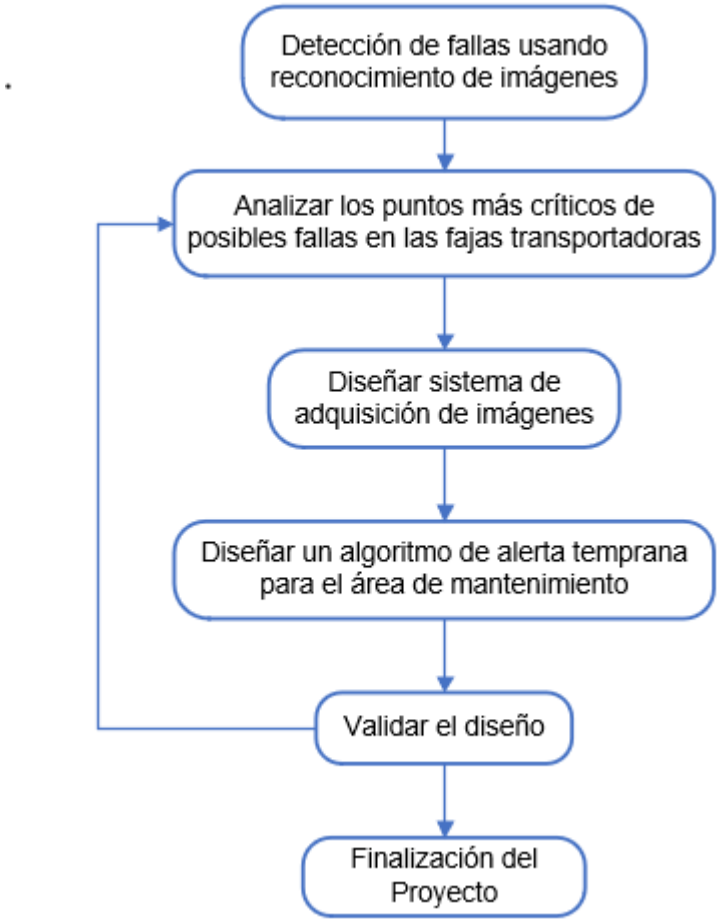

Figure 2. Pictorial block diagram of the solution to be developed

7.1.2 Functioning

The cameras are installed at the head of the retractable conveyor belt to detect the exit of the belt, a substation box must also be installed to prevent collisions that may occur as a result of the transport of minerals, this substation will allow the transmission of the sampled data to the master ground station. At important observation points, additional shockproof cameras are installed. The data transmitted by the cameras

from the substation box is processed by the algorithm and an alarm will be sent to the user when it detects a possible failure.

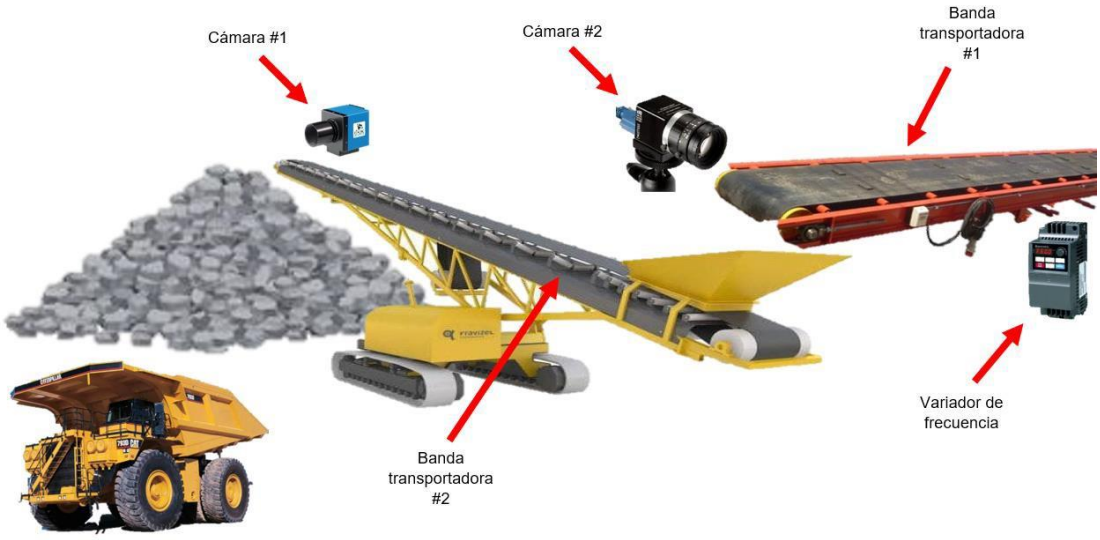

Figure 3. Diagram of the mining process with conveyor belt.

7.1.3 Devices and components to use

The main devices to use are security cameras, computers with the ability to process the data and transmit the information to the main station.

7.1.4 Limitations of the solution

The development of the solution allows to carry out a predictive maintenance plan based on the data collected and analyzed, predicting the risk of failure of the conveyor belt at the time of detect changes in the material, however the planning period for the maintenance area is reduced, this solution can be improved by implementing artificial intelligence algorithms that predict machine failures in a shorter time giving a greater response time to the maintenance area .

7.1.5 Expected results

With the proposed solution, it is proposed to develop a much more effective maintenance plan for the conveyor belts, which will reduce the risks and economic losses due to unscheduled plant shutdowns due to this type of failure.

At the end of this work, it is expected to obtain an optimal fault identification algorithm based on the digital image processing technique, which should provide a solution to the maintenance problem of conveyor belts used in mining.

7.2 DESIGN AND IMPLEMENTATION METHODOLOGY

7.2.1 Description

Stage 1: Information analysis and characterization of faults in conveyor belts.

- Identification of types the most common types of failures in conveyor belts, analysis of their components and critical points within the process they carry out.

Stage 2: Design of the image acquisition system.

- Select the equipment to be used inside the substation in which the acquisition and processing of the images obtained from the conveyor belt will be carried out.
- Develop tests of the prototype imaging system

- Final adjustments of the prototype structure and obtaining the final design.

Stage 3: Development of fault detection and recognition algorithms.

- Characterization of faults in RGB digital images: Evaluation of tones, textures, contrasts and color models.
- Development of digital image pre-processing algorithms: luminance uniformization, local and global thresholding by histogram and Otzu algorithm, contrast enhancement by histogram equalization and digital filtering, noise reduction by averaging, median and labeling filtering.
- Development of fault region segmentation algorithms: Segmentation by hue, texture, color, and contrast; application of correspondence functions, probability distribution functions, labeling algorithm, color models and thresholding.
- Development of algorithms for the extraction of characteristics, location, recognition and classification of faults: Geometric characteristics extraction algorithms of the fault for conveyor belts; application of mathematical morphology algorithms; description of objects by HU moments, chain rule, statistical descriptors, Fourier descriptors, etc;
- Validation and final adjustments of the fault detection algorithms: Generation of reports of detected faults through the developed algorithms.

Stage 4: Optimization of the fault detection algorithm

- Develop calculations and simulations that allow to visualize improvement characteristics for the chosen fault detection algorithm, make tables and graphs that allow to measure the degree of improvement in time and processing of the algorithm.

Stage 5: Development of the final software application and validation of the final product.

- Development of the visual interface: Configurations, user options, visualization of information and results through graphs and numerical values, generation and storage of reports. Validation and approval.
- Validation of the final product by specialized potential users. Generation of final performance reports. Final adjustments.

7.2.2 Block diagram

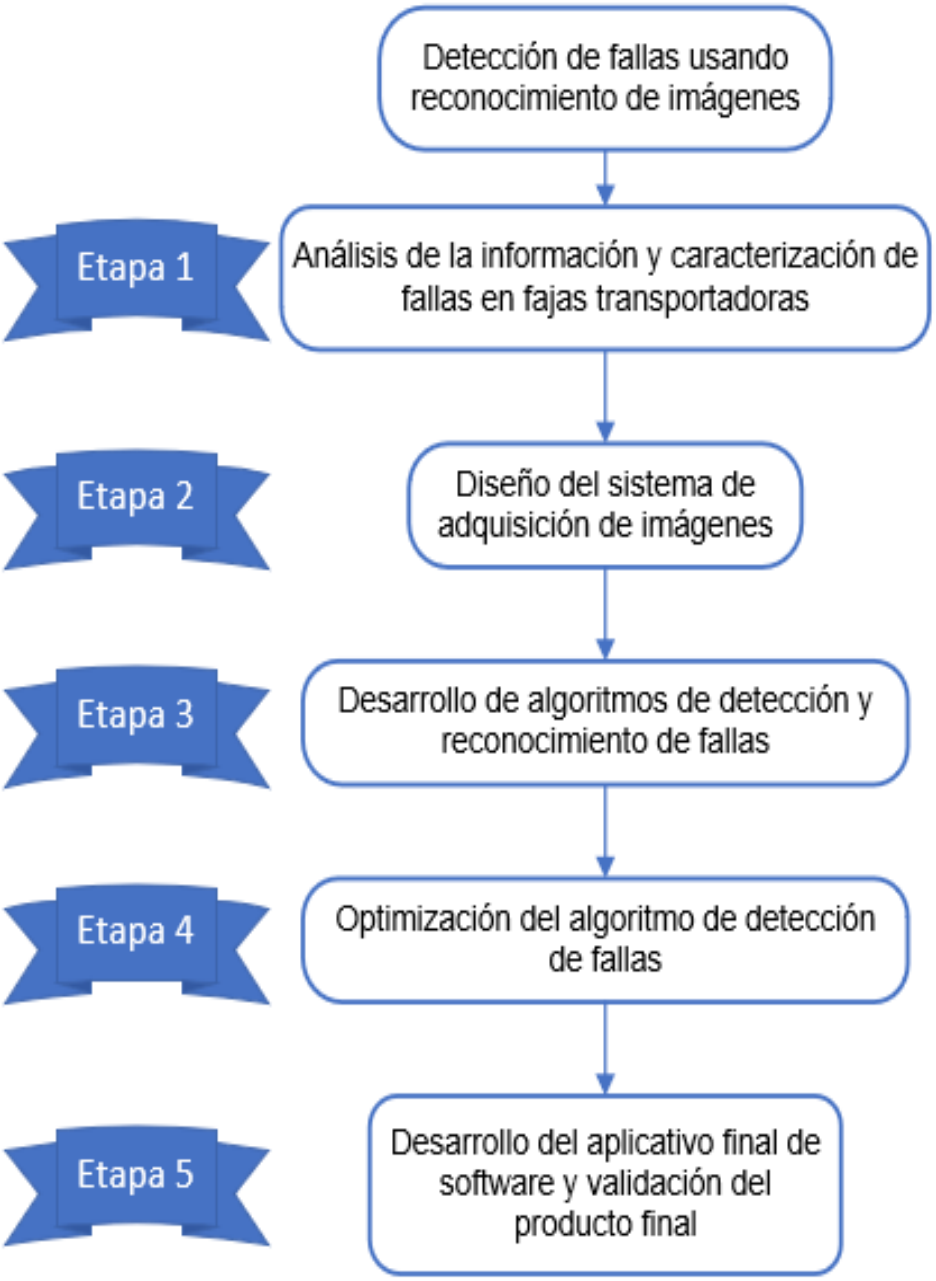

Figure 4. Block diagram of the project development stages

CHAPTER VII. APPLICATIONS AND POTENTIAL USERS OF THE PRODUCT

This work develops applications focused on the mining sector, due to the characteristics and working conditions of this industry, precision and a high degree of reliability are required in machines that are in constant production, so that every mining company that has a belt conveyor within its production process automatically becomes a potential customer.

Table 3 according to the Ministry of Energy and Mines shows all the mining companies in Peru, all these companies represent the market to which this research project can reach.

Table 3. Potential customers

	Potential customers	Location
1	Antamina	Ancash
two	Southern	Ilo
3	green Hill	Arequipa
4	The Bambas	Apurimac
5	Antapaccay	Cusco
6	Chinalco	Junin
7	Hudbay	Cusco
8	The Brocal	Pasco
9	Others	In some region of Peru

A direct application of this work is the preventive maintenance of a conveyor belt used in mining, but its use can also be extended to other types of conveyor belts used in other processes such as in the food industry or supermarkets. Preventive maintenance in all these cases will avoid or mitigate the consequences of failures in the conveyor belt systems due to wear caused by continuous use.

Another application is the development of the complete automation of the conveyor belt system within the mining processes, which would increase productivity, in addition to reducing operating costs, reducing energy consumption and increasing process safety. This application also implies for the company the correct optimization of human resources and considerably improves the diagnosis, supervision and quality control of production.

CHAPTER IX. FEASIBILITY

9.1 Technical Feasibility

The engineering and technical knowledge is available to develop the proposed project (RGB digital image processing, digital image pre-processing algorithms, analysis and selection of industrial instrumentation, analysis of critical processes in the mining industry, mechanical failure analysis by material wear, etc.). Likewise, there is the minimum equipment necessary to develop the model (a computer with the necessary capacity for data processing, a web camera for image acquisition and video data of the conveyor belt to be analyzed). Due to the current technology that is being developed in this field of the mining industry and the available information that could be obtained from the internet, the project is able to meet the objectives set.

9.2 Economic Feasibility

To carry out the project, we will work with the materials mentioned above with those that are already available, which will not require any additional investment to develop the proposed model.

9.3 Social Feasibility

The project to be developed will directly benefit the mining company by reducing its economic losses due to unscheduled plant shutdowns, but it is also a benefit for maintenance personnel who will not have to put their lives at risk to carry out monitoring of the conveyor belt. since currently periodic

monitoring is carried out without the machines stopping operating, which although the necessary security measures are taken, there is always the risk for the personnel in charge of supervision. With the current project, it is proposed to eliminate this risk for people Following the procedures and recommendations of the ISO 45001 standard, which will allow us to manage the safety and health of workers according to international standards, as well as contributing to the safe development of technology in this industry.

9.4 Operational Feasibility

The development of the project does not require a requirement from the mine since at the moment the implementation in the process is not considered, the project proposes to develop a fault detection model for which the necessary data is already available to design said model; Later, for an implementation and verification of the effectiveness of the model, it will be necessary to discuss its development with the person in charge of the maintenance area of the company, but this process is not contemplated in the development of the current project as specified in the scope of the project chapters behind.

9.5 Environmental Feasibility

The project to be developed hopes to give added value to the mining company by developing new technologies that seek to reduce the risk for workers and also reduce the waste generated during mining processes.. The development of the project and its subsequent implementation will be based on the ISO 14001 environmental standard, which will benefit the company, which will improve environmental performance, resulting in savings in waste management costs. Following the procedures and recommendations of the standard will improve the effectiveness of the environmental audit programs,

which produces an opening towards opportunities for competitive advantages by obtaining an international certification that endorses its good environmental performance in its operations.

9.6 Alternatives

The process in which the project is developed is part of a larger mining process, the technology to be developed improves the maintenance process of the machines used without harming the processes with which they are related, therefore the development of the project is viable as it does not affect the other production processes of the mine.

CHAPTER X. PROJECT DEVELOPMENT SCHEDULE

Table 4. Weekly project development schedule

Activity	Aspects to consider	Week
Presentation of the course and relevant aspects of the project	Current issues, research and innovation	1
Determination of the topic to be developed	Topics proposed by the teacher or students with teacher approval	two
formation of working groups	Group or individual projects that meet the criteria given in class will be approved	3
Definition of objectives and scope	Definition of the characteristics (specifications) of the product or process to be achieved A general objective and several specific objectives. For each objective indicate the way in which its achievement will be verified	Four. Five
First Preview Review Presentation 1	State of the Art Market Study Availability of data and information for the project (norms, standards, regulations).	6
Information development	Identify critical points of the conveyor belts	7
Image acquisition system	Design the image acquisition system	8
	Develop prototype tests of the acquisition system	9
	Develop the fault detection algorithm for the conveyor belt	10
Second progress review Presentation 2	Calculations, computer simulation.	eleven
Fault identification algorithm	Optimize the fault detection algorithm for the conveyor belt	12
	Validate the developed algorithm	13
	Optimize the proposed model for fault detection	14
Final presentation	Final report with the corresponding content. Oral presentation.	fifteen

CHAPTER XI. PROJECT PROGRESS

11.1 Design the image acquisition system

a) Progress objectives

Design the image acquisition system for the conveyor belt.

b) Theoretical support

Lighting system:

Lighting is a vital element in the development of image acquisition systems to obtain optimal results. Choosing the right lighting can achieve greater measurement accuracy, a reliable system, and shorter operating time. The main objectives regarding lighting are: to keep the intensity and direction of the light constant, and to optimize the contrast to differentiate the objects present from the background. In image acquisition systems for industrial or laboratory processes, a suitable lighting module is always designed to highlight the characteristics of the product to be analyzed. If you have a suitable lighting system, you do not need to correct lighting failures using algorithms. If an image is captured in an environment with arbitrary lighting without taking into account the information to be extracted, it is very likely that the image has low contrast, specular reflections, or shadows. Therefore, an image obtained with a suitable lighting system implies a shorter processing time, since it allows us to make the surrounding conditions independent and highlight the features of interest in it.(Maza, 2017)

The different types of lighting can be classified according to their intensity, direction and source of origin.

- **Depending on the intensity of the light:**

  When the intensity of the light is varied, we obtain different resulting effects in the captured image, for example, a strong intensity implies that large contrasts appear between the illuminated areas and the shaded areas, and at the same time, due to a limited dynamic range, they are lost details in the image in both the light and shadow areas. An opposite effect results when the intensity is soft, the details of the image are better appreciated in both the highlighted and shaded areas, but details are lost in the textures (Maza, 2017).

- **Depending on the direction of lighting:**

  Rear: Also called backlighting, it consists of placing the object between the light source and the camera. It is the most suitable type of lighting for the recognition and measurement of objects by means of edge detection, because the resulting images have a high contrast between the objects and the background, although some details of the scene are lost. A common problem is when there are objects located one on top of the other, and it should be taken into account that one of its biggest disadvantages is the way it is implemented within an automatic industrial system.

  Frontal: It consists of illuminating the object frontally, that is, the light falls directly on the object frontally. It allows visualizing the

external characteristics of objects such as shape, color or surfaces, which allow better segmentation and pattern recognition. It is the most used type of lighting, but sometimes a good contrast is not obtained between the object and the background, due to the appearance of shadows and reflections.

Directional: consists of projecting a light directed in some sense in space to highlight certain characteristics of the object, the orientation of the focus is towards the object. Shadows are generated on the object, which increases the contrast between three-dimensional parts and thereby obtain three-dimensional information.

Structured: It consists of projecting modulated lighting patterns on the object and acquiring information on the object's surface using reflected light. Generally the light sources are lasers and the main uses of this type of lighting are in 3D reconstructions of objects and shape recognition (Maza, 2017).

- **Depending on the light source:**

  Incandescent lamp: It was the first source of light originating from electrical energy and is the most common source of illumination. It is a device that produces light by heating by the Joule effect of a metallic filament until it turns white, thanks to the passage of electricity. Its main advantage is that there is a great variety of powers and some disadvantages are the generation of excessive

heat, relatively short life time, and the reduction of brightness over time.

Fluorescent: Provides a bright light without shadows but due to its limited variety of shapes, its application in artificial vision systems is limited. This type of lighting is more effective than incandescent lamp lighting and provides a more diffuse light, so it is recommended to use it on highly reflective objects. Generally, standard fluorescents are not used due to their flickering effect, that is why fluorescents that operate at high frequency are often used.

LED (light emitting diode): It is a solid state source that emits light when electricity is applied to a semiconductor. This type of lighting provides a very useful diffuse light of moderate intensity. It has a large number of advantages over traditional lighting, such as long service life, low power consumption, low heat generation, small size, economical, fast response, robustness, and lower sensitivity to vibrations.

Fiber Optic: provides a great intensity of uniform, cold light with the absence of shadows, and consists of directing the light from a halogen or xenon bulb, through a bundle of optical fibers that ends in a type of adapter

as required by the application.

Laser: it is used mainly in structured lighting. Its main disadvantage is that it is not efficient on surfaces that absorb light. This type of lighting is generally used by analyzing the

distortion of the emitted light in applications such as depth measurement, detection of surface irregularities, or 3D recognition (Maza, 2017).

Video surveillance systems:

Currently the development of electronics, video systems, storage and digital processing has led to a wide implementation of these systems in public and private areas. These systems are used as means of security to protect people and people, it is useful to identify intruders and people who carry out improper activities that put the integrity of a place or individual at risk.

A video surveillance system consists of installing video cameras with digital recorders that can be monitored from a central monitor in real time, controlling different rooms and corners, without having to go to each site (INTPLUS, 2021)

Cameras for image acquisition:

A digital camera is a photographic equipment that captures and stores images digitally, thanks to a device called a sensor. Generally, digital cameras use two types of sensors: CCD sensor (Charge Couple Device, in Spanish "charge coupled device") and CMOS sensor (Complementary Metal Oxide Semiconductor, in Spanish "complementary metal oxide semiconductor"). The quality of the resolution of a digital camera depends not only on the number and distribution of pixels that the camera can give me, but also on other factors such as the characteristics of the sensor and characteristics of the lens.

The appropriate selection of a camera for image acquisition depends on an appropriate selection of its technical characteristics, the main ones are the following:

- **Sensitivity:**It is the minimum amount of light that the camera requires to reproduce an image in low light conditions, color cameras can vary from 0.1 to 1 lux. as shown in Figure 5. The measurement in lux refers to a certain optic aperture(Aceves Bernal, 2013).

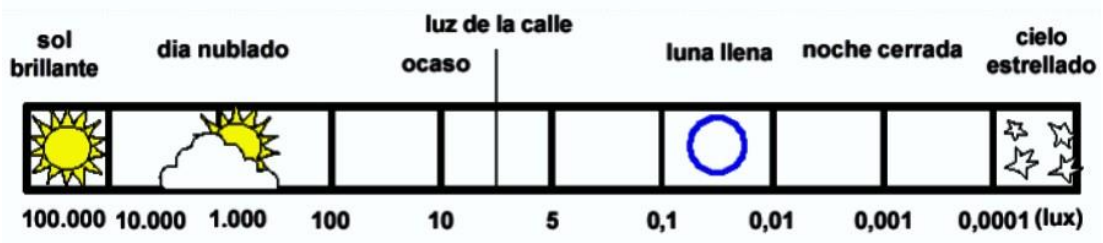

Figura 5. Lighting Units Range in Lux

- **Resolution**: It is the camera's ability to reproduce fine details, a standard camera has 380 to 420 lines of resolution (TVL). Based on CCD / CMOS image sensors, analog cameras can offer standard resolution video with 1000 TVL, 700TVL, 650TVL, 480, 420TVL for analog cameras. As for digital cameras, the number of pixels is used to refer to the image resolution, there are cameras from 0.3 MP, 2 MP, 3MP, 5MP, 8MP and higher, a higher number of Pixels represents a better image quality and higher resolution(Avitom, 2021).
- **Electronic iris:** Automatically controls the amount of light entering the camera, by using an automatic electronic shutter,

the higher the control speed, the better the image quality in bright light conditions, this can go from 1 / 60 to 1 / 100,000 of a second.

- **Phase control adjustment:** Allows you to synchronize the frequency of the video signal with the frequency of the network, avoid undesirable jumps during the playback of live video or when recording after an event.
- **Signal to noise ratio**: Measures the immunity to electrical noise from the electrical network, the standards recommend 46db as a minimum.

In this research, due to the current situation of the Covid 19 pandemic, a computer webcam has been used that was already available, it is a type of digital camera for network use that connects to a laptop through a USB port. For its installation, you only need to connect the camera to the laptop, but sometimes the installation driver is needed. This type of camera allows you to capture images of average quality.

Processing and software module:

The processing module can be a computer or an integrated system, it is the system that receives, stores the images and processes them through appropriate algorithms to extract the necessary information and then make decisions according to the need of the maintenance area. Integrated systems are those that incorporate the software and all the necessary hardware in the same system, have an integrated processor with the ability to make decisions.

Image processing software is the set of tools that analyze the image and extract information from it according to the algorithms on which these tools are based. Its basis is the interpretation and analysis of pixels.

Acquisition:

The acquisition of the object in digital format is the first stage of an artificial vision system and consists mainly in the digitization of the image and to achieve this there must be two essential elements. The first is a physical device that is sensitive to the energy radiated by the object (electromagnetic energy spectrum) of which we want to capture the image. And the second item, called the digitizer, is a device to convert the output of the physical detection device into digital form.(Gonzalez & Woods, 2002).

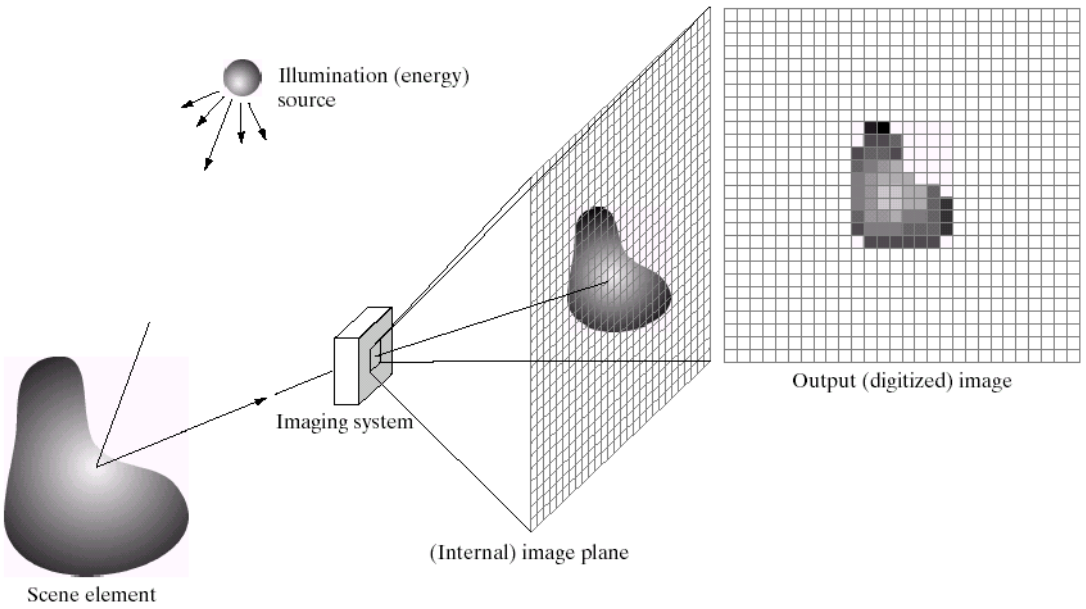

Figura 6. Acquisition process of the digital image.

Source: González and Woods, 2002.

c) Progress analysis

Based on the theoretical support presented in the previous section, the materials, both software and hardware necessary for the design of the image acquisition system that will be used in the conveyor belt, are selected.

Materials for the design of the image acquisition system:

- **Laptop (1 unit)**
  - ✓ Model: ROG G531GT
  - ✓ Processor: Intel (R) Core (TM) i7-9750H 2.60GHz
  - ✓ Installed memory (RAM): 16.00GB of RAM
  - ✓ System type: 64bits OS, Windows 10
- **Sony IMX179 CCTV camera (2 units)**
  - ✓ Sony IMX179 USB Webcam
  - ✓ 8 megapixel high resolution Mjpeg USB camera
  - ✓ USB UVC camera, compatible with Windows, Linux, Mac with UVC, also for Android system. Compatible with raspberry pi, Ubuntu, Opencv, Amcap, and many other USB webcam software and hardware.
  - ✓ USB webcam with 75 degree lens without distortion.
  - ✓ 38x38 / 32x32mm mini micro usb board camera.
  - ✓ USB webcam, well used in many machines, ATMs, medical machines, automatic vending machines, industrial machines.
  - ✓ Modifiable USB camera module parameters (brightness, contrast, saturation, white balance, gamma, sharpness, exposure).

- **LED Panel Light (2 units)**
  - ✓ Model: Neewer 90095562
  - ✓ Dimmable bi-color LED light, with 330 daylight and 330 balanced tungsten LEDs, the dimmable lights have a color temperature range of 3200-5600K.
  - ✓ The lights work with the included 100-240 VAC adapters, but can also be powered by optional NP-F batteries.
  - ✓ Aluminum alloy construction and secure locking make the 6.5 'brackets suitable for heavy duty work.
  - ✓ Adjustable U-mount bracket allows tilt adjustment to best suit process requirements.
- **Software: Matlab version 2020a**

  System requirements for Matlab 2020a:
  - ✓ Windows 10 (version 1803 or higher)
  - ✓ Windows Server 2019
  - ✓ RAM: 8GB (Recommended)
  - ✓ Processor: Any Intel or AMD x86-64 processor with four logical cores and AVX2 instruction set support (Recommended).
  - ✓ License: For this work, the student license was used.

Figure 3 shows the diagram of the image acquisition system that will be designed for the conveyor belt in which the two cameras that will be placed perpendicular to the belt are observed to obtain its main characteristics, the data is sent to the substation in which the laptop will be located, processing the images and applying the fault detection

algorithm for the conveyor belt. The results of this process will be sent to the central station of the mining company where the state of the belt can be continuously monitored and in case a failure is detected, the program will send an alarm to the maintenance area which must stop the production process of the conveyor belt and carry out the corresponding maintenance.

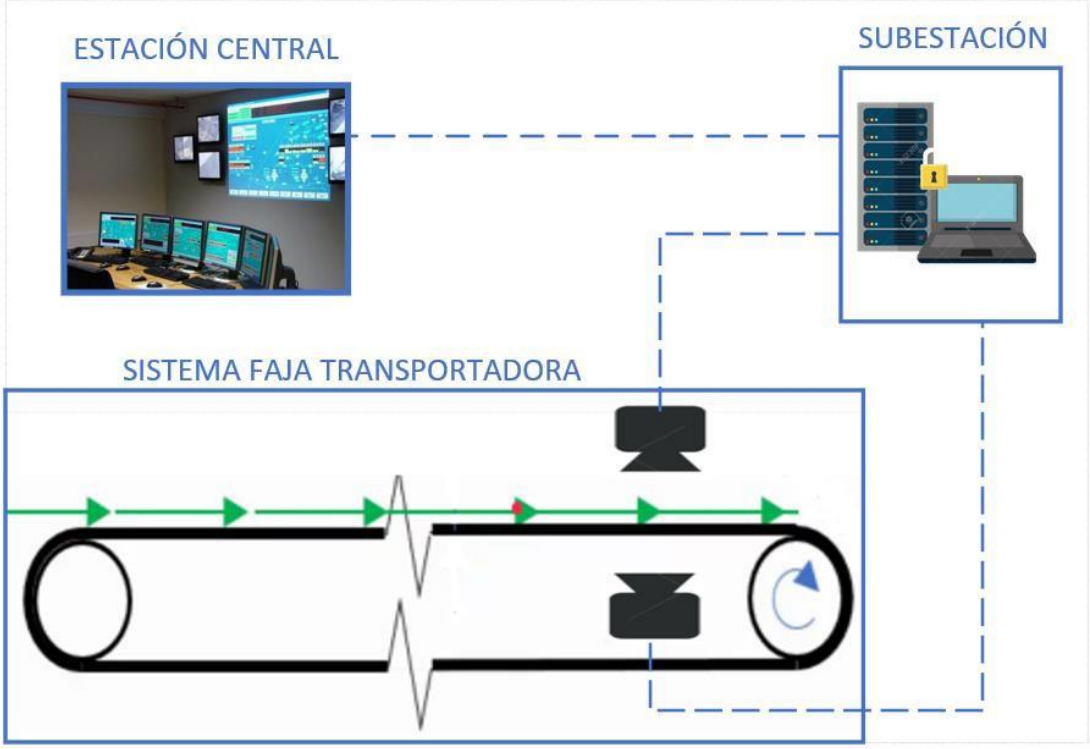

Figura 7. Image acquisition system diagram.

11.2 Detection of breakage of the conveyor belt

a) Progress objectives

Develop the algorithm that detects the longitudinal break of a conveyor belt.

b) Theoretical support

Image pre-processing:

Pre-processing consists of noise reduction, smoothing, detail enhancement, contrast enhancement, by binarizing images and edge detection techniques, allowing to increase the probability of success in subsequent processes. You can see in Figure 8 the result of applying the pre-processing to an image.

Figura 8. Noise removal.

In the present work, to detect the breakage of a conveyor belt, it is first necessary to perform the pre-processing of the acquired image, this process is carried out in order to improve the image, that is, this operation consists of removing the useless part of the original image thus allowing to achieve a more optimal image to be processed by the computer.

Image filtering:

Digital image processing is a subject that is currently being investigated and new techniques are being obtained that have interesting applications. There is a great variety of procedures

that allow, from a given image, to obtain a modified one (filtering techniques).

These are methods with which you can selectively highlight or suppress information contained in an image, to highlight some elements of it, or also to hide outliers.

You can distinguish between low-pass, high-pass, directional, edge detection filters, etc. Low-pass filters try to smooth an image, removing possible noise, or highlighting certain information present at a certain scale. They are based on the idea of assigning a pixel the value in color intensity from a weighting of nearby pixels. Examples are the mean, weighted mean, median, adaptive, and Gaussian filters. High-pass filters attempt to highlight areas of greater variability, just the opposite of low-pass filters. Some of them are the mean subtraction methods and derivative-based filters (see Figure 4).

Other techniques based on histogram specification (equalization) and on the frequency domain (low pass and high pass filters) are also known.

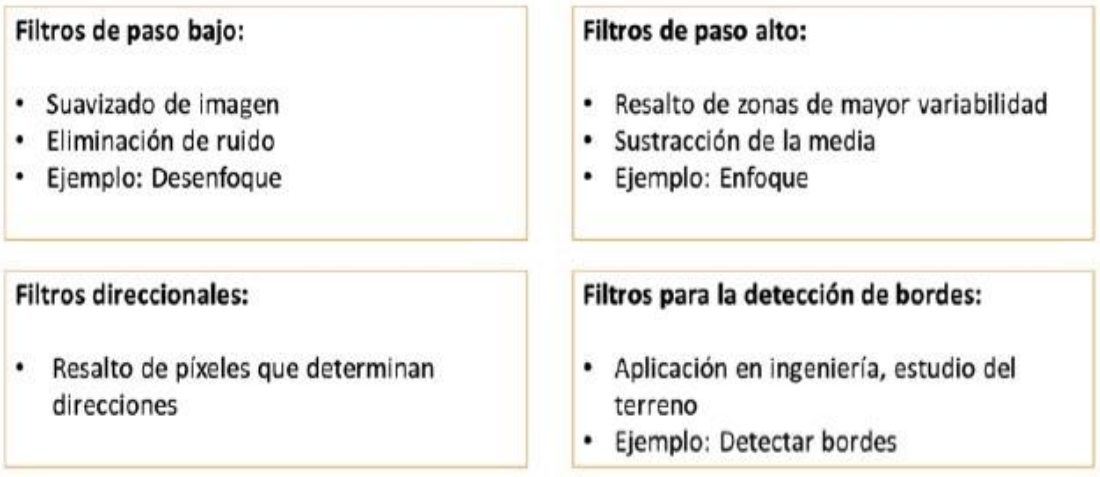

Figure 9. Types of filters applied to an image.

Convolution Matrix:

Definition. Given a matrix and a matrix with, the convolution of matrices A and C is defined as a new matrix defined after the expression.$2N+1 \times (2N+1) 2N+1 < = 2N+1\ 2N+1$

$$= \frac{1}{} \sum \sum \ldots (1)$$

Where (if c = 0 we take c = 1). Note that only y is defined.$= \sum^{2N+1}$

$= N+1, \ldots, N-1 = N+1, \ldots, N-1$

The matrix C is called the nucleus or kernel of the convolution.

For the filtering of images, kernel matrices of order 3x3 or 5x5 are usually used. These matrices are also called masks. In order to also apply the convolution in the pixels of the edge of the image there are several alternatives, some of which are:

- Complete the surrounding values with zeros.
- Repeat the values on the edge.
- Complete with the values of the opposite symmetric part.

Image 5 shows some of the most used mask matrices.

Enfoque $\begin{bmatrix} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{bmatrix}$ Desenfoque $\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$ Realce de bordes $\begin{bmatrix} 0 & 0 & 0 \\ -1 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ Repujado $\begin{bmatrix} -2 & -1 & 0 \\ -1 & 1 & 1 \\ 0 & 1 & 2 \end{bmatrix}$

Detección de bordes $\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$ Filtro de tipo Sobel $\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$ Filtro de tipo Sharpen $\begin{bmatrix} 1 & -2 & 1 \\ -2 & 5 & -2 \\ 1 & -2 & 1 \end{bmatrix}$

Filtro Norte $\begin{bmatrix} 1 & 1 & 1 \\ 1 & -2 & 1 \\ -1 & -1 & -1 \end{bmatrix}$ Filtro Este $\begin{bmatrix} -1 & 1 & 1 \\ -1 & -2 & 1 \\ -1 & 1 & 1 \end{bmatrix}$ Filtro de tipo Gauss $\begin{bmatrix} 1 & 2 & 3 & 1 & 1 \\ 2 & 7 & 11 & 7 & 2 \\ 3 & 11 & 17 & 11 & 3 \\ 2 & 7 & 11 & 7 & 1 \\ 1 & 2 & 3 & 2 & 1 \end{bmatrix}$

Figure 10. Most used masks

RGB model:

The RGB color model is an additive model in which the primary colors red, green, and blue are added together in various ways to reproduce different colors. The name comes from the initials in English of the three colors (Red, Green and Blue). A color in the RGB model is described by indicating the value of each red, green and blue color channel, which can vary from 0 to a maximum value that depends on the application. In computing, the component values are stored as integers in the range from 0 to 255.

YCbCr model:

In this format, the luminance information is represented by a single component, Y, and the color information is stored as two components of the color difference, Cb and Cr. The blue chrominance component or Cb is the difference between the blue component and the reference value, and the red chrominance component or Cr is the difference between the red component and the reference value. The matrix used to convert the RGB color model to YCbCr is:

$$\begin{matrix} Y \\ [\text{??}] \\ \text{??} \end{matrix} = \begin{matrix} 16 \\ [128] \\ 128 \end{matrix} + \begin{matrix} 65.481 & 128.553 & 24.966 \\ [-37.797 & -74.203 & 112.000] \\ 112.000 & -93.786 & -18.214 \end{matrix} * \begin{matrix} R \\ [G] \\ \text{?} \end{matrix} \dots (2)$$

HSV model:

This color model is considered closer to the RGB color model in the way that people describe color sensations. The HSV color model gets its

name from the acronyms in English (Hue, Saturation, Value) which in Spanish mean Tonality, Saturation, Value, respectively; is a non-linear transformation of the RGB color model, and the colors are a combination of the three values: Hue, Saturation or amount of color, and their value. These values are represented in a circular diagram.

The three quantities can have the following values:

- Tonality: It is the type of color (for example: red, green, or yellow), which are represented as the value of the degree of an angle, whose possible values are in the range of 0 ° to 360 ° (although for some applications these values are normalized from 0% to 100%).
- Saturation: It is represented as the distance from the black - white brightness axis. Possible values are in the range of 0% to 100%.
- Value: Represents the height on the black - white axis. Possible values are in the range of 0% to 100%. Where 0 is always black.

Image processing:

In the present work, the images acquired from the cameras use the RGB color model. Taking into account the working environment of the system and to improve image processing speed, gray processing is performed on color images. The transformation rules are given by formula (3). By processing gray, the image amount is reduced to 1/3 that of the original. Much redundant information is reduced and the processing speed of the system is improved.

$$Y = 0.2990 * R + 0.5870 * G + 0.1140 * \text{[illegible]} \quad \ldots (3)$$

Stages of image processing:

A digital image is a function f (x, y) that is discretized in rows and columns and each position has been assigned a brightness level, thus forming a matrix of elements called pixels or pels. The digital image defined as the numerical representation of an object must be subjected to a series of operations organized in stages to obtain the desired results. These stages are organized into three levels of processing:(Mut & Romero, 2016)

- **Low level vision**

  Automatic processes, do not require any intelligence, this level contains the Acquisition and pre-processing activities.

- **Intermediate level vision**

  It is associated with the processes that extract, characterize and label components of the image obtained from low-level vision. It involves the processes of Segmentation, Representation and description(Querejeta Simbeni, 2015).

- **High level vision**

  Refers to cognitive processing, based on knowledge and understanding of vision processes, they are more diffuse and speculative. These processes are called recognition and interpretation.

  Figure 10 presents the image processing subdivided into its main activities: Acquisition, Processing, Segmentation, Representation and description and Recognition and interpretation(Mut & Romero, 2016).

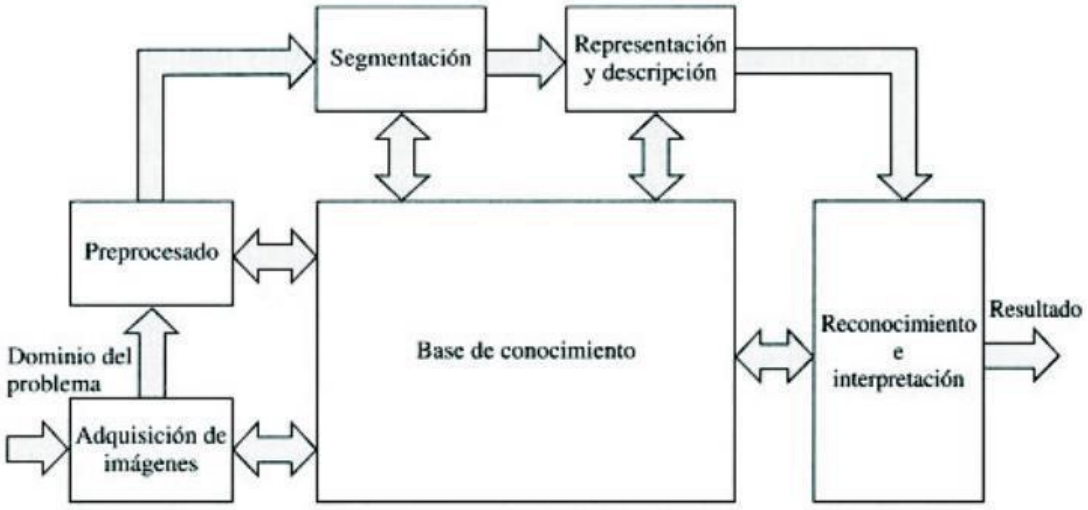

Figura 11. Stages of image processing.

Image binarization:

In image processing, image binarization is very important. You can reduce the amount of calculation when processing the image. Increase processing speed and save storage space. There are generally two methods for image binarization: global threshold method and local threshold method. The global threshold method is suitable for images with clear targets and backgrounds. It uses only one threshold T throughout the image binarization process. When comparing the grayscale value of each pixel in the image with T, if it is greater than T, the foreground color (white) will be taken, otherwise the background color will be taken. However, if the target's grayscale rate of change is large or the background is uneven, the global threshold method is no longer applicable. The local threshold method determines the threshold based on the current grayscale value of the pixel and the local grayscale value characteristics of the points around the pixel. It is suitable for images with severe interference and poor quality. The objectives and

backgrounds of the images processed in the present work are clear, so the global threshold method is used.

Image segmentation:

Segmentation subdivides an image into its constituent parts or objects, in order to separate the parts of interest from the rest of the image, therefore the level at which this subdivision is carried out depends on the problem to be solved. In the process of detecting the parts in an image, edges of the image are identified, or it is segmented into regions, lines or curves, etc. Another definition considers segmentation as the classification of the image points (pixels), indicating the classes to which the different pixels belong. The basic attributes of image segmentation are: luminance in monochrome images, color components in color images, texture, shape, etc.(La Serna Palomino & Román Concha, 2009).

Automatic segmentation is one of the most difficult tasks in image processing, this stage determines the eventual success or failure of the analysis, in fact it rarely reaches a satisfactory solution, an alternative method of verification must be sought

for verification of results. A considerable number of research works focus on this problem.

Monochrome image segmentation algorithms generally rely on one of the two basic properties of gray level values: discontinuity and similarity. In discontinuity the method consists of dividing an image based on sudden changes in the gray level. The most important issues in

discontinuity are: a) detection of isolated points, and b) detection of lines and c) detection of edges of an image. In similarity,

presents the regularity in the gray level values, the main methods are based on a) thresholding, b) region growth, and c) division and fusion of regions.

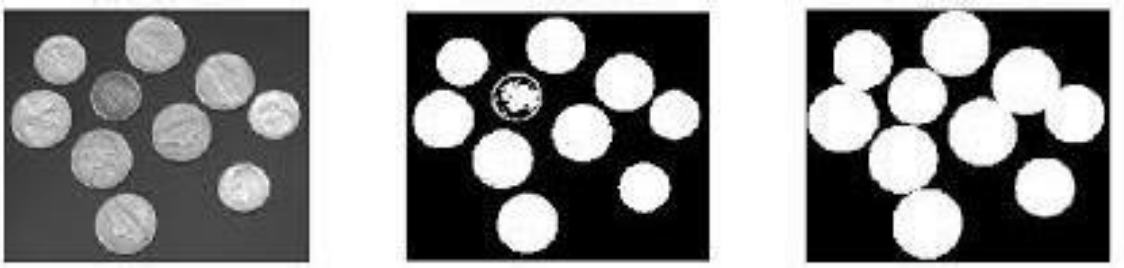

Figura 12. Image division into regions.

Canny edge detection:

One of the methods related to edge detection is the use of the first derivative, which is used because it takes the value of zero in all regions where the intensity does not vary and has a constant value throughout the intensity transition. Therefore, a change in intensity manifests itself as a sudden change in the first derivative (Pajares Martinsanz & De la Cruz García, 2001), characteristic that is used to detect an edge, and on which the Canny algorithm is based.

Canny's algorithm consists of three big steps (Valverde Rebaza, 2007) :

- Obtaining the gradient: in this step the magnitude and orientation of the gradient vector in each pixel is calculated.
- Non-maximum suppression: in this step, the width of the edges, obtained with the gradient, is thinned until edges of one pixel wide are achieved.

- Threshold hysteresis: in this step a hysteresis function based on two thresholds is applied; This process is intended to reduce the possibility of false contours.

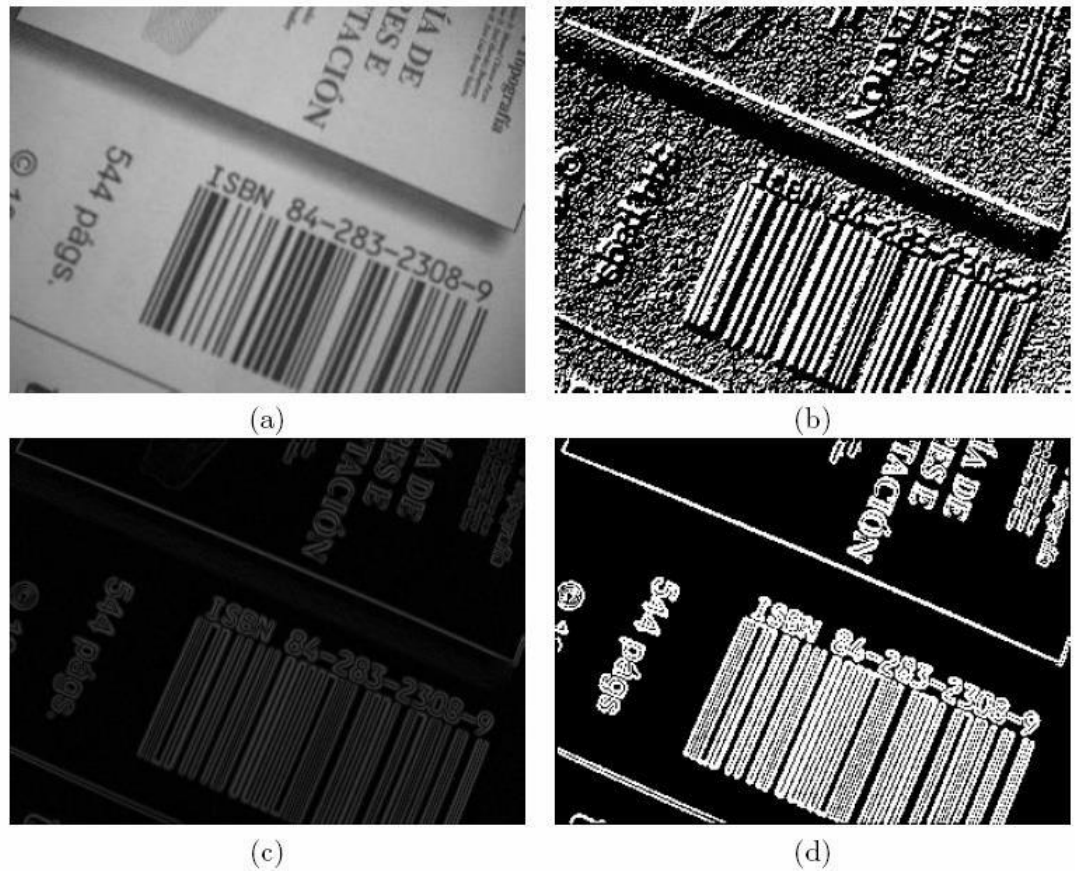

Figura 13. Result of applying Canny's edge detector

Source: Valverde Rebaza, 2007.

c) Progress analysis

Image pre-processing:

The methodology that will be used for the preprocessing of images is the reduction of the work area, then the reduction of noise and the enhancement of the contrast, thus the image will be ready to be processed.

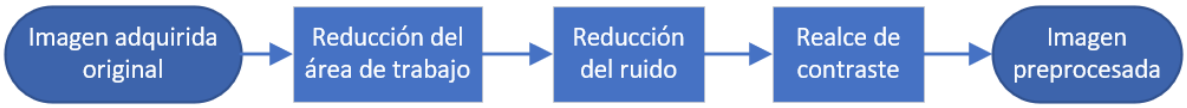

Figura 14. Image preprocessing methodology

Image processing:

The image processing system consists of the following stages: The first includes the creation of grays, the second is the enhancement of the image, the third is the filtering of images and the last stage is the segmentation of the image. To make an image gray is to reduce the intensity of the image data, the image enhancement is done by the histogram enhancement method which is to enhance the contrast of the image. Image filtering can reduce noise and its uncertainty while enhancing image contrast. Image segmentation divides the area of the strip to be analyzed using an image extraction algorithm (see figure 15).

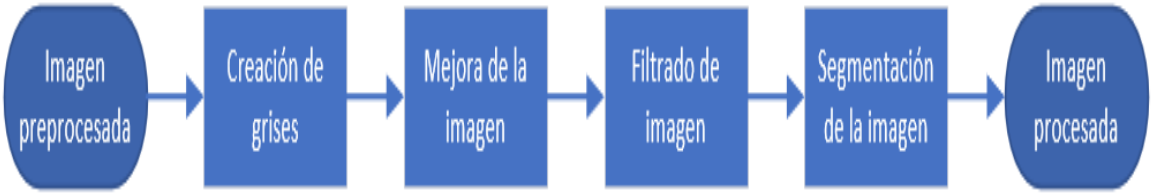

Figura 15. Image processing methodology

d) Results, Measurements and Validation

The video camera captures the image of the conveyor belt, this image is acquired by the computer. For the present work the image of a damaged part of the girdle is used (see figure 16).

Figure 16. Damaged conveyor belt.

The work area is reduced in order to obtain better characteristics of the image (see figure 17).

Figure 17. Reduction of the work area

The filter that will be used to improve the image is the Gaussian filter, in the left part of figure 18 the image is shown before the filter and in the right part the image is shown after applying the filter, with the naked eye it generates the impression if there is no change, but for the computer, it improves the quality of the image and allows better processing of the same.

Figure 18. Image before and after applying the Gaussian filter.

Image processing is performed to bring an RGB image to grayscale and subsequently detect the global threshold for image binarization (see figure 19).

Figure 19. Result of the binarization of the image.

The detection of the edges of the anomalies presented in the conveyor belt is carried out. Canny's edge detection method has good edge detection performance for this image, as well as a good balance between edge detection and noise suppression (see figure 20).

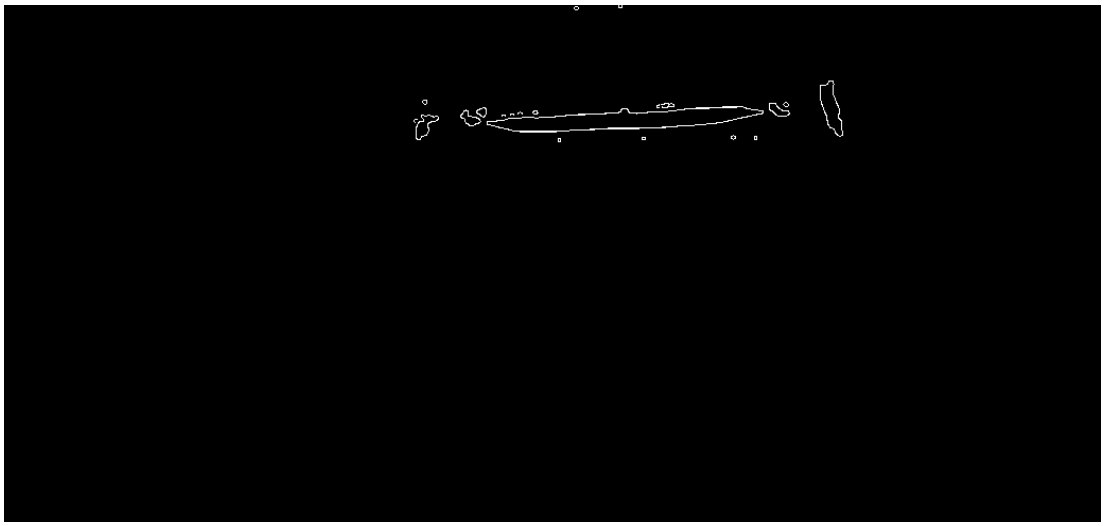

Figure 20. Edge detection of anomalies in the belt.

The anomalies present are identified to later identify their characteristics and the degree of breakage that occurs in the belt (see figure 21).

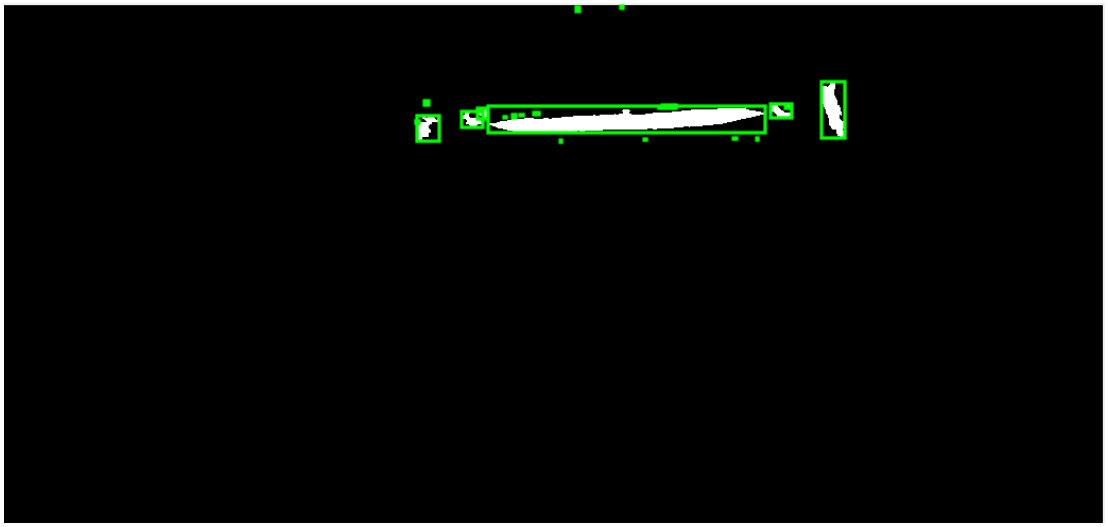

Figure 21. Identification of anomalies present in the strip.

The detection algorithm for longitudinal breaks in the belt is carried out, which identifies the characteristics of the previous image, obtaining the longitudinal breaks present in the belt, the result is shown within a red box which will be interpreted by the operator as an alarm that will indicate that the conveyor belt is about to fail (see figure 22).

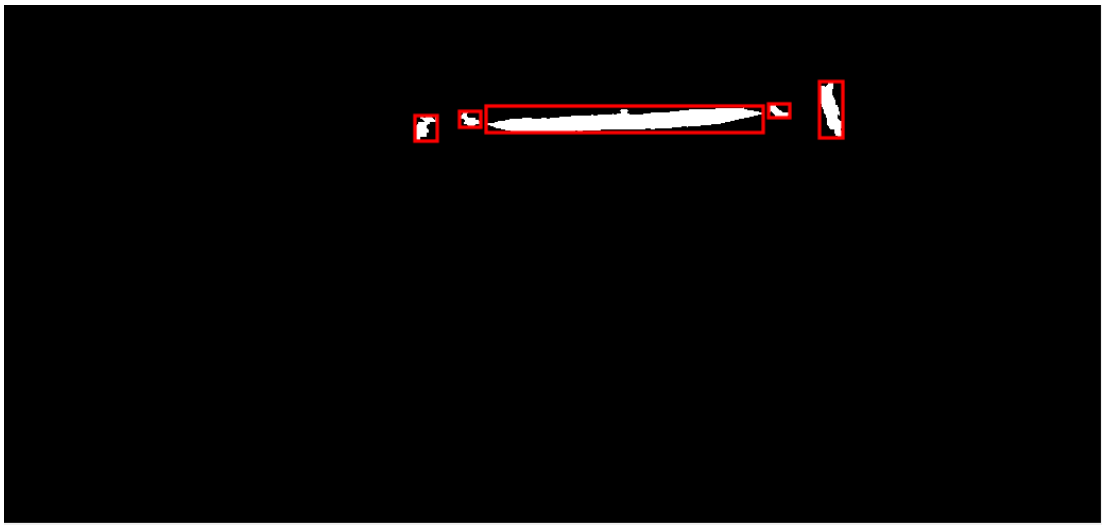

Figure 22. Longitudinal break detection in the conveyor belt

The problems that arose during the development of the advance are due to the quality of the image, if the image is not taken from a place perpendicular to the strip and with good lighting, the processing and fault detection algorithm obtains very low results. to the expected. Figure 23 shows the result of applying the same fault detection algorithm to an image of the conveyor belt taken obliquely and with very little illumination (low quality image).

Figure 23. Results obtained from the flaw detection algorithm applied to a low quality image.

In the left part of figure 24 the original image of the conveyor belt is presented without tears or longitudinal cuts, however in the right part it is observed that

the algorithm detects faults in the belt, which is an erroneous result of the algorithm, with which It is verified that for images obtained with very low quality the algorithm will present errors when identifying the faults in the conveyor belt.

e) Comments and conclusions regarding the progress and results obtained.

- The progress obtained manages to detect the longitudinal breakage of the conveyor belt, when this process is carried out it can be concluded whether or not there is a problem in the belt, if there is a problem an alarm is issued causing the motor to stop so that the process in where the conveyor belt intervenes, it stops working.
- This fault detection process can be carried out in real time and the motor of the conveyor belt can be controlled automatically to detect the process.
- The way in which the camera is located and the degree of illumination that it must have must be considered very importantly, since it was found that these two parameters have a considerable influence on the quality of the image.

11.3 Define the performance indicators for the proposed algorithm.

For the present work, two indicators are defined that will allow measuring the performance of the algorithm developed, the indicators proposed are the following:

a) **Image Illumination Amount Indicator (ICII):**

According to the data obtained, there are three types of images, the first type of image is acquired from a conveyor belt with poor lighting and with a degree of inclination of the camera that is not perpendicular to that of the belt, the second type of The image is acquired with medium lighting and with the camera perpendicular to the strip. Finally, the third type of image is acquired with good lighting and with the camera perpendicular to the strip.

There are 300 images of the first type, 300 images of the second type and 30 images of the third type to be processed by the proposed flaw detection algorithm.

The image illumination quantity indicator will express the number of hits that the algorithm has when detecting if the belt is damaged or not, this will measure the degree of influence that the amount of illumination has on the conveyor belt for correct processing and efficient performance of the proposed fault detection algorithm. For the first type of image, the strip is not damaged, so the algorithm should not detect any fault, for the second type of image, the strip is damaged, for which the algorithm should detect areas of the strip that are in bad condition. state and areas that are not damaged, for the third type of image the strip is also damaged so the algorithm should try to detect these faults.

Table 5 shows the results of this classification in detail and the values obtained by the image illumination quantity indicator.

Table 5. Image Illumination Amount Indicator Table.

	Classifications correct	Incorrect classifications	ICII
Image type 1: Low lighting, camera tilt different from 90º	0	300	0
Image type 2: Medium illumination, camera tilt 90º	42	258	0.14
Image type 3: Good lighting, camera tilt 90º	28	two	0.93

b) **Algorithm Efficiency Indicator (IEA):**

The efficiency indicator of the proposed algorithm is measured from the data acquired from Image type 3 (An image with good lighting and with a degree of inclination of the camera of 90º). The indicator will measure the number of correct classifications when detecting faults in the conveyor belt.

Table 6 shows in detail the results of this classification and the values obtained by the algorithm's efficiency indicator.

Tabla 6. Algorithm Efficiency Indicator Table.

	Classifications correct	Incorrect classifications	IEA
Image type 3: Good lighting, camera tilt 90º	28	two	0.93

11.4 Simulate the operation of the fault detection system

a) Progress objectives

It is proposed to show the operation of the fault detection system designed through a simulator.

b) Theoretical support

Due to the fact that the present work aims to solve an industrial problem, it was decided to choose the use of the TIA Portal program and the Factory I / O program, which allow programming the PLCs with which we work in the mining industry, in such a way that to a future implementation the code to use would be the same for the controllers.

- **TIA Portal:**

TIA Portal is the innovative engineering system that enables all planning and production processes to be configured intuitively and efficiently. It convinces with its proven functionality and by offering a unified engineering environment for all control, visualization and drive tasks.

The TIA Portal incorporates the new version of the SIMATIC STEP 7 engineering system for planning, programming and diagnostics of all SIMATIC controllers.

With a new generation of more productive schedule editors, the quality, efficiency and consistency of the entire production process is optimized. Thus, structured text, ladder diagrams, operating diagrams, instruction lists and the possibility of programming the process chain are available.

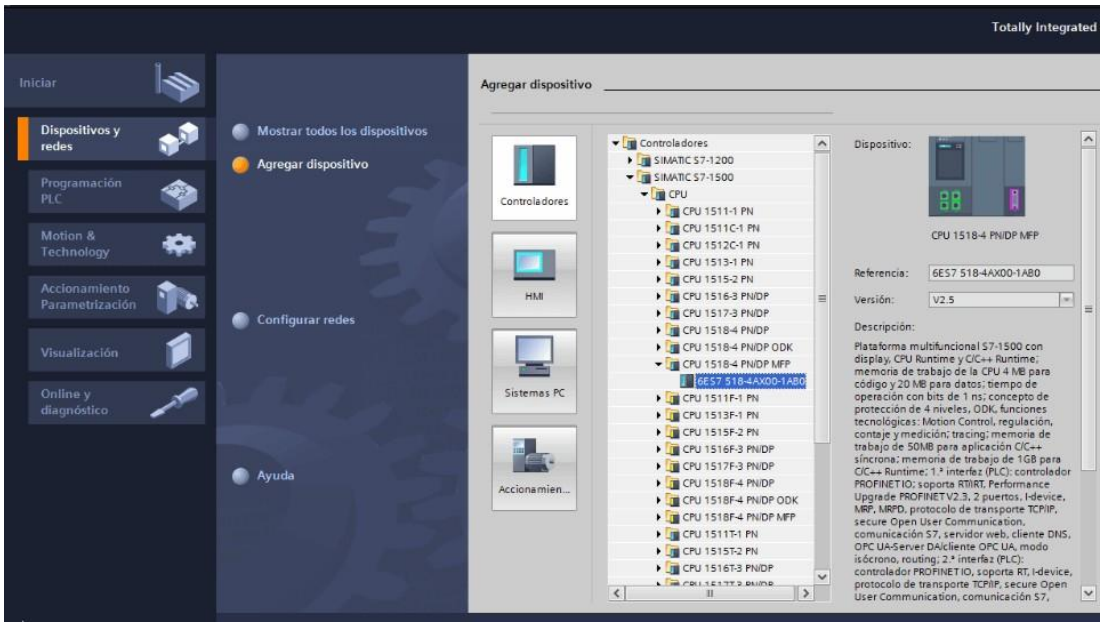

Figure 24. TIA Portal programming interface.

- **Factory I / O:**

Factory I / O is a 3D factory simulation for learning automation technologies. Designed to be easy to use, it allows you to quickly build a virtual factory using a selection of common industrial parts. Factory I / O also includes many scenes inspired by typical industrial applications, ranging from beginner to advanced difficulty levels.

The most common scenario is using Factory I / O as a PLC training platform, as PLCs are the most common controllers found in industrial applications. However, it can also be used with microcontrollers, SoftPLC, Modbus, among many other technologies.

Figure 25. Factory I / O program simulation scenario.

c) Progress analysis

The methodology that will be used to simulate the operation of the fault detection system is shown in figure 26.

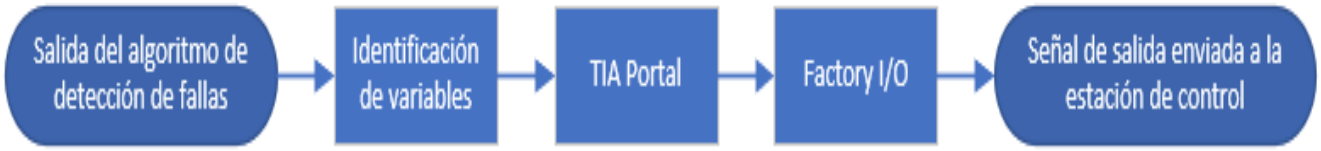

Figure 26. Methodology used to simulate the operation of the fault detection system.

d) Progress analysis

The Factory I / O simulation environment is shown in which we have our conveyor belt in operation, for the better visualization of the movement of the belt, boxes are placed on it because the program allows us to use this tool.

Figure 27. The image shows the correct operation of the belt.

To start the industrial process with the conveyor belt, press the Start button on the control panel. In the upper part of the control panel there is a sound alarm next to an indicator button which will turn on when the fault detection algorithm detects a possible break in the conveyor belt, with which the operations manager will be aware that a problem occurs with the conveyor belt, the alarm signal is also sent to the control station where the maintenance area must plan the technical review of the conveyor belt.

Figure 28. Process control board with conveyor belt.

We start the industrial process and observe the normal operation of the conveyor belt.

Figure 29. Normal operation of the conveyor belt.

The moment the algorithm detects a failure in the conveyor belt, it turns on the alarms, sends the signal to the central control station and stops the production process.

Figure 30. Detection of a fault in the belt

CHAPTER XII. FINANCIAL AND ECONOMIC REPORT

Project budget.

The Table presents the required resources for the project, description, quantity, unitary cost, and total cost.

Table 7. Economic budget table for the project.

Name	Description	Quantity	Unit cost (s /.)	Total cost	Comments
Information search	Necessary for the planning, development and justification of the research	50 hours	10	500	Contribution made by the project researcher
Virtual interview	Interview with the specialist of the mining process to investigate	4 hours	fifty	200	Specialist in charge of the mining maintenance area
Use of Software	Programs used for the development of the project	4 programs	Free software	0	Free downloaded student version
Laptop	Required for image processing and fault detection algorithm	1	4000	4000	Laptop owned by the project researcher
Camera	Required to acquire images of the conveyor belt	two	262.5	525	Acquire on website
LED panel	Necessary for the correct lighting of the camera	two	342	684	Acquire on website
Contingencies (10% total)	-	-	-	590.9	-
TOTAL:				6500	

CHAPTER XIII. CONCLUSIONS

- To carry out the design of the image acquisition system, fundamental aspects such as the type of illumination that will be given to the conveyor belt, the intensity of the light, the direction in which the belt is illuminated and the source of light must be taken into account. source of illumination, all these aspects will define the quality of the image acquired by the designed system, these results are concluded after analyzing two types of images with the fault detection algorithm used (The type 1 image with low illumination and inclination of the different 90º camera and the type 2 image with medium illumination and 90º camera tilt).
- The fault detection algorithm presents a good performance with the images of the damaged strip that were analyzed, according to the efficiency indicator of the algorithm it presents 93% efficiency with respect to the total of images analyzed, however when using an image that was acquired with low lighting and with a direction of the camera inclined with respect to the strip, the algorithm presents inefficient results (0% because it cannot differentiate the texture of the material and because of that the algorithm throws faults in the strip when in fact it does not there is), with which it is possible to verify the importance of the type of lighting and the orientation of the camera when acquiring the images.

- The processing time of the fault detection algorithm developed is optimal to be able to carry out constant and real-time monitoring of the belt, which is why the implementation of a monitoring system in time can be proposed as a future improvement for later work. real for a conveyor belt.

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TABLE INDEX

INDEX OF FIGURES

APPENDIX A

Engineering Standards Applied in the Project

1. **ISO 21183-1.-**
   Light conveyor belts — Part 1: Principal characteristics and applications

   For the study and analysis of lightweight conveyor belts with a fabric structure they must comply with the international standard ISO 21183-1.

   Fabric-structured conveyor belts are manufactured with multiple layers, with the synthetic layers providing the tensile strength. The fabric is usually polyester and, in some cases, polyamide or aramid. The fabrics are bonded with adhesive agents or by interlayers of thermoplastic materials. The material, thickness and texture of the transport side depend on the function. The coatings are mainly made of thermoplastic materials such as TPU, TPO, PVC, etc. and elastomers such as rubbers, PUR, etc. The sliding side is normally a fabric, often impregnated with a thermoplastic material or with a special wear resistant PUR.

2. **DIN 22102 and 22131.-**
   Conveyor belts with textile plies for bulk goods - Part 1: Dimensions, specifications, marking.

   For the minimum necessary values of tensile strength, elongation at longitudinal break and abrasion of the different materials that can be used in the manufacture of conveyor belts, they are included in the DIN 22102 and 22131 standards, establishing the categories W, X, Y, Z.

According to the DIN-22102 standard, apart from those indicated for normal qualities, they are the following:

- Extra anti-abrasive

  For belts subjected to work with highly abrasive materials, we have a special quality that corresponds to a grade greater than 20 N / mm2 and abrasion less than 80 mm3.

- Fireproof Underground use

  For applications in indoor mining and in accordance with current standards and requirements, we supply belts in self-extinguishing and antistatic qualities of type "S", in accordance with DIN and ISO standards, to prevent the spread of fire and generation of static charges or generation of heat by friction that can initiate the deflating of flammable gases.

- Flameproof Exterior use

  In open-pit applications both in mines and in coal farms of thermal power plants, it is recommended, due to the existing fire risk, the use of anti-flame and anti-static bands type "K" (DIN Standard), which prevent the spread of fire .

- Flameproof and Oilproof Exterior use

  For transporting materials with abundant presence of oily substances and in order to avoid their chemical attack to the

rubber coating of the anti-flame and anti-static conveyor belt that resists the degradation of the coating. The "K + G" band is recommended for these cases.

- Flameproof and Oilproof for Underground use

  It is used in facilities where oleaginous materials are transported and protection is required to prevent the spread of fires. It is frequently used in bucket elevators for all types of cereals and grain unloading maritime terminals.

- Temperature resistance

  In this type of application, it is advisable to foresee an oversizing of the textile carcass, the diameters of the drums and the thickness of the coatings, in order to compensate for the loss of characteristics of the materials due to aging. We recommend minimum coating thicknesses of the order of 5 + 2mm.

- Resistance to oils and greases

  When the belt works in contact with lubricants, greases, garbage, etc., rubber qualities with due resistance to contact with these materials must be used in its composition. Type G: Specific for use in the continuous transport of solid materials that contain or may contain oils or their derivatives of raw animal or vegetable origin.

  Type GG: Specific for use in the continuous transport of solid materials that contain or may contain derivatives of mineral oils or greases: diesel, kerosene, release agents, etc.

3. ISO 14001: 2015

Environmental Management Standards

The ISO 14001 Environmental Management Standard is focused on the protection of the environment, through the prevention or mitigation of adverse environmental impacts of production processes or services, supporting compliance with legal requirements and other requirements that are applicable to them. This is added to the improvement of environmental performance based on data and indicators and the control or influence on the way in which the organization designs, manufactures, distributes, consumes and carries out the final disposal of products or services, in a way own and / or outsourced, using a life cycle perspective that can prevent environmental impacts from being involuntarily transferred to another point in the same cycle, thus ensuring the consideration of legal and other applicable requirements.

The present work contributes to the protection of the environment because it seeks to replace the traditional mining transport carried out by trucks and forklifts by the autonomous use of conveyor belts, which would reduce the carbon dioxide emissions produced by mining companies.

4. ISO 45001: 2018 / OHSA S18001

OHSAS 18001 is a standard developed in the UK to help the entire company continually improve the occupational health and safety it offers to its employees.

The ISO 45001 standard can be understood as an update of OHSAS 18001 but in essence, it is a new ISO Standard, which provides a

reference framework to manage risks and opportunities, also of the same management of safety and health at work (SST), focusing on objectives to prevent work-related injuries and health deterioration; and achieve safe and healthy workplaces, thus improving management performance.

5. ISO / IEC 27001: 2013

The Information Security Management System (ISMS) provides the necessary bases for the creation, implementation and maintenance of a Management that promotes a strategic approach for the adoption of a management model by processes under parameters that preserve confidentiality, integrity and availability of information based on risk management in a manner appropriate to the type of information. Integration with the organization's processes and the global management structure is essential, considering from the design of processes, information systems and controls according to the needs of the organization. The management framework is structured on the basis of the General Information Security Policy, which establishes a foundation of security principles,

6. NEMA ICS 6: Enclosures for industrial control and systems.-

This standard provides practical information on the design, construction, testing, performance, and manufacturing of industrial control equipment. These standards provide guidelines for the proper

manufacturing and application of products and equipment and promote the benefits of repetitive manufacturing and product availability.

One of the main purposes of this standards publication is to promote the production of reliable control equipment, as well as provide information on electrical distances and interruptions that have a direct influence on safety.

In the present work, this standard is used for the correct selection of the controller in charge of the autonomous process of the conveyor belt.

The important factors for the design mentioned in this regulation are:

A) Environmental conditions

B) System design

C) Equipment selection and application

D) Installation

E) Operating practices

F) Maintenance

7. <u>IEC 61511 - Functional safety - Safety instrumented systems for the process industry sector.</u>

This International Standard gives the requirements for the specification, design, installation, operation and maintenance of a safety instrumented system (SIS), so that it can locate and / or maintain the process in a safe state. This standard has been developed as a process industry implementation of IEC 61508.

In particular, this standard specifies the requirements to achieve functional safety, it applies when developing application software for

systems with limited variability or fixed programs, it applies to a wide variety of industries within the process sector including chemicals, petroleum, refining, oil and gas production, pulp and paper, non-nuclear power generation, describes the relationship between safety instrumented functions and other functions, results in the identification of safety requirements, integrity and functionalities, specifies requirements for system architecture and hardware configuration, and specifies requirements for application software for users and security integrators.

For a subsequent implementation of the failure detection system for a conveyor belt, all the requirements that this standard specifies for its correct installation and operation of the failure detection system within the different mining processes in which it will be developed will have to be taken into account.

APPENDIX B

Realistic Multiple Constraints Considered in the Project

1. **Constraints regarding the disassembly/assembly of the system**

   The system was designed for an straightforward and intuitive assembly and disassembly of all the mechanical and electronic components. The data acquisition system is easy to use and to configure for adjusting the image resolution, image size and frequency of data acquisition.

2. **Constraints when designing the image acquisition system**

   Due to the current situation of COVID 19 pandemic, the scope and cost of the project has been limited and the testing has been carried out for the most common faults affecting conveyor belts. The reference data for other types of faults had to be generated and used to verify the effectiveness of the system.

3. **Constraints in the detection of breakage of the conveyor belt**

   Given to the CVD 19 pandemic it was not possible to travel to Antamina Mining Company to verify the operability and effectiveness of the project in a real-world environment. However, the company provided the required equipment and data to test the system in a laboratory environment.

4. **Constraints to define the performance indicators for the proposed algorithm**

   Despite the little variety within the database used for the study of faults in the conveyor belt, it is tried to give it the greatest possible utility, although this

allows us to carry out the study and the corresponding tests of the algorithm, it limits the development of a greater number of performance indices because there is not a greater variety of bands to be able to analyze and compare the different performance indices.

5. Constraints when simulating the operation of the fault detection system

At this stage of the project, there were limitations regarding the hardware available for the project because the equipment (desktop PC) is not powerful enough to run the simulation programs, this delayed the progress of the project considerably. Due to cost limitations, we cannot acquire other equipment with better performance, however, despite the delay, the proposed simulations were out and the expected results for this part of the project were obtained.