

**DEVELOPMENT OF AN AUTOMATED ROBOT VISION
COMPONENT HANDLING SYSTEM**

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Dissertation submitted in fulfilment of the requirements for the degree

MAGISTER TECHNOLOGIAE: ENGINEERING: ELECTRICAL

in the

Department of Electrical, Electronic and Computer Systems Engineering

of the

Faculty of Engineering and Information Technology

at the

Central University of Technology, Free State

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June 2013

Declaration

I, RUDOLPH JOHANNES JANSEN VAN NIEUWENHUIZEN, identity number [REDACTED] and student number 9412883, do hereby declare that this research project which has been submitted to the Central University of Technology Free State, for the degree MASTER TECHNOLOGIAE: ENGINEERING: ELECTRICAL, is my own independent work and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State, and has not been submitted before by any person in fulfilment (or partial fulfilment) of the requirements for the attainment of any qualification.

.....

SIGNATURE OF STUDENT

.....

DATE

Acknowledgments

I would like to take this opportunity to thank the people who helped me in completing this qualification:

Firstly I thank God for giving me the wisdom and understanding and for His grace in this time.

My promoter Mr PS Veldtsman for his time, guidance, patience and dedication to my studies.

Prof HJ Vermaak, my co-promoter, for his wise council, for believing in me and encouraging me to follow through.

Prof GD Jordaan, thank you for your guidance and assistance.

Mr B Kotze for his guidance and interest in my dissertation.

The Central University of Technology, Free State, for the provision of their facilities and financial support.

My family for their love and support, especially my dad for his encouragement and helping out wherever he could.

Special thanks to Florian and Petri for their participation and enthusiasm in my project, I appreciate your hard work.

Thank you to my wife, Rozelma, for standing by my side and supporting me through this time.

To all my colleagues at CUT, thank you for your input and your support, it didn't go by unseen.

SUMMARY

In the industry, automation is used to optimize production, improve product quality and increase profitability. By properly implementing automation systems, the risk of injury to workers can be minimized.

Robots are used in many low-level tasks to perform repetitive, undesirable or dangerous work. Robots can perform a task with higher precision and accuracy to lower errors and waste of material.

Machine Vision makes use of cameras, lighting and software to do visual inspections that a human would normally do. Machine Vision is useful in application where repeatability, high speed and accuracy are important.

This study concentrates on the development of a dedicated robot vision system to automatically place components exiting from a conveyor system onto Automatic Guided Vehicles (AGV).

A personal computer (PC) controls the automated system. Software modules were developed to do image processing for the Machine Vision system as well as software to control a Cartesian robot. These modules were integrated to work in a real-time system.

The vision system is used to determine the parts' position and orientation. The orientation data are used to rotate a gripper and the position data are used by the Cartesian robot to position the gripper over the part.

Hardware for the control of the gripper, pneumatics and safety systems were developed. The automated system's hardware was integrated by the use of the different communication protocols, namely DeviceNet (Cartesian robot), RS-232 (gripper) and Firewire (camera).

OPSOMMING

In die industrie word outomatisering gebruik vir optimale produksie, verbeterde produkkwaliteit en om wins verhoog. Deur outomatiseringstelsels reg te implementeer, word die risiko van beserings aan diens geminimaliseer.

Robotte word gebruik vir laervlak take soos om herhaalde, ongewenste of gevaarlike prosedures te volg. Robotte kan take meer presies en akkuraat uitvoer met minder foute en vermorsing van materiaal.

Masjienvisie maak gebruik van kameras, beligting en sagteware om visuele inspeksies te doen wat normaalweg deur 'n mens gedoen word. Masjienvisie word gebruik vir inspeksies waar herhaalbaarheid, hoë spoed en akkuraatheid belangrik is.

Die studie konsentreer op die ontwikkeling van 'n toegewyde robotvisie stelsel om komponente outomaties van 'n vervoerband na 'n "Automatic Guided Vehicle" oor te plaas.

'n Persoonlike rekenaar word gebruik vir die beheer van die outomatiese stelsel. Sagteware modules is ontwerp vir die beeldverwerking van die masjienvisie stelsel asook om die „Cartesiese" robot te beheer. Die modules is geïntegreer om in reële tyd te werk.

Die visie stelsel word gebruik om die onderdele se posisie en oriëntasie te bepaal. Die oriëntasie data word gebruik om 'n robothand te draai en die posisie data word deur die „Cartesiese" robot gebruik om die robothand oor die onderdeel te posisioneer.

Hardeware is vir die beheer van die robothand, pneumatika en veiligheidsstelsels ontwikkel. Die outomatiese stelsel se hardeware is geïntegreer deur die gebruik van verskillende kommunikasieprotokolle, naamlik DeviceNet („Cartesiese" robot), RS-232 (robothand) en Firewire (kamera).

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List of Acronyms

AGV	Automatic Guided Vehicle
HMI	Human Machine Interface
A/D	Analog to Digital
AC	Alternating Current
AGV	Automatic Guided Vehicle
AI	Automated Inspection
CMOS	Complementary Metal Oxide Semiconductor
CPU	Central Processing Unit
CVS	Compact Vision System
DAQ	Data Acquisition card
DC	Direct Current
HMI	Human Machine Interface
I/O	Input/Output
LCD	Liquid-crystal display
LVDT	Linear Variable Differential Transformer
LED	Light Emitting Diode
MAX	Measurement and Automation (MAX) explorer
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
MPa	Mega Pascal
MV	Machine Vision

N	Newton
NI	National Instruments
PAC	Programmable Automation Controller
PC	Personal Computer
PLC	Programmable Logic Controller
PSU	Power Supply Unit
RGEMS	Research Group in Evolvable Manufacturing Systems
SW	Switch
TTL	Transistor–Transistor Logic
USB	Universal Serial Bus
VGA	Video Graphics Array
VI	Virtual Instruments

Chapter 1: Introduction

1.1 Overview

To succeed in the competitive global marketplace of today, it is vital for an organisation to optimise its operational costs [1]. Organisations need to find new ways to design, manufacture and deliver quality products. At the same time, quality improves reliability - which translates to fewer warranty claims and increased customer satisfaction. Process improvements can decrease waste, improve workflow and enhance workplace safety, all contributing to the profitability of an organisation [2].

Automation is the use of machines, control systems and information technologies in the production of goods and the delivery of service to optimize productivity [3]. In the industry, the incentive for applying automation is to increase production with improved quality at a lower price without the risk of injury to workers [4].

Robots are programmable, electro-mechanical machines designed to perform specific tasks, such as moving, holding, placing or transferring parts or sub-assemblies along a specified assembly line. Robots are suitable for continuous, repetitive and monotonous tasks. They can be used to perform tasks involving undesirable, dangerous or work requiring heavy physical effort or that which a human is unable to perform [5][6].

Human vision and response can be slow and are vulnerable to errors due to boredom, fatigue or other circumstances. Some human inspections are time-consuming and then selective sampling is used for part assurance. Processes where only some parts are checked have the potential to produce errors with some irregular parts passing through the system. Replacing human inspection with Machine Vision can drastically reduce these kinds of errors.

Machine vision inspections and measurements of specified criteria may be performed tirelessly at high speed and with high accuracy [7]. Machine Vision applications include visual quality control, measuring, recognition, sorting and

robot guidance. In quality inspection a pass/fail output can be used and for robot guidance the parts' position and orientation will be used.

By integrating the results of the Machine Vision inspection with a robotic system, the inspection and handling of the parts can be intelligently automated in the manufacturing or production environment. By the correct implementation, the production will be able to continuously achieve higher speed, accuracy and reliability.

One could think of the automation process as the replacement of a human's functions. The eyes can be replaced by Machine Vision to gain information of the environment. The brain can be replaced by a controller to make decisions from the captured data in order for the robot to perform the physical movement and handling.

A robot with vision capabilities can be taught to find and place components on an assembly line. The vision camera can either be fixed or mounted on the robot arm, which allows a greater degree of reconfigurability of the vision system [8].

1.2 Problem statement

During the late 1970s and early 1980s, many United States companies lost significant market share, due to foreign competition - particularly from Japan. In 1980 Detroit's share of the U.S. automotive market was 71.3 percent and by 1991 declined to 62.5 percent. One third of the world's demand is now supplied by Japan. Steel, electronics and other industries faced similar losses in market share [9].

Automation technology has had a tremendous impact on industries all over the world. To produce high quality products at high speed, manufacturing plants need to be extremely effective. Therefore, quality control must be done at high speed with low error rate. Automation systems must be able to run consistently and continuously.

Traditional automation systems are usually built around a single part or a small family of products that can run on the same production line [10]. If the component

is changed, a number of changes must be made to the mechanical setup of the system. Mostly new fixtures, feeders and positioning guides are required with time-consuming setup procedures.

Machine Vision, using cameras and specialised programs, can replace or even improve on human vision where precise and repeatable visual measurements and inspections are required [8]. A Machine Vision system can identify parts, determine the parts' spatial properties and perform quality inspections all while the component is on a conveyor.

By integrating Machine Vision with a robot, the parts' position and orientation can be used by the robot to pick the part and place it at a required destination. This can be performed on a 24-hour basis while increasing production quality and speed.

1.3 Aim of study

The Research Group in Evolvable Manufacturing Systems (RGEMS) has launched a number of projects at the School of Electrical and Computer Systems Engineering at the Central University of Technology, Free State. RGEMS is developing high levels of technological expertise with respect to the design and development, commissioning and maintenance of automated production lines and subsystems [11].

A research platform is being developed by means of which staff and students can develop research skills. The different researchers' projects are integrated into the system to function as a workable, automated component handling process. The project began with a conveyor system as the central component.

This study will concentrate on the development of a dedicated robot vision system to automatically place components, exiting from the conveyor system, onto Automatic Guided Vehicles (AGV). The project will consist of the integration of the following components:

- Machine vision system
- Cartesian robot

- Gripper
- Computer with dedicated software.

The Machine Vision system will detect a part, compare the part with predefined size for quality control and determine the part's position and orientation. Illumination plays a major role in capturing high quality images. The illumination will be designed to be unobtrusive to the robot and other handling mechanisms, but with adequate illumination of the part.

The Cartesian robot will be used to move the camera to capture optimal images of the part under inspection and will use the resulting Machine Vision data to move the gripper to pick the part up and move it to a required destination.

The gripper will be able to rotate to the best angle (as determined by Machine Vision) to pick up the part. The gripper must be able to grip the part with enough force so that the part will stay in the claws while it is being transported.

A personal computer (PC) will be used as the controller for the system. Readily available interfacing devices will be used to ensure easy maintenance. The software will be designed in an easy-to-understand manner that is fast and consistent.

1.4 Hypothetical resolutions

On completion of the study, the robot vision system must be able to do the following automatically:

- Detect a component on the conveyor belt.
- Determine the position and orientation of the part.
- Move the gripper to a position where the gripper will be able to grasp the part.
- Rotate the gripper and grasp the part.
- Move the component to the desired destination.

1.5 Research Method

The system was divided into subsystems with modules developed in LabVIEW to do image processing for the Machine Vision system, control the Cartesian robot and to control the gripper. These modules were integrated in one LabVIEW program to work in a real-time system.

1.5.1 Machine Vision system

The development of a software module in LabVIEW to perform machine vision is an important part of this study and required a lot of attention. The resulting data from this module is used to control the system.

The Machine Vision system detects parts on the conveyor and determines the part's position and orientation.

The orientation data is used to rotate the gripper and the position data is used by the Cartesian robot to position the gripper over the part.

1.5.2 Cartesian robot

In this system, a three-axes Cartesian robot with intelligent motor-drive controllers for each axis is used. By means of the drive controller, the position of the axis is controlled. Communication between the personal computer (PC) and the drive controllers is achieved by a Devicenet interface.

Different methods to control the axis of the robot will be investigated and tested to find the optimum method for incorporating the robot in the system. The best travelling path for the Cartesian robot to move the parts from the conveyor belt to the appropriate AGV inspection bay is determined by moving the robot through the path and recording the coordinates at regular intervals. This is done for the different paths and stored in the program memory. Depending on the action that needs to be performed by the robot, a specific path program will be selected and executed.

1.5.3 Gripper

The gripper used in this system consists of a pneumatic cylinder with two fingers. It has two states; open and close.

A rotator system for the gripper and the control thereof was developed and implemented. The computer software was written in LabVIEW in such a way that it can easily be implemented with other modules.

1.5.4 Personal computer as controller

A Devicenet interface card from National Instruments is installed in the computer to enable communication on the Devicenet bus. A data acquisition card is used to allow sensing and switching of sensors and control gear. Firewire is used for interfacing of the Machine Vision camera. RS232 is used to communicate to the rotator's control circuit. LabVIEW modules are integrated into one program to use the PC as the system controller.

1.5.5 Safety system

The safety aspects considered are emergency stops, light curtains, a safety mat and braking during power failure and malfunction.

1.6 Structure of chapters

Chapter 2 is a literature review of the products and techniques that can be applied in the system. This includes transport systems, robots, computer vision, illumination and LabVIEW as software platform and safety systems.

Chapter 3 gives a system overview and then discusses the actual products used in the system and the design of other required products.

Chapter 4 discusses the steps needed for the system to perform as an automated robot vision component handling system. The design and implementation of the different parts of the system are discussed.

Chapter 5 gives the results, challenges, and adjustments or changes that were made to ensure the system functions properly.

Chapter 6 provides a conclusion of the system's results, contributions and suggestions for future work.

Chapter 2: Literature review

Introduction

In this chapter, an overview of the components and technologies that are used for material handling is presented. The focus will be on components relevant to this study because automation, robotics and Machine Vision have so many applications and variations.

Topics covered in this chapter are transport systems, robots, sensors, imaging systems, computer vision, Machine Vision, illumination, camera standards, a software platform, safety systems and technologies currently used in component handling.

2.1 Transport systems

2.1.1 Conveyors

Conveyors are used to transport items to positions where it can be sorted or stored. Some conveyor configurations are the loop sorter and the line sorter. When a product is put on the loop sorter, the product will circulate endlessly on the system until the product is moved to the correct destination. An example of the loop sorter is a conveyor system found in the passenger baggage pickup area at airports, as shown in Figure 2.1. When a product is placed on the beginning of the line sorter it will either be moved from the system to be sorted or it will travel on the conveyor to the exit point. The loop sorter takes up more floor space with higher capacities.



Figure 2.1 Loop conveyor used in airport for baggage collection [12]



Figure 2.2 Tilt tray loop sorter [13]

Shown in Figure 2.2 is a loop sorter using tilt trays to sort items. The sorter makes use of a fully electronic tilt mechanism, which allows the trays to be tilted to a maximum of 45 degrees to discharge the transported item. This is a high-speed, high-throughput sorter and the trays are banked through curves to counter centrifugal forces of the transported items [13].

2.1.2 Automatic Guided Vehicles

An Automated Guided Vehicle or Automatic Guided Vehicle (AGV) is a mobile robot that follows markers or wires in the floor. Some can also work with vision or lasers to get the packing and moving of products done. They are most often used in industrial applications to move heavy materials around a manufacturing facility or a warehouse [14].



Figure 2.3 Forked Automatic Guided Vehicles [15]

The Forked AGV as shown in Figure 2.3 has the ability to handle heavy, big, round and all other types of products or loads such as pallets, carts, trays, racks and rolls. They are extremely popular because of their versatility and flexibility and can work with many types of equipment such as conveyors, racking and stands in addition to floor "pickups" and "drops". This makes the Forked AGV an excellent solution for applications where changes to the facility are expected during the lifetime of the AGV system [15].

2.2 Robots

The Encyclopaedia Britannica defines a robot as any automatically operated machine that replaces human effort, though it may not resemble human beings in appearance or perform functions in a humanlike manner [16].

Robots are used to perform tasks that humans could find difficult to do; tasks that are boring - such as domestic cleaning; or dangerous operations like exploring the inside of a volcano or kilometres under the sea. Other tasks include those that are physically inaccessible for humans, such as exploring another planet - which could be hard for humans to reach. Medically, robots can help doctors save dozens of lives by being used in surgeries such as heart transplants or performing laparoscopic surgery [17].

Typical applications of robots include welding, painting, cutting, assembly, handling, sorting, packaging, palletizing, product inspection and testing. Robots can accomplish all the above with high endurance, speed and precision - often at a lower cost than human labour [18][19][20]. In Figure 2.4 a robot is used for metal die casting in a foundry.



Figure 2.4 A Pick and Place robot in a factory [17]

Typical fields where robots are used in healthcare are during surgery, as pointed out above, or more personally in assisting individuals. Robots can also help in the metal industry with aspects mentioned above, including welding, moving heavy objects and assembling. Military robots are used in ground-based combat and unmanned combat air vehicles. In mining, due to the hazardous surroundings, autonomous, semi-autonomous and tele-operated robots are used.

2.2.1 Robotic arm

The design of a robotic arm is similar to a human arm. The robotic arm is made up of linkages connected together, each controlled by a stepper motor. The stepper motors are controlled by drives, which in turn are controlled by a programmable controller.

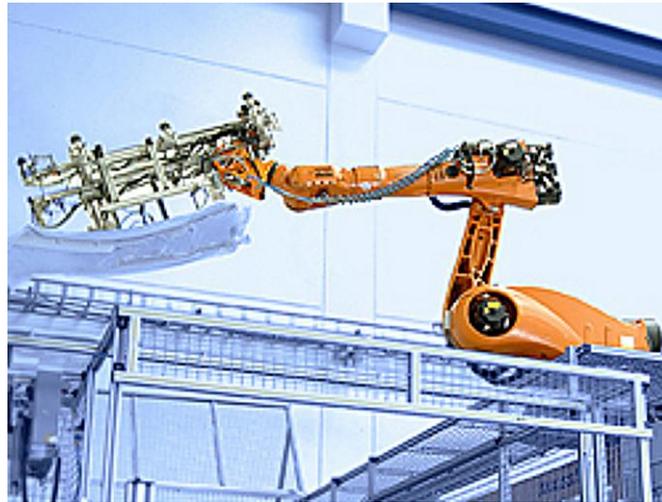


Figure 2.5 Robots in the automotive supply industry [21]

Robots, as shown in Figure 2.5, are playing a huge role in the automation of the car industry. These days, 75% of a car is manufactured by the component industry. From tires to windows, engine blocks to fuel lines, and steering wheels to plastic trim, whatever the component, the use of robots pays for itself. The reasons companies use robots in cases such as these include their flexible applications and user-friendly control technology. They are maintenance-free and reliable, even under extreme conditions, where humans would usually fail to complete a project. Robots carry a low investment cost and have utmost processing flexibility; this enables them to make the industry efficient and thus fit for the future [21].

2.2.2 Cartesian coordinate robot

A Cartesian coordinate robot, or linear robot, is an industrial robot whose three principal axes of control are linear (i.e. they move in a straight line rather than rotate) and are at right angles to each other [22].

Typical applications of the Cartesian robot are handling systems, packaging machines, mounting systems, printing machines, machine tools and circuit board plotters [23].



Figure 2.6 Circuit board plotter [24]

The plotter as shown in Figure 2.6 is used at the CUT by Project Design students to manufacture prototype circuit boards. Through the use of this unit, a student can easily mill and drill single-sided or double-sided circuit boards.

The unit makes use of a 10-position tool changer that automatically changes milling and drilling tools while the board is being produced. The spindle is positioned by a three-axis system with the Z-axis movement done by a moving machine table; the X-axis and Y-axis movement are achieved by linear drives.



Figure 2.7 A three-axis Cartesian robot moving accelerometers for testing [25]

Figure 2.7 is a photo of a three-axis Cartesian robot with dual-function, end-of-arm tooling for moving accelerometers from waffle packs to and from the testing nests [25].

Prof. Harry H. Asada uses a gantry robot in a hands-on course where students design, build and test their own robots in a undergraduate programme at the Massachusetts Institute of Technology. He found LabVIEW, as the software platform, easy for the students to use and it provides an intuitive programming approach for robotic system [26].



Figure 2.8. Circuit breaker welding system [27]

A circuit breaker welding system is shown in Figure 2.8 and has the potential to cut production time, increase throughput and improve quality and profits [27].

2.2.3 Robot end effector

The device at the end of a robotic arm which interacts with the work environment is called an end effector. The design of the device depends on the application of the robot. The end effector may consist of a gripper or a tool. The tools can be for spot welding, spray painting or other applications where the working conditions can be dangerous for humans [28].

Grippers are used to pick up objects for transfer to a location to place the object. The number of fingers and gripping surface of a gripper is determined by the shape of the object that needs to be moved.

There are numerous forces acting on the body of the object being moved by a robot. The main force is frictional force. The grip force must be adequate to secure the object and to withstand acceleration and motion forces during movement.

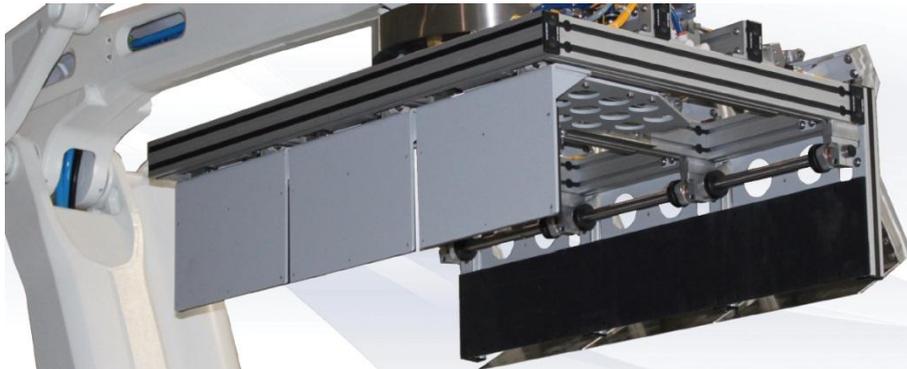


Figure 2.9 End effector [29]



Figure 2.10 End effector [29]

The end effectors shown in Figure 2.9 and 2.10 can be used for palletizing and material handling.

2.3 Sensors

A sensor is used to measure a physical quantity and convert it into an electrical signal. In material handling, a sensor is used to give indications of the environment the system is operating in.

Table 2.1 is a comparison of different sensor technologies and table 2.2 lists the type of material the technology can sense.

Table 2.1 Sensor technologies [30]

Sensor	Advantages	Disadvantages	Applications
Electromechanical limit switch	<ul style="list-style-type: none"> • High current capability • Low cost • Familiar "low-tech" sensing 	<ul style="list-style-type: none"> • Requires physical contact with target • Very slow response • Contact bounce 	<ul style="list-style-type: none"> • Interlocking • Basic end-of-travel sensing
Linear potentiometer	<ul style="list-style-type: none"> • Simplicity • Low cost 	<ul style="list-style-type: none"> • Finite lifetime 	<ul style="list-style-type: none"> • Solenoid positioning • Valve positioning
LVDT	<ul style="list-style-type: none"> • Excellent linearity • Wear free • High resolution 	<ul style="list-style-type: none"> • Signal conditioning 	<ul style="list-style-type: none"> • Machine tools • Servomechanism
Hall effect sensor	<ul style="list-style-type: none"> • Cost effective • Contactless 	<ul style="list-style-type: none"> • Signal conditioning 	<ul style="list-style-type: none"> • Pneumatic cylinders • Tachometers • Anti-lock braking systems

Inductive	<ul style="list-style-type: none"> • Resistant to harsh environments • Very predictable • Long life • Easy to install 	<ul style="list-style-type: none"> • Distance limitations 	<ul style="list-style-type: none"> • Industrial and machines • Machine tool • Senses metal-only targets
Capacitive	<ul style="list-style-type: none"> • Detects through some containers • Can detect non-metallic targets 	<ul style="list-style-type: none"> • Very sensitive to extreme environmental changes 	<ul style="list-style-type: none"> • Level sensing
Ultrasonic	<ul style="list-style-type: none"> • Senses all materials 	<ul style="list-style-type: none"> • Resolution • Repeatability • Sensitive to temperature changes 	<ul style="list-style-type: none"> • Anti-collision • Doors • Web brake • Level control
Photoelectric	<ul style="list-style-type: none"> • Senses all kinds of materials • Long life • Longest sensing range • Very fast response time 	<ul style="list-style-type: none"> • Lens subject to contamination • Sensing range affected by colour and reflectivity of target 	<ul style="list-style-type: none"> • Packaging • Material handling • Parts detection

Table 2.2 Comparison of technology and the detectable material [30]

Sensor type	Objects detected	Technology
Inductive	Metal	Electromagnetic field
Capacitive	Any	Electrostatic field
Ultrasonic	Any	Sound waves
Photoelectric	Any	Light

2.3.1 Proximity sensors

An object being sensed by a proximity sensor is mostly referred to as “the target”. Different types of proximity sensors are shown in Figure 2.11. A proximity sensor is able to detect the presence of nearby targets without physical contact.



Figure 2.11 Proximity sensors [30]

The operation principle of a proximity sensor is to emit a signal and to measure the changes in the return signal. Different target materials require different sensing technologies to be used by proximity sensors. A photoelectric or capacitive sensor might be more suitable for a plastic target where as an inductive proximity sensor only senses metal targets [31].

2.3.2 Rotary encoder

A rotary encoder, also called a shaft encoder, is an electro-mechanical device that converts the angular position or motion of a shaft or axle to an analog or digital code. The information about the motion of the shaft is typically processed elsewhere into information such as distance, position and speed. Figure 2.12 is an example of a typical rotary encoder.

Two types of rotary encoders are available, namely: absolute and incremental encoders.

An absolute encoder indicates the current position of the shaft. This information is maintained when the power is removed and is immediately available when power is applied.

A controlling system, using an incremental encoder, will normally move to a home position to initialize the position measurement. The incremental encoder indicates the movement of the shaft and by processing the current position is determined. During a power failure or failure of the processing data, the position of the incremental encoder system is not guaranteed [32].

An absolute encoder was chosen for the orientation unit because it always gives the current position of the shaft.



Figure 2.12 Rotary encoder [31]

2.4 Imaging systems

Figure 2.13 illustrates the five factors of an imaging system, which are resolution, field of view, working distance, depth of field and sensor size [33] [34].

1. Resolution – Imaging system's ability to distinguish object detail [34].
2. Field of view – The portion of the object under inspection that the camera can acquire.
3. Working distance – The distance from the object under inspection to the front of the lens.
4. Sensor size – Typically defined by the horizontal area of the camera sensor's active area.
5. Depth of field – The distance between the nearest and furthest objects where the objects are in focus.

Figure 2.13 also shows a representation of the image captured by the camera and illustrates the most important features of an image.

6. Image – Image of object captured by camera.
7. Pixel – The smallest element in an image.
8. Pixel resolution – The minimum number of pixels to represent the object.

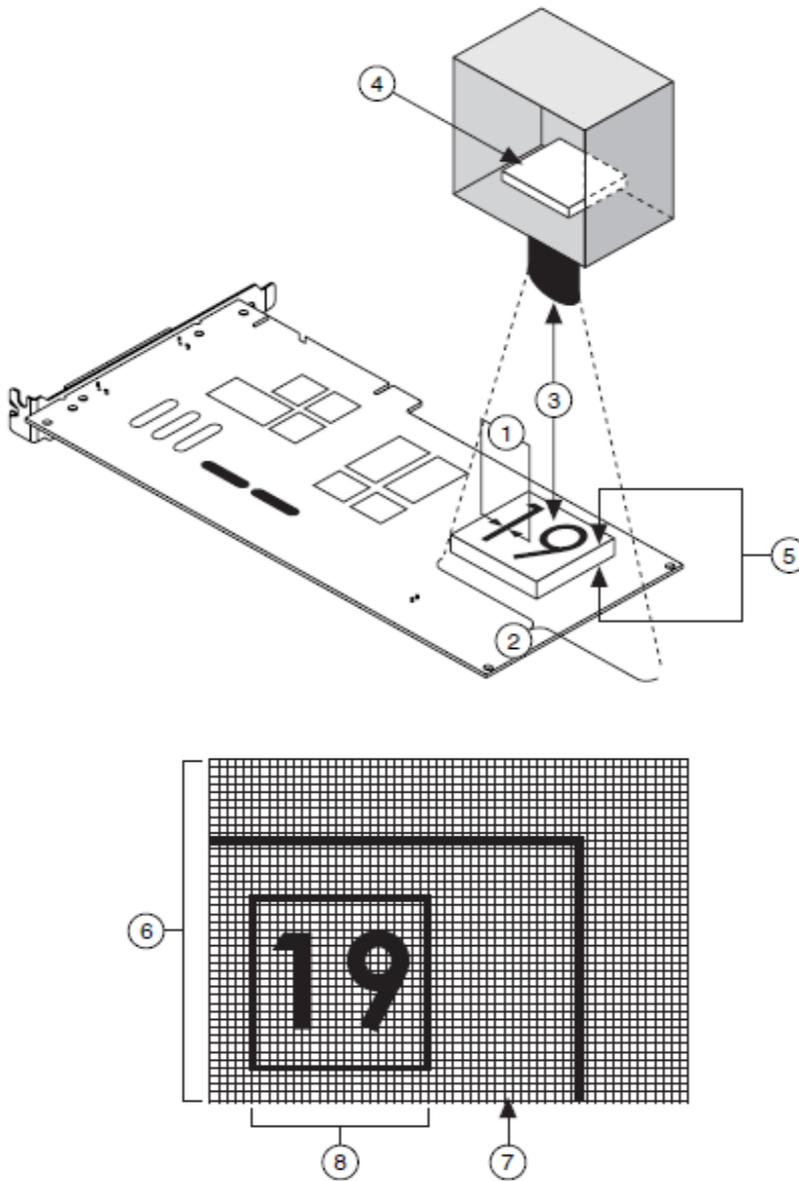


Figure 2.13 The fundamental parameters of an imaging system [34]

2.4.1 Computer vision

Computer vision covers the core technology of automated image analysis to provide automated inspection and robot guidance in industrial applications [36].

In a high-speed, detailed, repetitive manufacturing process, computer vision is more cost-effective and reliable than human intervention. Examples are in the manufacturing of semiconductors, medical, pharmaceutical, and computer products [37].

Consumer products such as cellular phones, disk drives, components, pagers, monitors and printers must pass quality standard tests required by ISO 9001. Vision systems can be used to identify and record fault conditions [37].

2.4.2 Machine Vision

Machine Vision (MV) is the process of applying a range of technologies and methods to provide imaging-based automatic inspection, process control and robot guidance in industrial applications [38].

The primary uses for Machine Vision are automatic inspection and robot guidance [38]. Common Machine Vision applications include sorting, robot guidance, material handling, optical gauging and quality checks.

Machine Vision can be used to solve common tasks such as completeness checking, dimensional and shape inspection, surface inspection, position detection and object identification [39].

Solving a Machine Vision problem can be divided into five steps [40]:

- Image acquisition - Illumination, optics, techniques and camera
- Image processing - Shading correction, filters, contrast and brightness
- Image segmentation – Threshold and edge detection
- Feature extraction - Centre of gravity, perimeter and area
- Image classification - Fuzzy classification, neural networks and statistical classifications.

2.4.3 Image processing methods

After an image is captured, image processing methods are used to enhance required features. These features are then used in the measurement of a object to determine the physical properties of the object under inspection. Typical methods used are given hereafter.

2.4.3.1 Thresholding

This is a process that is used to isolate an object in an image; thresholding converts the image from a greyscale image, with pixel values ranging from 0 – 255 to an image with pixel values of 0 – 1 (or a binary image). This process sets all grey-levels outside the threshold interval to a 1 and all the other values in the picture to 0 [17].

2.4.3.2 Binary Morphology

The resulting image of the thresholding function may contain unwanted noise particles like particles touching each other or the border of the image. By applying a binary morphology function these unwanted particles can be removed to improve the image information.

2.4.3.3 Gauging

Gauging is used to make precise measurements of products; for example, it's length, angle and diameter to determine if a product was manufactured correctly. Gauging can also count products and can be used in in-line and off-line production.

2.4.3.3.1 In-Line Gauging Applications

In-line inspection is mostly used in container inspection, electronic packaging and mechanical assembly. This is very accurate as each component is inspected as it is manufactured.

2.4.3.3.2 Off-line Gauging Applications

These gauging applications are used to measure the quality of products off line. A sample of a product is extracted from the assembly line and measurements are made to ensure the sample is within an acceptable tolerance limit [37].

2.4.3.4 Detection

A detection application is used to determine if an object is present in a certain area or not.

2.4.3.5 Edge detection

Edge detection is a fundamental tool in Machine Vision, computer vision and image processing to determine the object's spatial measurements. Edge detection identifies sharp changes in the image brightness to do feature extraction and feature detection to be used for alignment, gauging and detection [41].

2.4.3.6 Alignment

Alignment determines the position and orientation of a part. In many Machine Vision applications, the object that one wants to inspect may be at different locations in the image. Edge detection finds the location of the object in the image before one performs the inspection, so that one can inspect only the

regions of interest. The position and orientation of the part can also be used to provide feedback information to a positioning device [42].

2.4.3.7 Pattern Matching

Pattern matching quickly locates regions of a grayscale image that match a known reference pattern, also referred to as a model or template [42].

2.5 Illumination

The specification of the image acquisition subsystem entails the proper design and/or selection of lighting sources, sensors and supporting optics and their positioning with respect to the objects being imaged [41]. The goal of the imaging subsystem is to acquire an image with high contrast between background (noise) information and any object features (signal) required to perform the task [41].

Illumination is the most critical aspect of any Machine Vision application. It is a serious and costly mistake to assume that inadequate lighting can be compensated for in an algorithm. In fact, the desired image quality can typically be met by improving the illumination scheme of the system, rather than investing in higher resolution detectors, imaging lenses, and software [38].

The presence of ambient light input can have a tremendous impact on the quality and consistency of inspections, particularly when using a multi-spectral source, such as white light [44].

The goal of illumination in Machine Vision is to make the important features of the object visible and suppress undesired features of the object [39].

Common light sources are fluorescent tubes, halogen and xenon lamps, light emitting diodes (LEDs) and lasers [45].

2.5.1 Illumination techniques

Illumination techniques comprise of the following [44]:

- Backlighting
- Diffuse lighting (also known as full bright field)
- Bright field (actually partial bright field or directional)
- Dark field

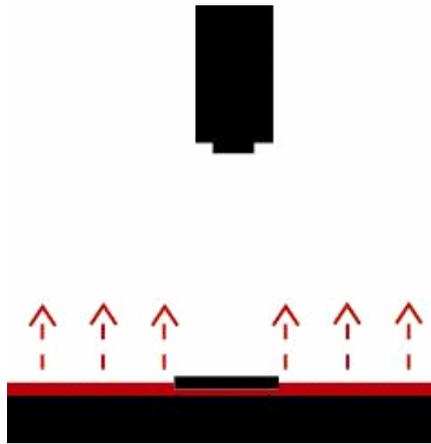


Figure 2.14 Backlighting [44]

Backlighting, as shown in Figure 2.14, is a method commonly used to determine object placement, orientation and to measure dimensions. The camera and light source are placed on different sides of the object generating a good contrast with dark silhouettes against a bright background.

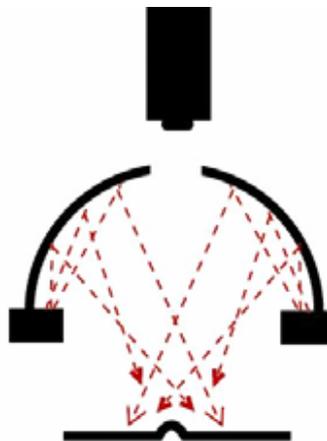


Figure 2.15 Dome Diffuse [44]

Diffuse or full bright field lighting, as shown in Figure 2.15, is used on shiny or reflective objects. With this setup, shadows are minimized but surface features are also less distinct because the object is not hit by direct light rays.

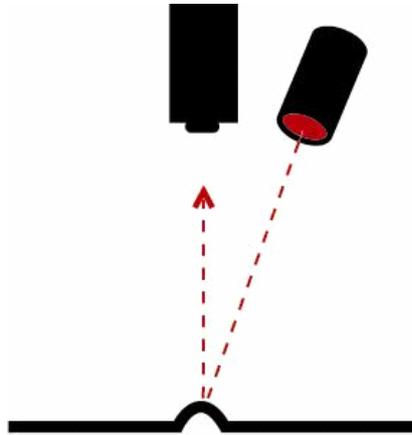


Figure 2.16 Directional Bright Field [44]

Shown in Figure 2.16 is the directional bright field lighting technique. This technique generates a strong, relatively even illumination which is a good choice for generating contrast and enhancing topographic detail.

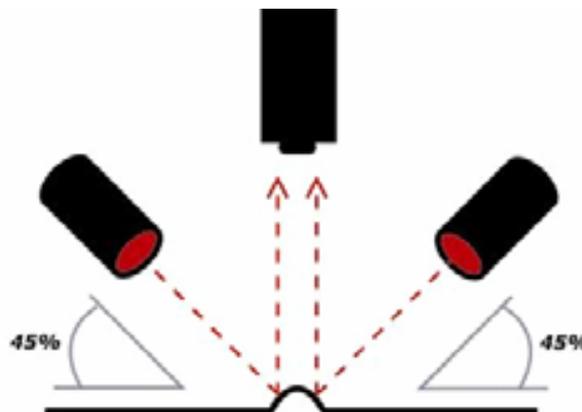


Figure 2.17 Medium Angle Dark Field [44]

With dark field illumination, as in Figure 2.17, there is no direct path between the light source and camera. This technique is used to do surface inspections where the surface appears black and a scratch on the object surface appears be bright.

2.6 Camera Standards

Table 2.3 contains the rankings of the different bus standards in use today as given by National Instruments while the graph in Figure 2.18 is a visual interpretation thereof [46]. A rating of 5 is high and a rating of 0 is low.

Table 2.3 Camera bus standards and ratings [46]

Bus	Through-put	Cost Effect	Cable Length	Standard Interface	Power over cable	Camera Available	CPU Usage
Analog	1	3	4	3	1	5	5
Camera Link	5	1	3	3	3	4	5
USB	2	5	1	2	5	1	1
IEEE 1394	3	4	1	5	5	3	3
GigE Vision	3	4	5	5	1	1	2

The goal of the comparison in Figure 2.18 is not to determine the best bus, but rather to determine the best bus for the application at hand.

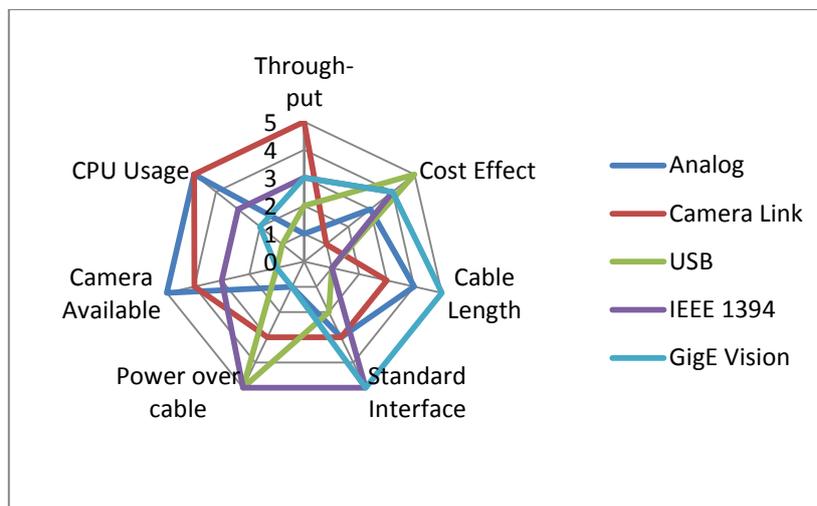


Figure 2.18 Camera bus standards and ratings

Some advantages of the different busses are:

- Analog is easily available and uses a frame grabber resulting in low CPU usage.
- Camera link has the highest throughput and uses a frame grabber resulting in low CPU usage.
- USB is very cost-effective and receives power through the interface cable.
- IEEE 1394 uses a standard interface and receives power through the interface cable.
- GigE Vision has a cable length of up to 100m.

Some disadvantages of the different busses are:

- Analog has low throughput; frame grabber must be used and an extra power cable is needed.
- Camera link is expensive and a frame grabber is needed.
- USB has a maximum cable length of 5m and low resolution.
- IEEE 1394 has a maximum cable length of 5m.
- GigE Vision makes use of a separate power cable.

As can be seen from this discussion, the application will determine the type of busses to consider.

2.7 LabVIEW

LabVIEW offers a package with a wide range of solutions for many measurement and automation applications.

LabVIEW is a graphical programming language and makes use of icons instead of lines of text. The graphical approach allows users with limited programming skills to build programs by dragging and dropping virtual representations of lab equipment with which they are already familiar [47].

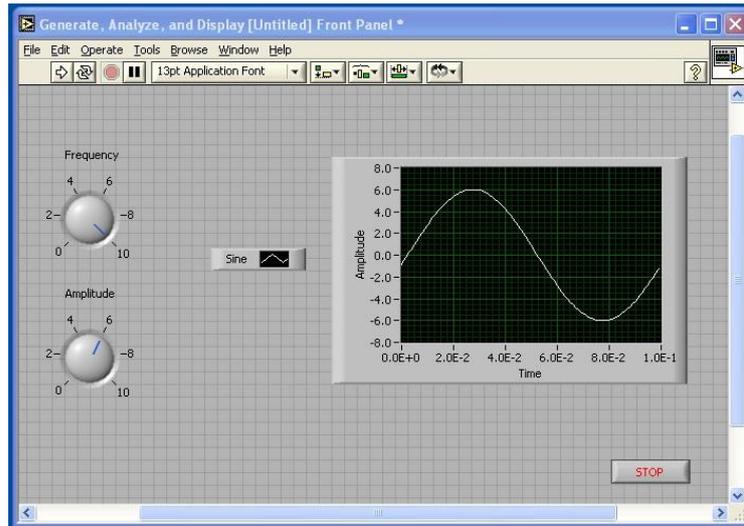


Figure 2.19 LabVIEW Front panel

The user interface of a LabVIEW program is shown in Figure 2.19 and is known as the Front panel. The Front panel is built with a set of tools and objects. This is where the user will interact with the program. Controls are the inputs simulated by objects like switches and outputs by objects like dials and indicators.

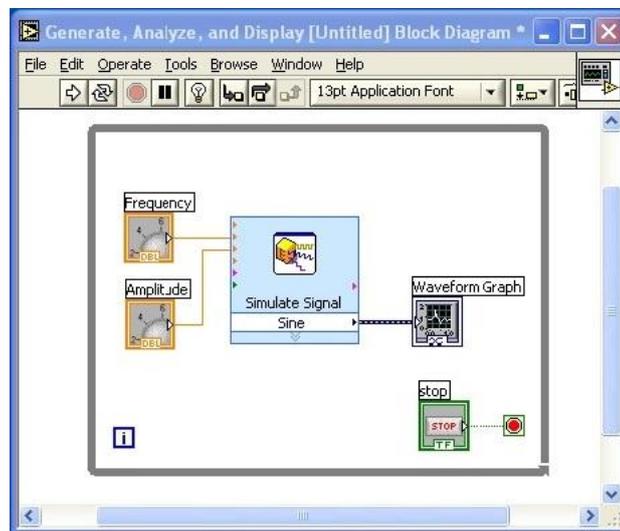


Figure 2.20 LabVIEW Block diagram

The block diagram resembles a flowchart and is where the program is written with graphical representation of functions. An example of a LabVIEW block diagram is shown in Figure 2.20. The objects in the block diagram control the front panel and can include terminals, subVIs, functions and wires - which transfer data among other block diagram objects [48].

Physical instruments like Oscilloscopes and signal generators can be imitated by LabVIEW, which is why LabVIEW programs are called VIs (Virtual Instruments) [49].

Before VIs are placed into a larger program as a subroutine it can be easily tested by the user. The modularity of the LabVIEW program enables the user to easily adapt the program to the user's needs [50].

What makes LabVIEW better than other programs is its ability to access instrumentation hardware with unending support in development environments [47].

2.8.1 NI Vision Assistant

NI Vision Assistant can be used to accelerate the development of Machine Vision applications as it is used as a tool in testing image processing applications [51].

2.8.2 NI Vision Builder AI

With National Instruments Vision Builder for Automated Inspection (AI) a complete automated inspection task can be configured and inspected, which can run as standalone software without LabVIEW [56].

Vision Builder AI can be used for deploying Machine Vision applications, building and benchmarking. It also includes the ability to control digital I/O devices, communications with serial or ethernet devices such as HMIs, PLCs and PACs and the ability to set up complex pass/fail decisions [52].

Vision Builder AI will enable the user to do programming in a much shorter amount of time as little programming experience is needed [51].

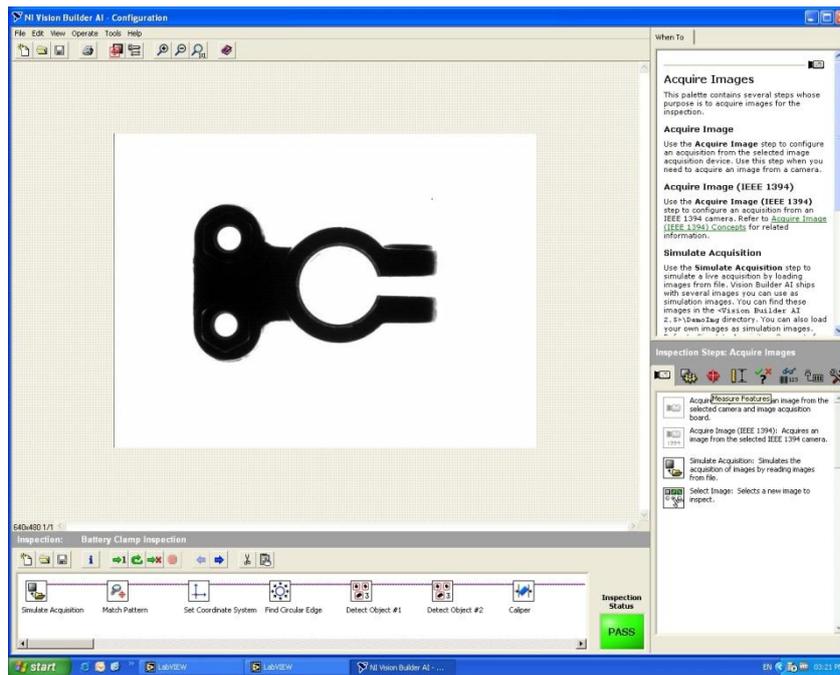


Figure 2.21 Vision Builder AI configuration mode

Vision Builder AI has two modes of operation – configuration or inspection.

- Configuration is used to test and configure an inspection.
- Inspection interface is used to perform online or offline visual inspections and to deploy software [53].

The configuration interface is used to configure and debug an inspection. The interface has an inspection diagram window that displays the list of steps that comprise the inspection. The user can run the inspection once, in a loop or until a failure occurred. It is possible to run the inspection from a camera, or a simulated image can be used.

When the results obtained from the configuration and debugging are satisfactory, the program can be switched to the inspection interface to deploy the software and perform online or offline visual inspection. Here the final inspection application can be run from within Vision Builder AI.

2.9 Safety

Studies show that people continuously subjected to stressful situations are more susceptible to psychosomatic illnesses. Even though people can adapt to extreme situations over the long term, a great strain is placed on the individual [54].

One of the objectives of a safety system should therefore be that operators and maintenance personnel must be able to rely on the safety of a machine [54].

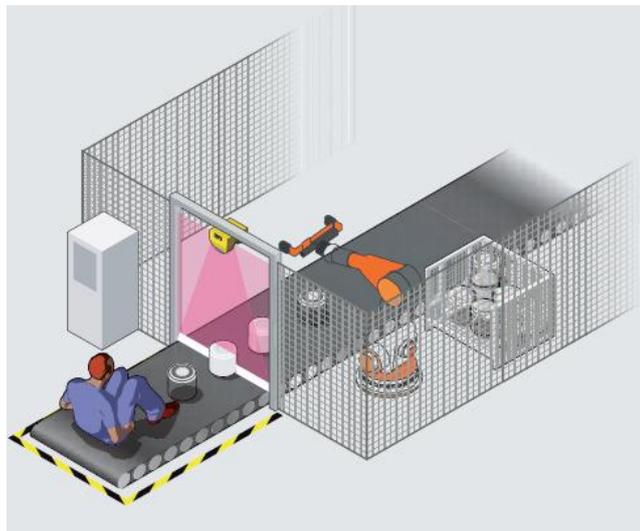


Figure 2.22 Safety systems should stop the process when a person is detected [55]

The safety system must be able to differentiate between people and material. When material goes through the process, as in Figure 2.22, the system should continue as programmed, but when people are detected the system should stop.



Figure 2.23 Hand detection safety systems [55]

A light curtain makes use of a transmitter emitting an infrared light beam in a sequence and a receiver at the other end to detect only the sequenced infrared light beam. Should this infrared light beam be broken, a signal will be sent to the safety system to stop dangerous conditions in the work environment. Figure 2.23 shows how a light curtain is set up to detect a person's hand approaching a dangerous area.

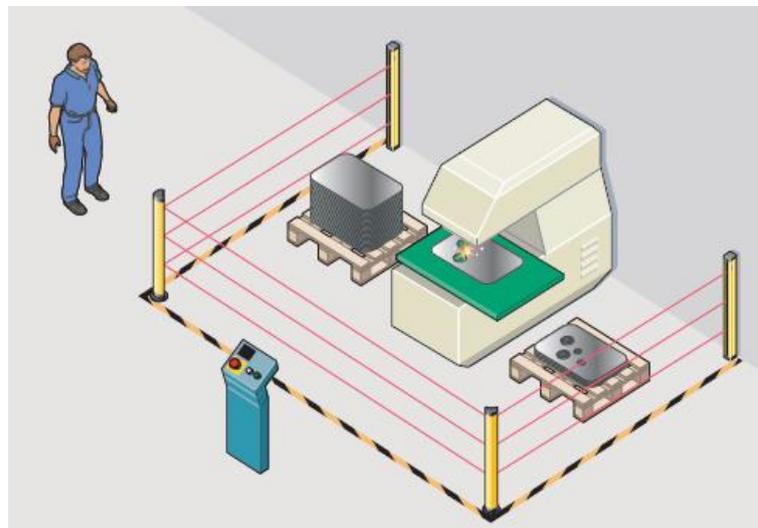


Figure 2.24 Safety systems to detect a human entering a hazardous area [55]

Figure 2.24 is a typical setup of a safety system using light curtains to detect a human body entering a hazardous area. With this kind of safety system a person outside the hazardous area will have no effect on the process, but when a person enters the hazardous area the process will be stopped [55].

2.10 Technology currently used in component handling

2.10.1 Tripod handling system

The Tripod handling system as shown in Figure 2.25 is from Festo. The Tripod handling system makes use of electrical linear drives for rapid movement of small parts at speeds up to 150 picks per minute. Through the tripod design, the unit is highly dynamic and at the same time more accessible than Cartesian systems. This unit is a good choice for pick and place applications, sorting and palletising tasks, as well as adhesive applications [56][57].



Figure 2.25 Tripod designed by Festo [56]

2.10.2 Bionic Handling Assistant

The elephant's trunk inspired the structure and function of the Bionic Handling Assistant developed by Festo and is shown in Figure 2.26.

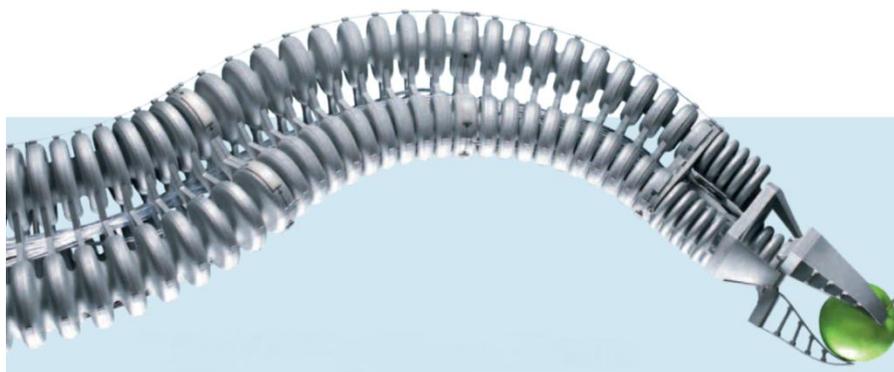


Figure 2.26 Bionic Handling Assistant developed by Festo [58]

The bellow structure makes use of polyamide to make the system inherently flexible, while the pneumatic control unit stiffens the system in a specific manner. With this system, humans and machines can work safely and efficiently as a team. This flexible structure prevents danger in the event of direct human-machine contact. Should a collision occur, the system immediately yields with no change to the desired overall dynamic behaviour. The Bionic Handling Assistant was chosen to receive the German future award in 2010 because of the system's yielding characteristics and the resulting risk-free human-machine contact [58][59].

2.10.3 Grippers

An adaptive gripper was developed by Festo and fitted on the Bionic Handling Assistant that consists of a pneumatic drive and three fingers. The finger design is based on the Fin Ray Effect, derived from the movement of a fish's tail fin. The flexibility and resilience of the grippers are especially useful when holding and transporting objects with varying contours or sensitive objects - like fruit or bulbs [58].

When handling flowers, bulbs or fruit with conventional metallic grippers, a high level of loss or damage results, which is counter to the two objectives of automation technology: speed and quality [60].

This gripper is currently used by Total Systems, to sort Dutch flower bulbs and was proven to be quick and efficient, improving the productivity at the plant [60].



Figure 2.27 Adaptive gripper with integrated camera [58]

The miniature camera, as shown in Figure 2.27, is implanted in the gripper to enable the system to register the working area, detect target objects, follow them and issue the command to grasp them at the appropriate time [58].

2.10.4 3D Imaging



Figure 2.28 Kuka robot used for bin picking [61]

Scape Technologies have developed a system to pick parts from a bin and place them on mounting assembly. The system is shown in Figure 2.28 where the camera takes a snapshot of the parts in the bin; the camera is then moved to a different angle to take another snapshot of the parts. From the result of the image processing of the two images, the position and orientation of a part is determined. The gripper grasps the part and moves it to the mounting assembly.

2.11 Summary

For this study an overview of the conveyor, Cartesian robot, camera and software platform were provided. To make the system as effective as possible the appropriate sensors, illumination and component setup needs to be used.

As can be seen from the discussion on new technologies used in handling systems, it is clear that much research and development are being done to make the handling process more effective.

Chapter 3: Development

In this chapter, an overview of the automated robot vision system is given and it is explained how it will be used in the automated handling system. The hardware components used in the automated robot vision system are discussed and explained how they will be integrated into the robot vision system.

3.1 System overview

As stated in chapter 2, the aim of this study is to develop an automated robot vision system. The system consists of a Cartesian robot and a Machine Vision system. The Cartesian robot should have the ability to move a camera to an optimal position for the Machine Vision system to capture a high quality image of the part. The Machine Vision system will:

- Do quality control
- Calculate the part's position
- Determine the part's orientation

These results will be used by the Cartesian robot to move a gripper to a position to grasp the component and move it to the collection bay.

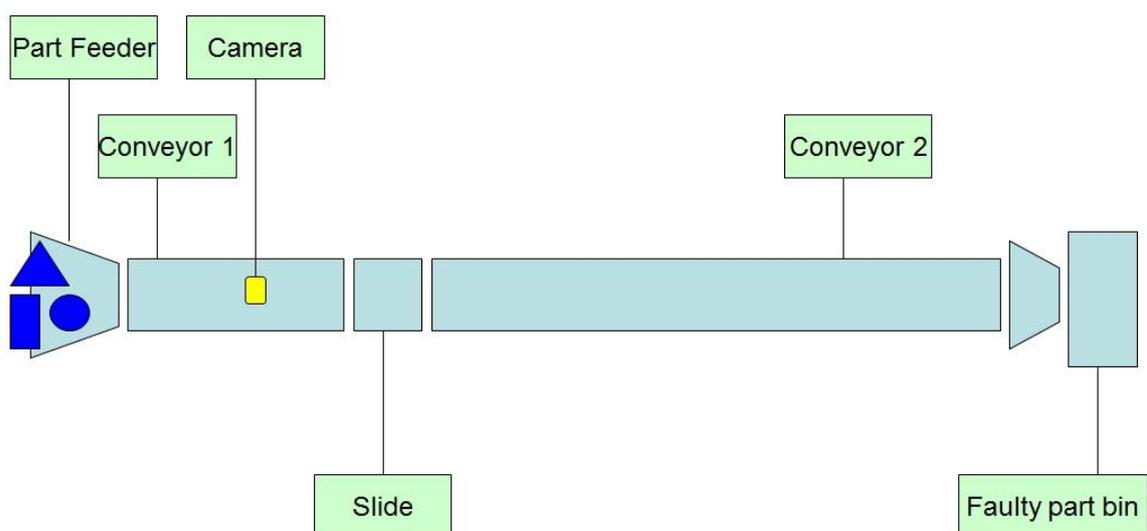


Figure 3.1 Automation system for quality control and sorting of parts

The automated robot vision system is incorporated into a larger automation system as indicated in the layout in Figure 3.1. The aim of the automation system is to do quality assurance and sort parts. The automation system was assembled in different stages with the help of different developers.

The system consists of a part feeder to place parts on the first conveyor. While moving on the first conveyor, the type of part is determined by an existing Machine Vision system. For this system an enclosure was built and it was mounted on top of the conveyor. Two halogen lamps as well as a Basler camera are mounted inside the enclosure. By the use of this enclosure design, the ambient light cannot have any effect on the image captured of the parts traveling on the conveyor. This system was designed by different students. They used a compact vision system (CVS) for Machine Vision processing.

The quality and fault tolerances for this automated handling system were determined by P Williams in her final year project.

From the first conveyor the part slides to the lower second conveyor.

The complete automation system is controlled by a programmable logic controller (PLC). The automated robot vision system is designed to communicate with the automation systems via the PLC.

Outputs from the CVS System is processed by the automation PLC. The conveyor system will react to outputs form the PLC. See paragraph 3.4 for a detailed explanation of the PLC simulator.

3.2 Automated robot vision system

A personal computer (PC) is used as the controller of the automated robot vision system. Figure 3.2 gives a block diagram of how the system is integrated. LabVIEW is used as the software platform and for the communication to the devices connected to the PC.

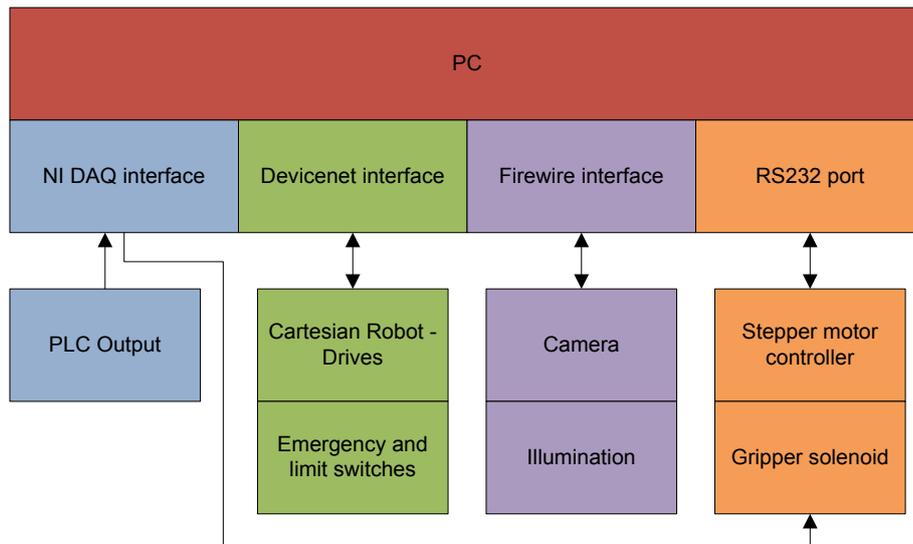


Figure 3.2 System block diagram

3.3 Computer data acquisition

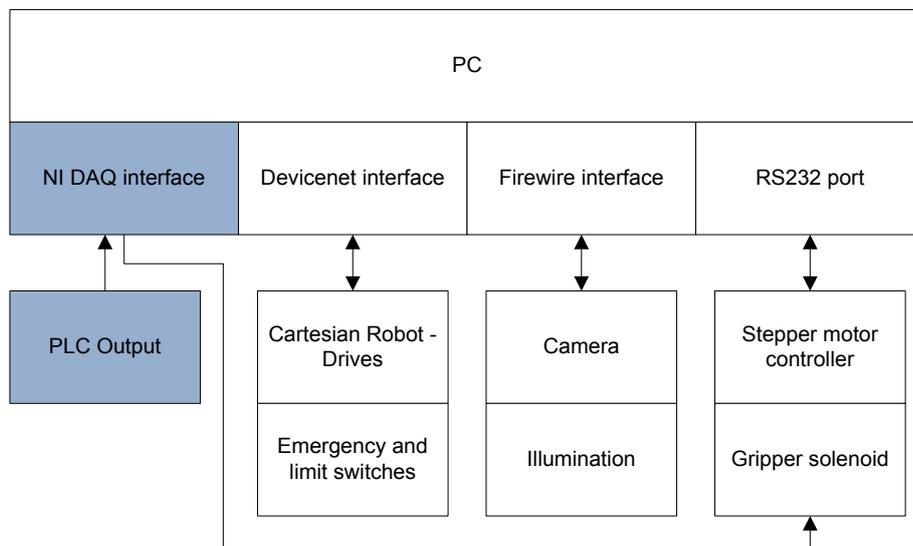


Figure 3.3 Computer data acquisition

The blocks used for data acquisition are highlighted in Figure 3.3. Data acquisition is the process of measuring real-world physical conditions and converting them into digital numerical values [62]. A National Instruments card was fitted in the PCI slot of the PC to enable the PC to do data acquisition.



Figure 3.4 NI PCI 6014 Data Acquisition card [63]



Figure 3.5 NI CB-68LP termination accessories [64]

The PCI 6014 DAQ card as shown in Figure 3.4 is used for digitizing measured voltages and the control of digital data output signals. The NI CB-68LP as shown in Figure 3.5 has 68 screw terminals for easy connection of the signal wires to the PCI 6014.

Two of the digital inputs of the DAQ are used to monitor the PLC simulation unit outputs. These signals will give the appropriate signal to the control program to indicate a new component has arrived on an inspection bay.

A digital output of the DAQ is used to switch the pneumatic valve control unit. This signal is generated by the control program when the gripper should close to grasp a part or open to release the part.

3.4 PLC simulation

The PLC in the main automation system sends a signal to indicate that a component was placed on a inspection bay. To be independent from the operation of the other developers in the automation system, switches are used to simulate the signal received from the PLC. These signals are connected to the DAQ card as shown in Figure 3.6

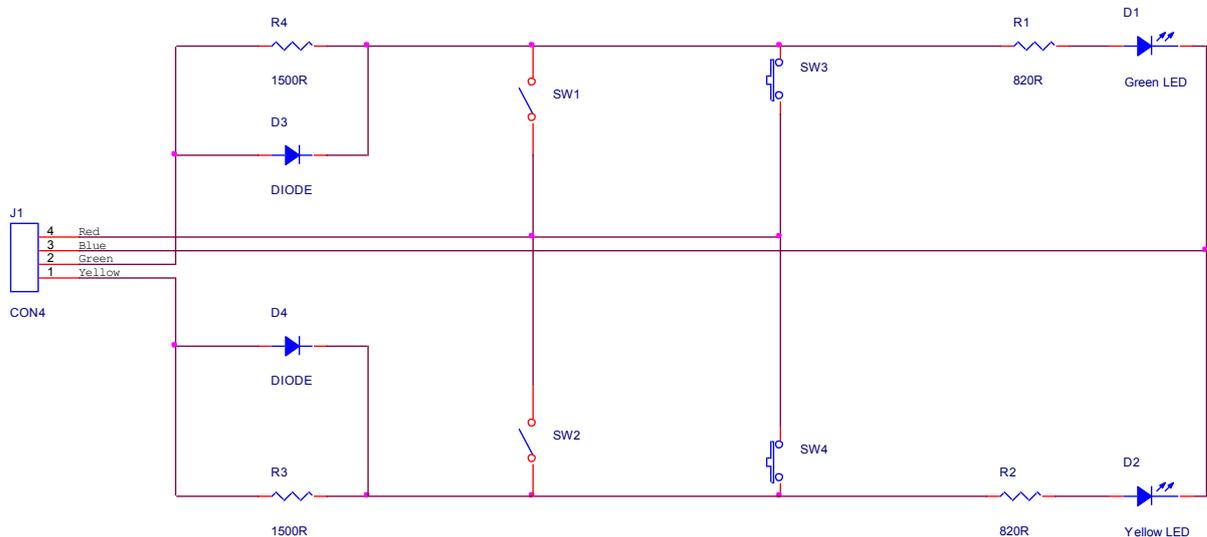


Figure 3.6 Schematic of PLC simulator

Pin 4 is connected to 5V, pin 3 to ground and pin 2 and pin 1 is connected to the digital inputs of the DAQ card. When SW1 or SW3 is closed pin 2 will be made a TTL high state to simulate a part present signal.



Figure 3.7 PLC simulator switch unit

The toggle switches on the bottom of the simulation unit, as indicated in Figure 3.7, were used during the first stage of the simulation software design. One of the toggle switches was switched to the *on* position until the software acknowledged the *on* state. With changes to the program, the push buttons are used to simulate a part present and the state is kept active in software until a software reset signal is received.

3.5 ROTATOR UNIT

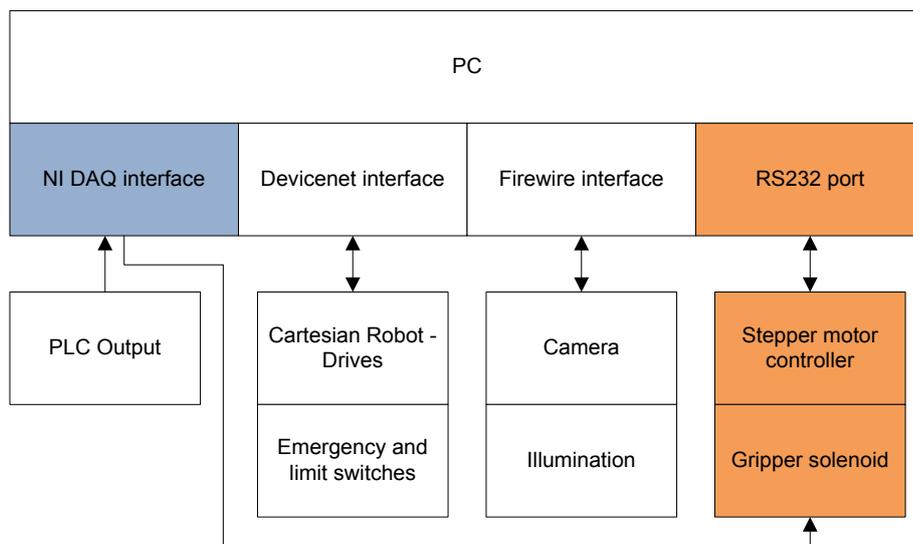


Figure 3.8 Rotator unit

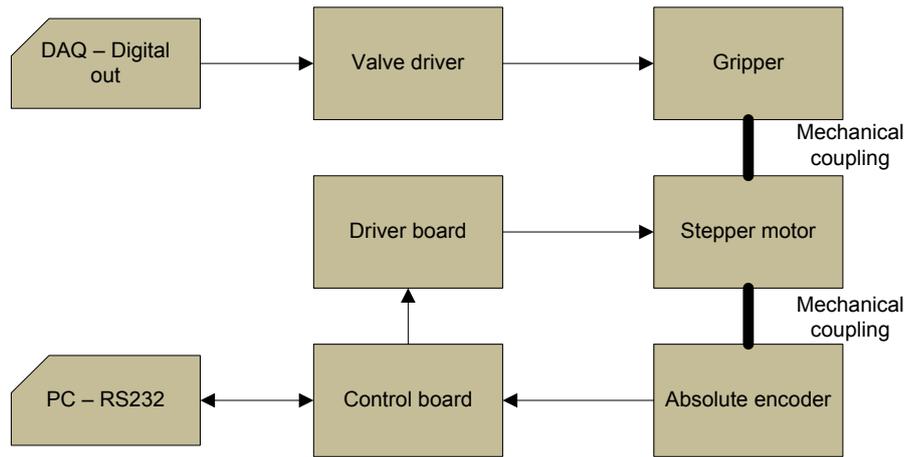


Figure 3.9 Block diagram of rotator unit

The blocks discussed for the rotator unit are highlighted in Figure 3.8. A block diagram of the components used in the rotator unit is shown in Figure 3.9. The unit consists of the gripper, the gripper’s valve driver, a stepper motor, an absolute encoder, a driver board, and a control board. The gripper is mounted on the front shaft of the stepper motor and the encoder is mounted on the rear shaft of the stepper motor. A camera, used with the Machine Vision system, is mounted on the front part of the rotator unit.

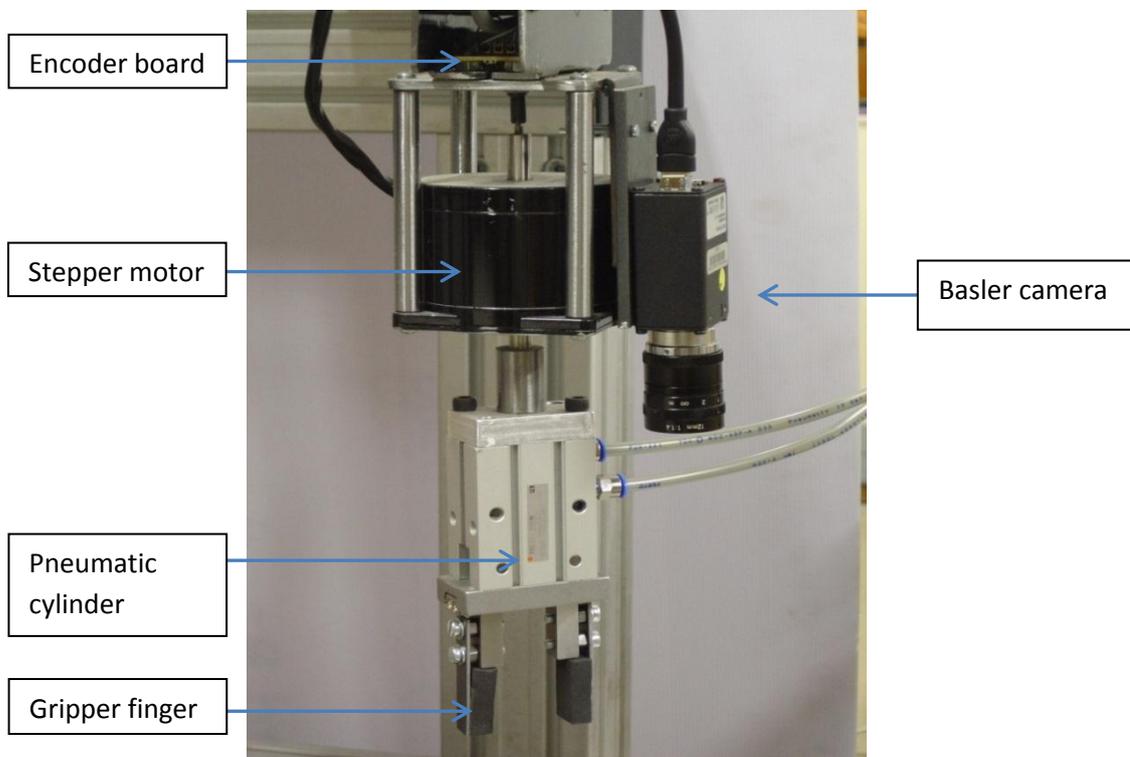


Figure 3.10 Rotator unit and Machine Vision camera

Figure 3.10 is a photo of the rotator unit with the camera mounted on the front.

The Machine Vision system calculates the part's position and orientation. The orientation value is sent through the serial RS232 connection to the rotators control board to adjust the gripper's rotation accordingly. The gripper is positioned by the Cartesian robot over the part and the PC sends a signal through the DAQ card to the valve switch to close the gripper's claws.

3.5.1 Stepper motor

A four-phase hybrid stepper motor from RS Components is used in the system. The motor operates at 3 volt and a current of 2 ampere. See Figure 3.11 for an example of a stepper motor.

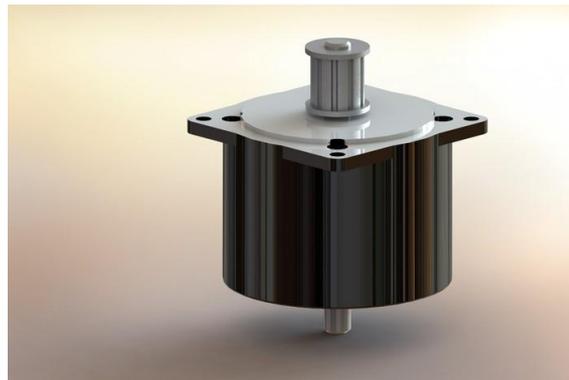


Figure 3.11 Hybrid stepper motor [65]

The stepper motor used is a four-phase hybrid stepper motor capable of delivering much higher working torques and stepping rates than a permanent magnet type. This stepper motor can also maintain a high detent torque, which is particularly important for this project as a gearbox was not implemented [68].

When correctly loaded and driven, this motor produces discrete steps at a 1.8 degree step angle. The number of steps and speed of rotation are determined by the number of pulses and frequency from the driver board. This provides an ideal method for both speed and position control.

The stepper motor has a rear extension shaft to enable the attachment of a feedback device. The pneumatic cylinder is coupled to the front shaft of the motor and the position encoder is connected on the rear shaft.

3.5.2 Gripper

The pneumatic cylinder used in the system is a double-acting, two finger cylinder from SMC (see Figure 3.12). The pneumatic cylinder has only an open or closed state with a stroke distance of 14 mm. The external gripping force is 65 N per finger at a pressure of 0.5 MPa and a gripping point of 20 mm. The operating pressure of these cylinders is between 0.1 and 0.7 MPa. The maximum operating frequency of the cylinder is 180 cycles per minute.



Figure 3.12 SMC cylinder [66];[16]

A Festo two-way pneumatic valve, as shown in Figure 3.13, is used to control the cylinder. The valve is electrically actuated by a 24 volt dc solenoid coil.



Figure 3.13 Festo pneumatic valve [67]

The controlling software was designed in LabVIEW. The software design is simple and has two states, *on* or *off*. The software communicates with a National Instruments data acquisition (DAQ) card and the software controls the pneumatic valve driver board (see Figure 3.14) using the outputs of the DAQ card.

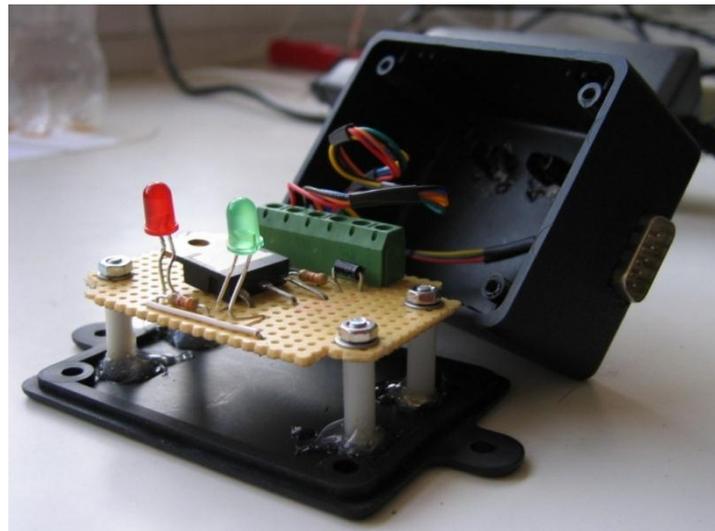


Figure 3.14 Pneumatic valve driver board

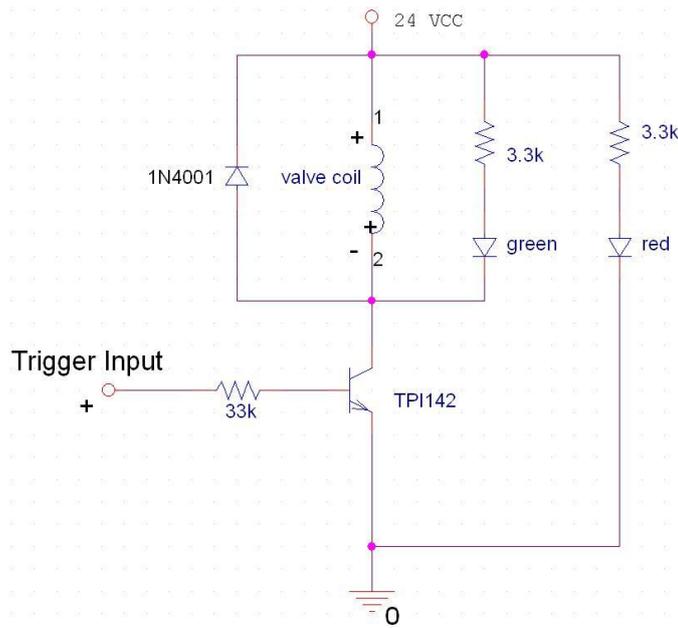


Figure 3.15 Schematic representation of pneumatic valve driver board

The circuit in Figure 3.15 is a current amplifier used to activate the pneumatic valve's solenoid. The red LED indicates that power is supplied to the circuit and the green LED illuminates when the valve is energized.

This board uses a Darlington transistor for better current gain. The solenoid switching the valve is energized by 24VDC at 188mA. By using a Darlington transistor circuit with a gain of 500 the switching current from the DAQ will be 0.376mA, which is well below the maximum source current of 5mA.

To use the pneumatic cylinder as a gripper, fingers had to be designed to enable a part to be properly grasped. The first attempt was to make universal fingers to grasp a wide variety of part shapes and sizes. To accomplish this goal, the fingers needed to have a large stroke distance. The part of the fingers that would grasp the part was designed with a curved shape. Fingers as shown in Figure 3.14 were made and fitted on the pneumatic cylinder.

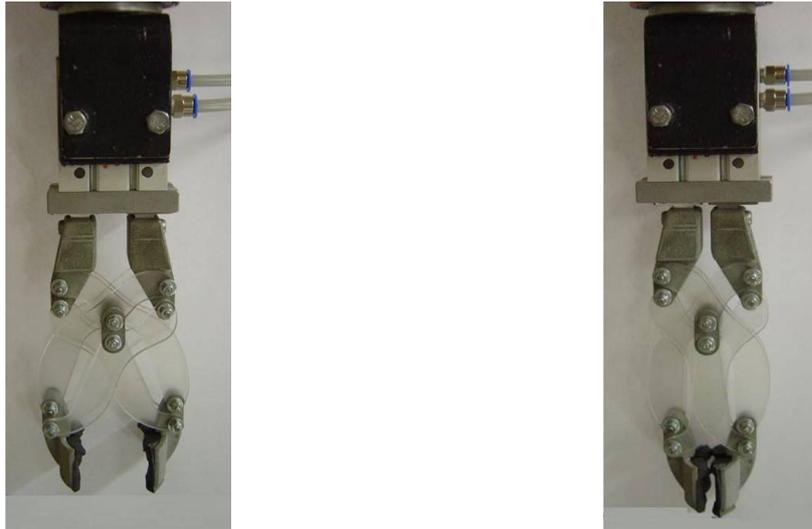


Figure 3.16 Downwards movement of the fingers when the gripper closes

When the fingers were positioned over a part and the gripper was closed, the fingers' curve mostly did not match the shape of the part. This led to only a small part of the fingers being in contact with the part. A soft material was applied to the inside of the gripper fingers to increase the coefficient of friction between the gripper and part and still allow the force to be low enough not to damage the part.

When this design was tested, it was found that the mechanism needed a lot of force just to open or close the gripper. When a part was picked up, there was not enough force to keep the part in the fingers while moving the part to counter the acceleration and motion caused by the movement.

Another challenge of the finger design as in Figure 3.16 is that the fingers move downwards when the gripper is closed. The gripper will stop closing depending on the part's size and the downwards movement will also stop depending on the part's size. When a small part is picked up, the gripper should not move as low as with a smaller part. This needed to be calculated by the Machine Vision system and then compensated for in the robot's software design.

The focus of this project was to use and integrate the gripper and not the mechanical design of the gripper. This led to the search for a design - especially for the parts that will be handled in this system.

The parts' dimensions that needed to be handled in this system were noted and it was realised that both parts had the same width. The parts' sides are parallel to

each other. This made the design of the gripper fingers simpler. The gripper's fingers as shown in Figure 3.17 works very well to grasp the specific part.



Figure 3.17 Parallel fingers designed for the pneumatic cylinder

The two types of blocks used in the system is shown in Figure 3.18. The one block is square and the other is rectangular. Fingers were designed for the cylinder to enable the gripper to grip the blocks.

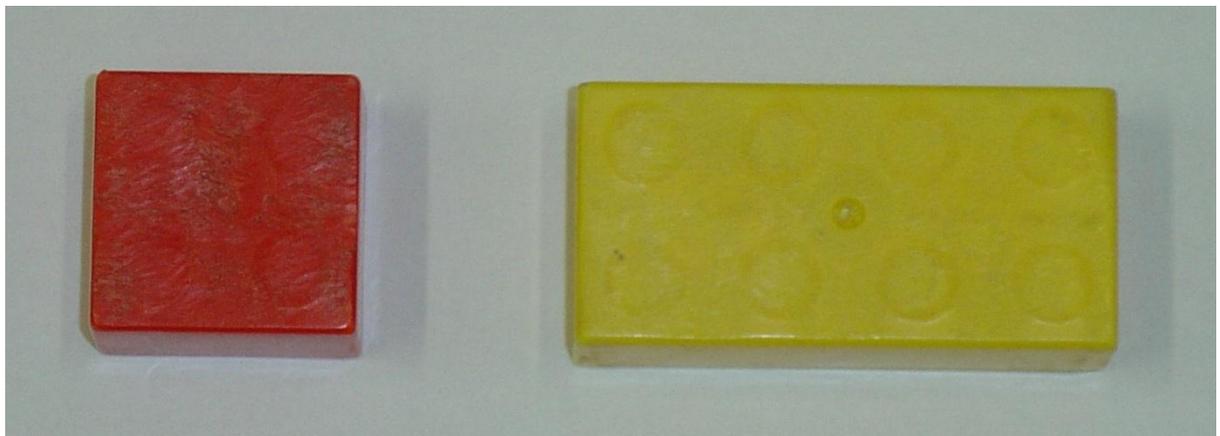


Figure 3.18 Blocks used in the automation system

3.5.3 Encoder

A digital absolute encoder from Bourns, as shown in Figure 3.19, is coupled to the rear shaft of the stepper motor. A special feature of this encoder is that it

assigns a unique, digitally encoded signal to each increment, which prevents erroneous readings. For example, if a power failure or transient malfunction occurs, the position can be measured when the power is restored without moving back to a reference position, as would be required with incremental encoders.



Figure 3.19 Absolute encoder [69]

Unlike a traditional potentiometer which requires an A/D converter, the encoder provides an absolute digital output. The absolute digital output simplifies the electronic circuit by allowing the micro-processor to be directly linked to the encoder.

By using this principle, the absolute position of the motor is always known. Should the motor slip a step, for example, the position data could be read from the encoder and the fault condition could be rectified by the controller.

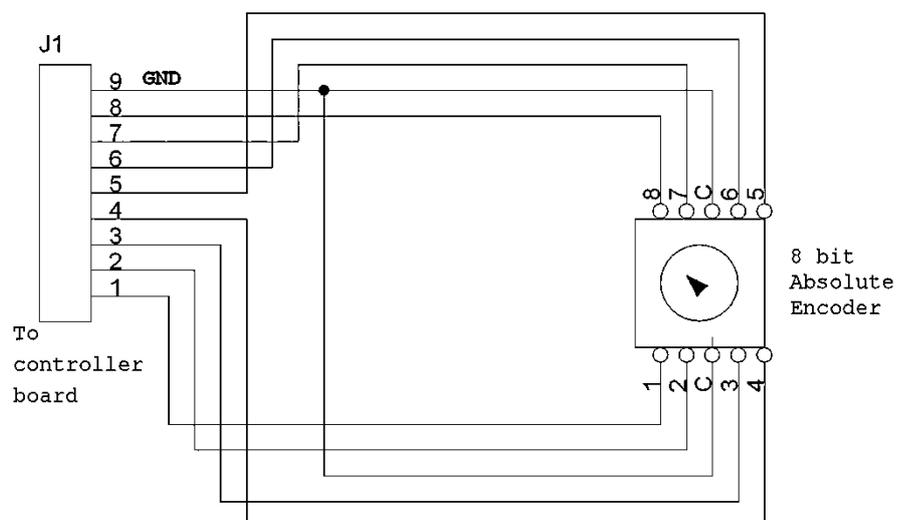


Figure 3.20 Schematic diagram of the encoder board

Figure 3.20 is the schematic diagram of the absolute encoder board with connector J1 connected to CON2 of the stepper motor controller board.

3.5.4 Stepper motor driver

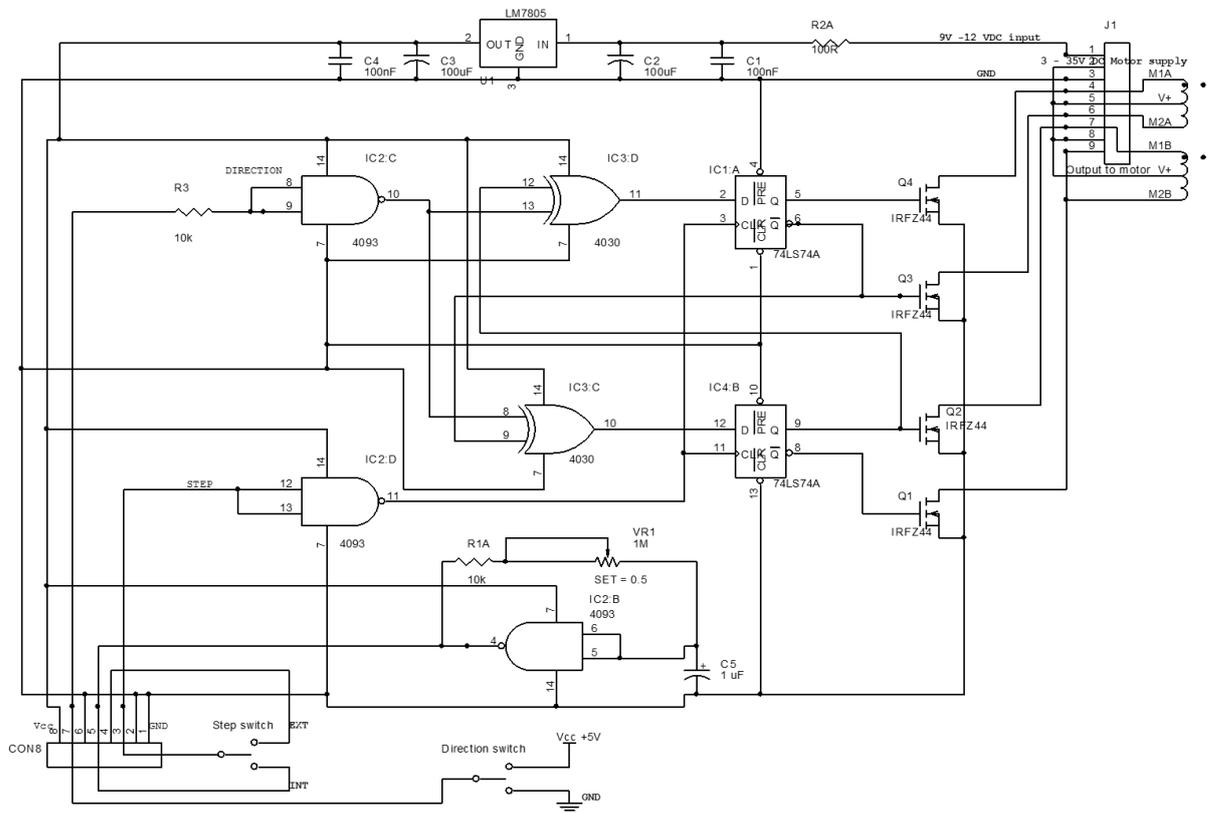


Figure 3.21 Stepper motor driver board

Examples of stepper motor driver schematics were found on the internet and a circuit was built accordingly, as in Figure 3.21. The stepper motor driver board consists mainly of control logic and high current drivers. The control logic uses CMOS logic gates. The logic gate circuit supplies the MOSFET drivers with the appropriate pulse train. By using the on-board oscillator, the driver board could be used to manually control the stepper motor as well. Two controlling signals are supplied to the driver board. The first determines the stepping direction and the other is the step signal. The motor will step once each time this step signal is pulsed. The pulse signals must have a 50% duty cycle. CON8 of the driver board is connected to CON3 of the stepper motor controller board to receive power for the logic circuit and the step and step direction signals.

3.5.5 Stepper motor controller board

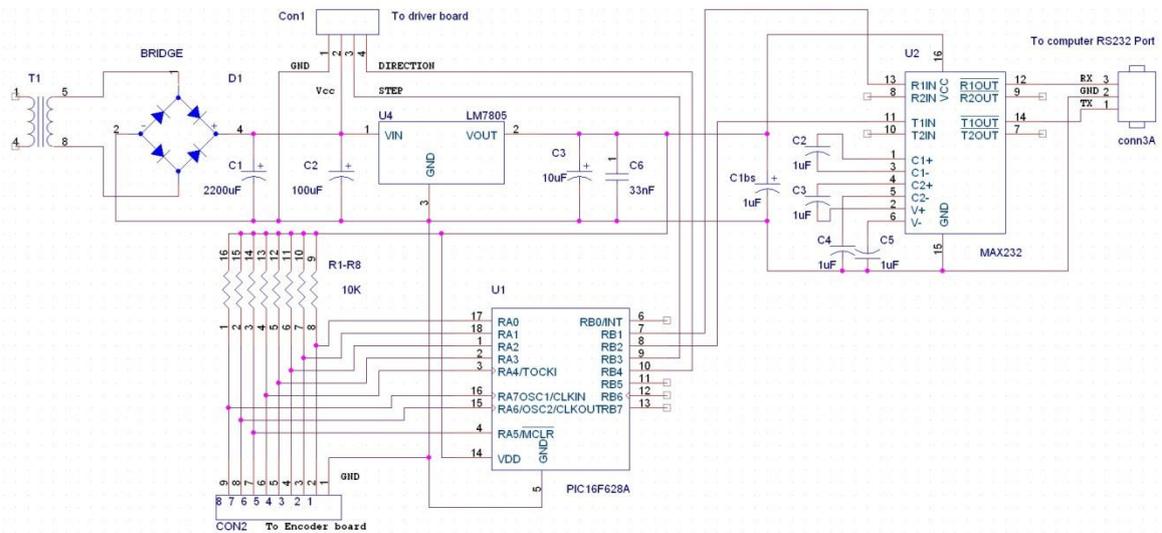


Figure 3.22 Stepper motor controller board

A stepper motor controller board which consists of a microcontroller and a TTL to RS232 converter for communication to a PC was designed as shown in Figure 3.22.

The function of the board is to receive the parts orientation data from the PC, read the data from the absolute encoder and through the use of the driver board, step the motor to the position as given by the PC. The microcontroller firmware used in this controller board was developed in the C programming language.

The parts angle data received from the PC are converted by the microcontroller to a usable format and compared to the data read from the absolute encoder. The direction and the amount of steps are then calculated and the driver board is pulsed to synchronise the gripper's angle to the data received from the PC.

The real-time position of the motor is read at regular intervals from the absolute encoder. Should it be different from the last position received from the PC, the controller board will calculate the direction and amount of steps to rectify this error and will pulse the driver board without any further commands from the PC.

3.6 Robot

Figure 3.23 highlights the blocks that will be discussed for the robot. A Cartesian robot from Bosch Rexroth was used in this study.

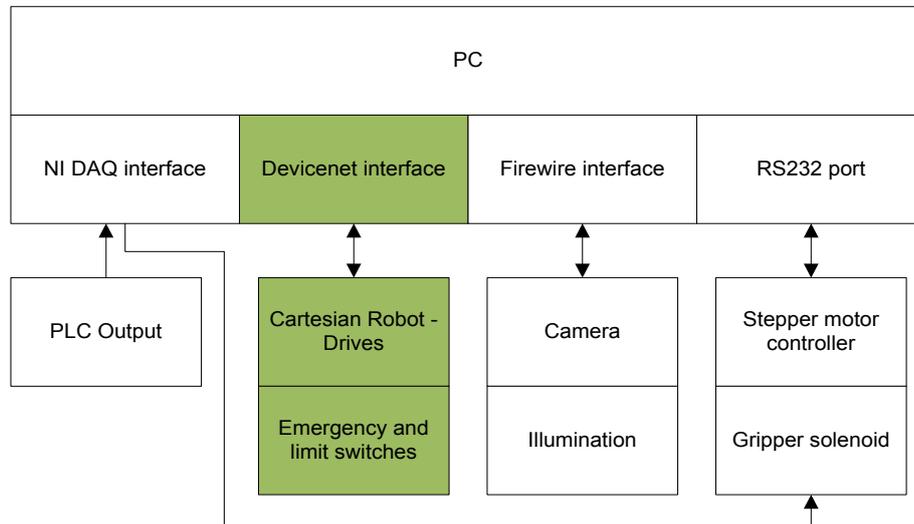


Figure 3.23 Robot

These systems have been proven to provide significant cost- and time-savings due to dramatic reductions in planning and assembly stages [70].

This was the first robot system bought in the School of Electrical and Computer Systems Engineering at the CUT. This system was a cheaper alternative than a six-axis robot like the Kuka and was the only robot available to use for the project.

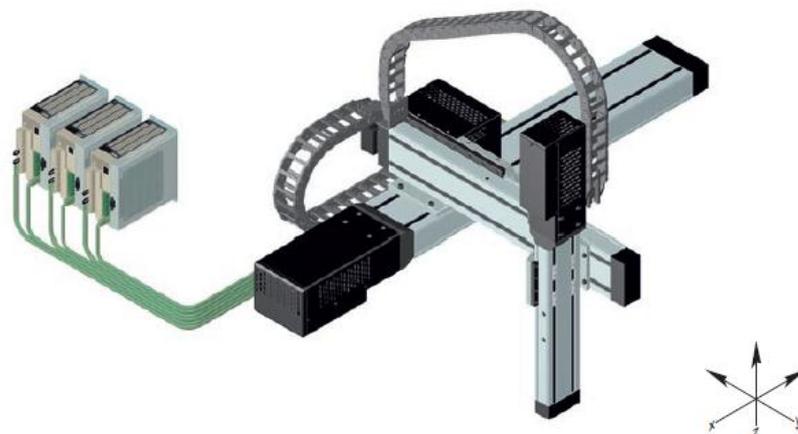


Figure 3.24 Cartesian Motion System [71]

The Cartesian robot consists of three linear drives with a drive controller for each, as shown in Figure 3.24 [71]

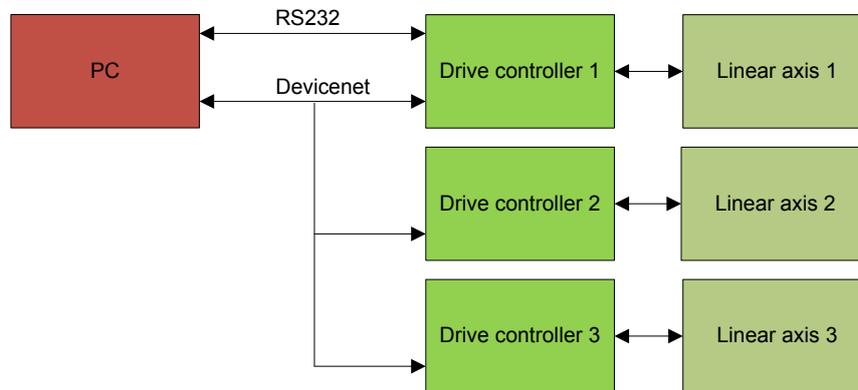


Figure 3.25 Communication interface to the ECODRIVE Cs

A drive can be connected through an RS232 interface to a computer and DriveTop software can then be used for commissioning and maintenance of the drive. As indicated in Figure 3.25, only one drive can be connected through the RS232 interface to the computer at a time.

A Devicenet card from National Instruments is installed in the PC. The Devicenet interface is connected between the PC and the three drives. Real-time data can be transmitted with the Devicenet interface to all three drives. This data is used to initiate and control the drives' position and speed of travel.

Each linear axis is equipped with an AC servomotor, an absolute rotary encoder for continuous position feedback and an integrated holding brake. An ECODRIVE Cs AC servo drive (ECODRIVE Cs) is used to compare the signal from the rotary encoder with the target value supplied by the PC to control each axis's position [71]. The ECODRIVE Cs used in this project is fitted with a DeviceNet communication module for the interface to the PC.

Figure 3.26 shows the connection diagram of the Cartesian robot motors, encoders, safety system and supply to the drives. The supply voltage is connected directly to the control voltage of the drive controllers to ensure that a permanent supply is available to the controlling devices of the drive. The supply voltage is connected to the motor driver circuit input of the drive controllers

through a magnetic contactor to enable the power to be cut from the motors during an emergency stop.

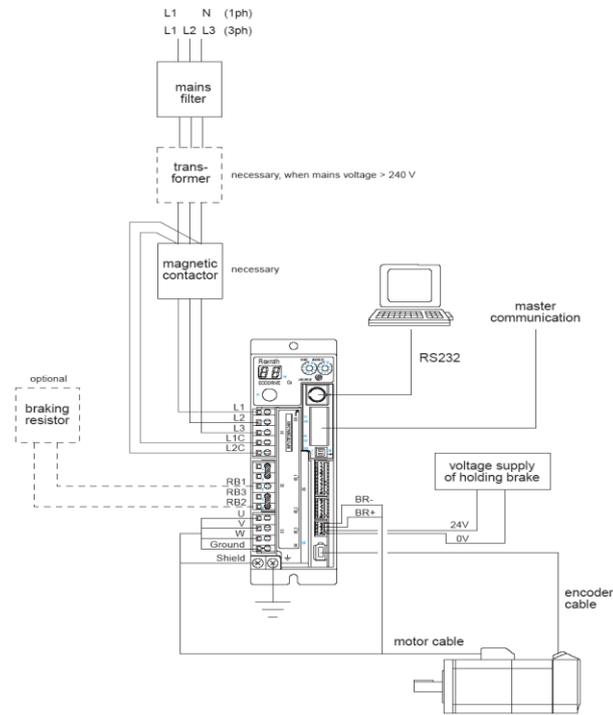


Figure 3.26 Schematic representation of the connection diagram for the Bosch Rexroth ECODRIVE Cs Drive [72]

Additional limit switches are mounted at the ends of each drive to stop the robot when a drive is driven beyond a safe working distance. Figure 3.27 indicates how these switches and the emergency switch are electrically connected in series. Should any one of the switches be activated, the power to the motors will be disconnected, by deactivating the contactor at the motor input while power is maintained to the control voltage of the drive controllers.

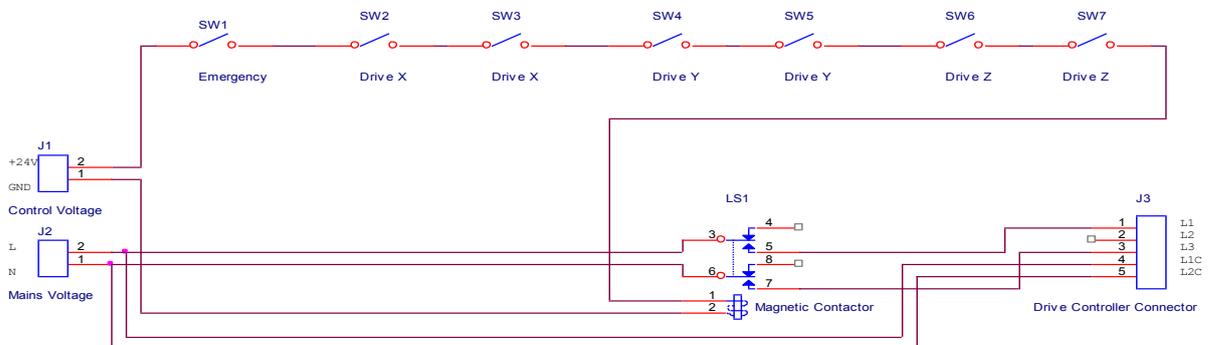


Figure 3.27 Schematic diagram of the limit and emergency switches

3.7 Machine Vision

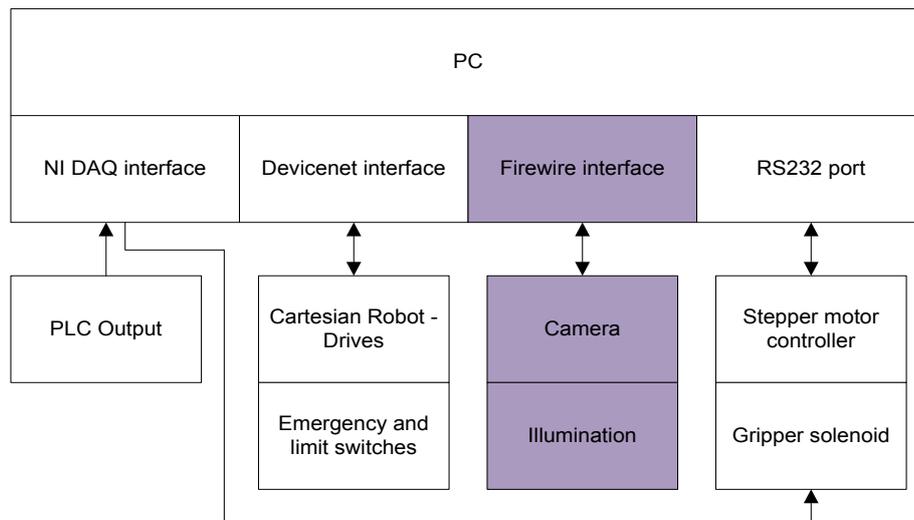


Figure 3.28 Machine Vision

The blocks of interest for the Machine Vision system are highlighted in Figure 3.28.

3.7.1 Illumination

The goal of the imaging subsystem is to acquire an image with high contrast between background (noise) information and the object features (signal) [4].

The different light sources and lighting methods experimented with are: frontlighting, diffused frontlighting, a ring LED light and backlighting.

3.7.1.1 Frontlighting

With this method, two 50W Halogen lamps were placed on the sides of the camera at an angle so as to shine directly on the part under inspection on the conveyor belt. The conveyor belt and the components are reflective and it was challenging to place the lights at the correct positions to minimise reflections. Another challenge was the shadows of the component and the changing ambient light in the laboratory.

3.7.1.2 LED Ring light

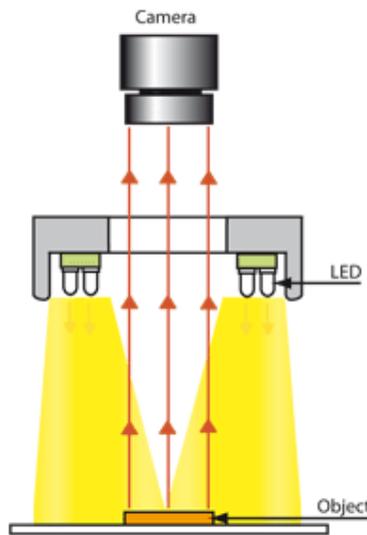


Figure 3.29 Typical configuration of a ring light [73]

Figure 3.29 shows a typical setup of a ring light. A direct type LED ring light was tested in search of shadow-free illumination as a ring light encircles the camera lens and produces even illumination. With this method there were still a circular reflection from the conveyor belt and the changes in ambient light was a big challenge.

3.7.1.3 Backlighting

Backlighting is used whenever feasible, because it provides the greatest scene contrast and highest lighting efficiency of any lighting technique [4]. The term “diffuse” refers to illumination sources that have their radiant energy emitting from a translucent material. Although the light source may be highly directional, the light radiation pattern resulting from the diffusing surface is uniform.

Figure 3.30 shows the principle of backlighting. Diffuse backlighting places the target between the camera’s sensing lens and the light source. By illuminating the target from the rear with respect to the lens, the background appears uniformly white and the target is silhouetted. The use of backlighting effectively produces a black and white (binary) image directly [4].

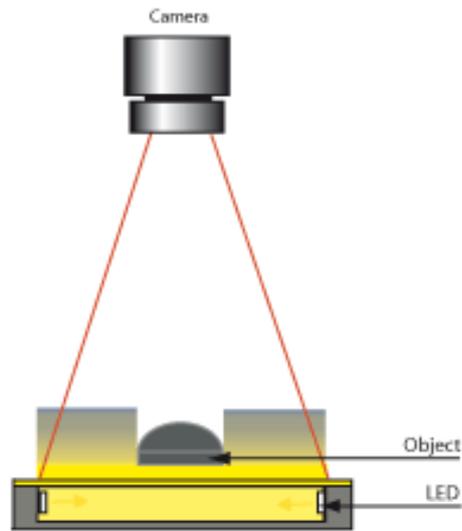


Figure 3.30 Diffused backlighting [73]

3.7.2 Machine Vision Camera



Figure 3.31 Basler A601f camera [74]

The Basler A601f camera, as in Figure 3.31, makes use of a firewire (IEEE1394) interface. By the use of the correct software driver it is hot pluggable to allow the camera to be connected or removed from the computer with the software automatically recognizing the change. This camera is of industrial standard and the full VGA resolution was used. The camera operates from a single supply voltage through the 6 pin firewire interface connected between the camera and the PC. According to specifications it can be used in 8bit output mode at up to 60fps and in 16bit mode up to 30fps. In this project a lower frame rate is sufficient as the part is not moving while the image is being captured. The firewire cable

needed to be long enough for the camera to be mounted on the rotator and be fed through the cable housing on the Cartesian robot to the PC. The IEEE1394 standard limits the maximum cable length to 4.5m, which was just long enough for the traveling distances of the Cartesian axes [67].

3.8 Adding of inspection bays

As discussed in chapter 5, the conveyor's surface is reflective and this made it difficult to capture high quality images. The solutions found were to install two inspection bays at two exit points as shown in the block diagram in Figure 3.32 and the photo in Figure 3.33. The second inspection bay was incorporated as a buffer to allow a higher flow rate of parts through the system.

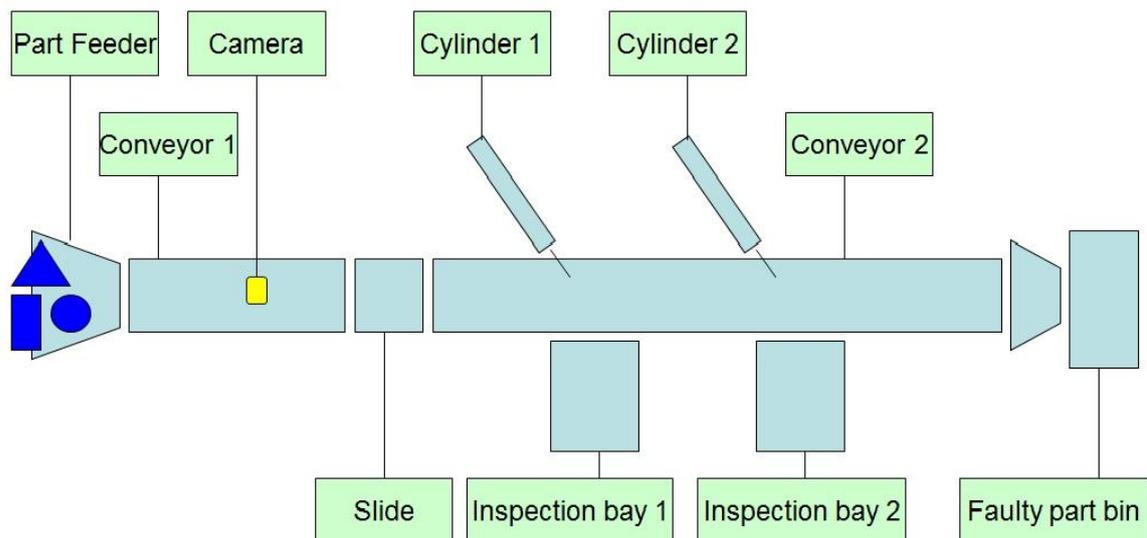


Figure 3.32 Automation system with the added inspection bays

Proximity sensors were mounted on Conveyor 2 to detect objects on the conveyor belt. Two swing arms, each connected to a pneumatic cylinder, are also mounted on the second conveyor. The proximity sensors are used for the correct timing in order to activate a swing arm to push a part from the conveyor onto the appropriate inspection bay.

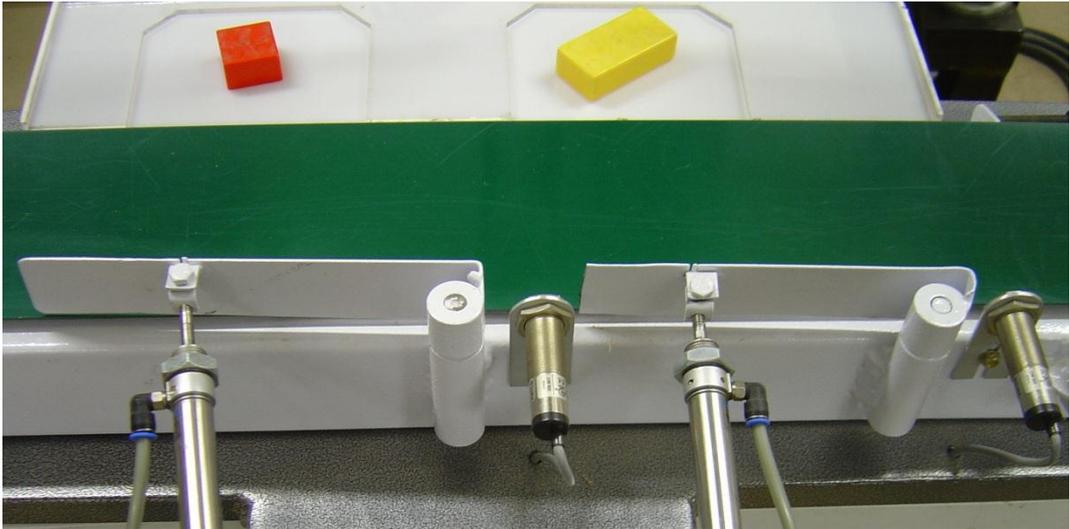


Figure 3.33 Inspection bays mounted on the conveyor assembly

3.9 Summary

In this chapter, components, technologies and techniques to consider for this study were discussed.

Chapter 4: System integration

In this chapter, the operational steps of the automated robot vision system are described. The design of LabVIEW modules to manipulate the input data and to control the hardware, as well as the integration of these modules to function as described are subsequently discussed thereafter. The setup of the hardware to operate efficiently in the system is discussed.

4.1 Operational Process

The flow diagram in Figure 4.1 is an illustration of the step-by-step operational process of the automated robot vision system. On startup, the control program initializes the Cartesian robot, the vision system and the gripper.

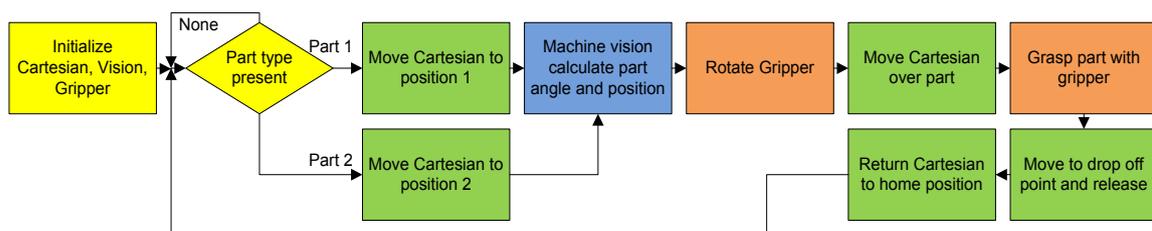


Figure 4.1 Process flow diagram

The control program will go into a loop polling the output lines from the PLC to determine if a part was sent to the inspection bays.

When the PLC indicates a part was sent to the inspection bay, the Cartesian robot will be moved to camera position 1 for inspection bay 1 or camera position 2 for inspection bay 2. The Machine Vision system will then take a snapshot of the part under inspection. Image processing will be done on the captured image to determine the part's position, coordinates and angle.

The gripper is rotated to the angle as calculated by the Machine Vision system and then the robot positions the gripper's claws over the part.

The gripper is closed to grasp the part and then the robot moves the part to the drop off point. The gripper then releases the part and the robot returns to the home position.

These steps are all controlled by a PC fitted with the IO and interfacing cards to communicate to the hardware.

The software design was done modularly with LabVIEW to enable the separate development and testing of the different parts of the control program. When a LabVIEW module is tested and operates as expected, it can either be copied or combined into another program or a VI can be made of that program.

4.2 Rotator

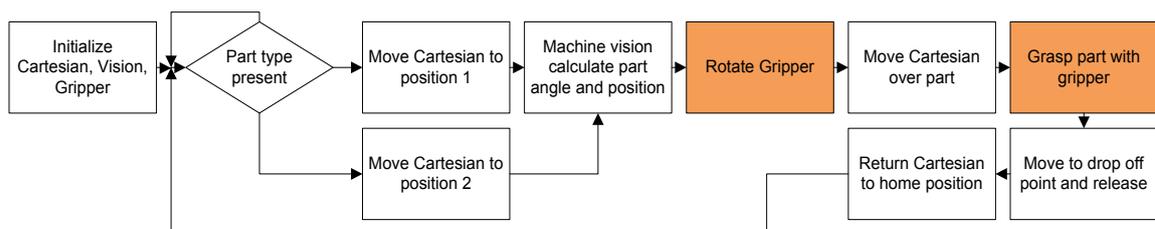


Figure 4.2 Steps of the flow diagram where the Rotator is discussed

The blocks discussed for the steps of the rotator are highlighted in Figure 4.2.

The first LabVIEW module that was developed, was for the PC communication with the rotator unit. The front panel is shown in Figure 4.3 where the RS232 initialization values and a rotational value for the rotator is set.

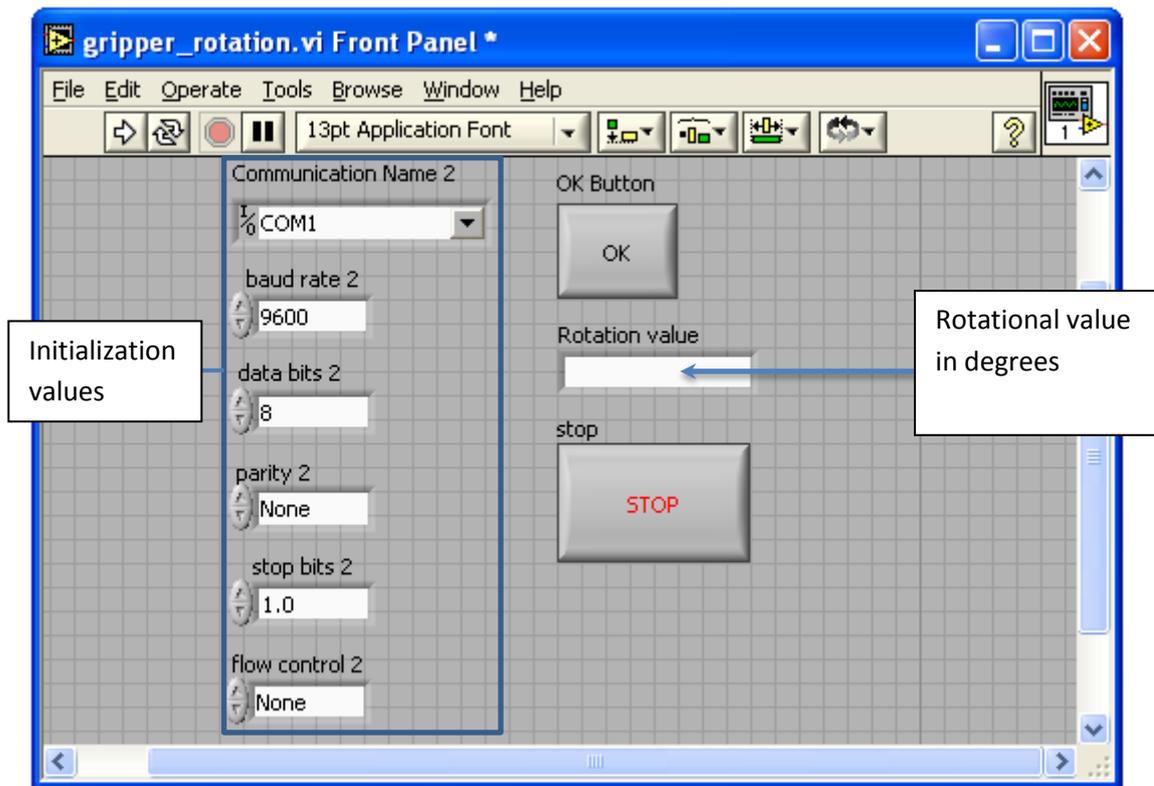


Figure 4.3 LabVIEW Front panel of rotator control program

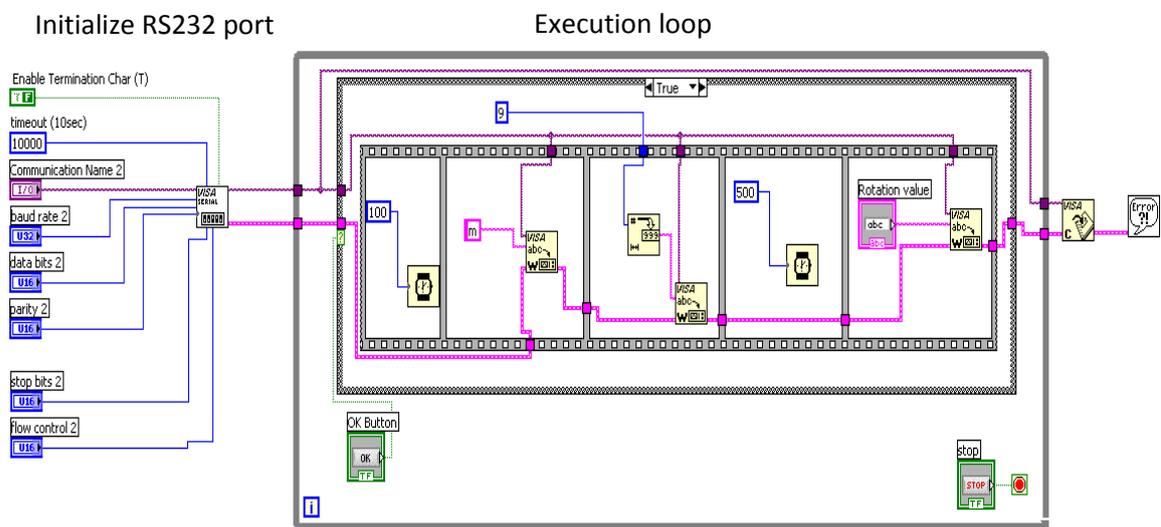


Figure 4.4 LabVIEW Block Diagram of rotator control program

The initialization for the PC's RS232 port is done once. After that, the program runs in a loop as indicated in Figure 4.4. During each loop execution the value entered in the rotational value box of the LabVIEW program's front panel is sent through the RS232 port to the controller.

As mentioned in chapter 2, the device at the end of the robot that interacts with the environment is called an end effector. The photo of the end effector on the Cartesian robot is shown in Figure 3.10. The unit consists of the stepper motor with encoder mounted on the back shaft and the gripper mounted on the front shaft. The camera is mounted on the front of the end effector. The planned steps are to move the camera over the region of interest and to capture the image of the part. The Machine Vision will calculate the position and angle of the part and give this data to the Cartesian robot. The robot will move the gripper to the position calculated by the Machine Vision system to grasp the part and move the part to the inspection area.

As can be seen in Figure 3.10, there will be a rotational area where the gripper's pneumatic pipes obstruct the camera's view of the part. Another challenge was the pipe's high resistance to the rotation of the gripper compared to the strength of the stepper motor. As the gripper's fingers are symmetrical, it is possible to use the gripper in the 180 degree area where the pneumatic pipes will not obstruct the camera's view. By experimenting with different routes for the pneumatic pipes, a route was found where the pneumatic pipes had the lowest resistance to the rotational movement.

4.3 Cartesian robot

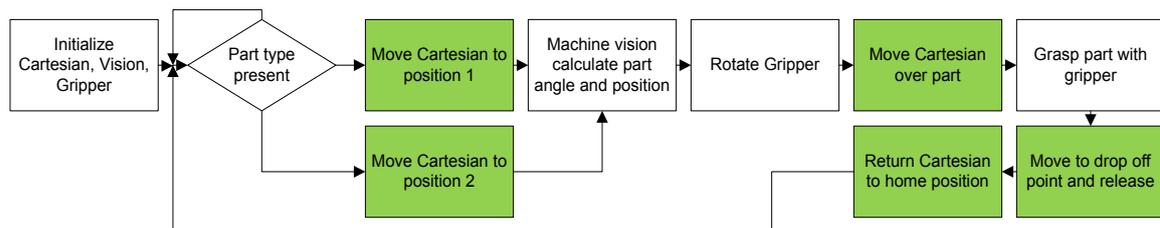


Figure 4.5 Steps of the flow diagram where the Cartesian robot is discussed

The steps of interest for the discussion of the Cartesian robot are given in Figure 4.5.

An exchange student, Florian König, helped to develop the control program for the Bosch Rexroth Cartesian robot.

Different programs were written to test the robot and find a suitable configuration to satisfy the requirements of the project. For this project, the aim of the robot is to move to different position coordinates as determined by the control program. For this purpose, the position control configuration was found to be the best option, because the only variables needed from the control program are position and speed.

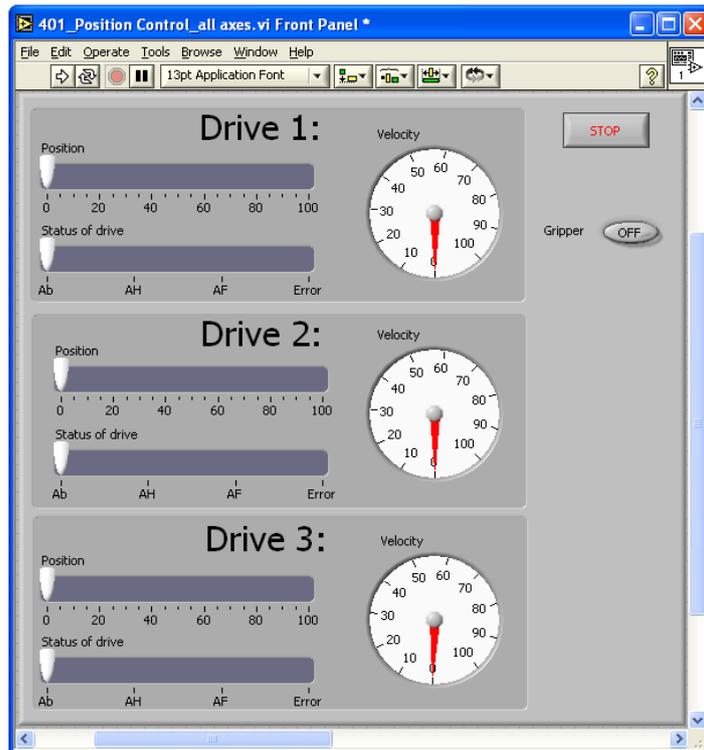


Figure 4.6 LabVIEW Front Panel for the control of the Cartesian robot

The front panel of the position control program is shown in Figure 4.6. On this panel the robot's initialization, speed and position values are set. In this program, the gripper's valve control was also incorporated.

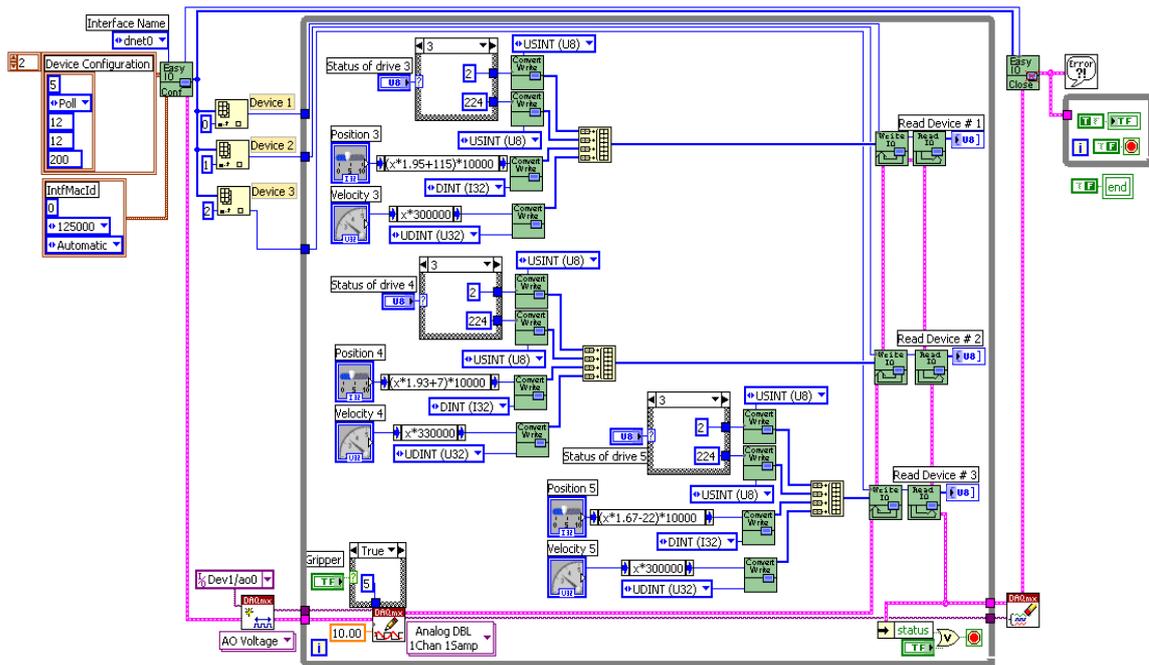


Figure 4.7 LabVIEW Block diagram for the control of the Cartesian robot

The block diagram shown in Figure 4.7 is the section of the program where the Devicenet and DAQ interface cards are set up. After the initial setup, commands are sent through the Devicenet bus to the three EcoDrives for their initialization. From there, the program runs in a loop where the front panel controls are read and those values are sent through the Devicenet bus to the EcoDrives.

This program enables a user to move the robot to a position as entered on the front panel and to open or close the gripper's claws by the activation of the gripper button on the front panel. This program is very useful for the manual testing of the robot movements and the gripper's grasping action.

During the testing phase, the robot was moved to position the gripper over the part. The gripper's claws were closed to grasp the part. The robot lifted the gripper and moved the part to the drop-off point and released the part. One should work cautiously during the manual control of the Cartesian robot and move one axis at a time using the position control program.

The PLC input simulation was incorporated by placing parts in a specific region, moving the robot along a safe path and recording coordinates on the path to create a point-to-point program [76]. Depending on the PLC switch output read

by the DAQ, one of the two paths was followed by applying the point coordinate values to the position control program. A delay is used to give the robot enough time to move to a coordinate. With every execution of the program loop, the next coordinate value is sent to the Ecodrive controllers and the robot is moved in steps through the path. With this setup, the part had to be at the same position and angle as the part's position and angle could not be measured yet.

4.4 Machine Vision

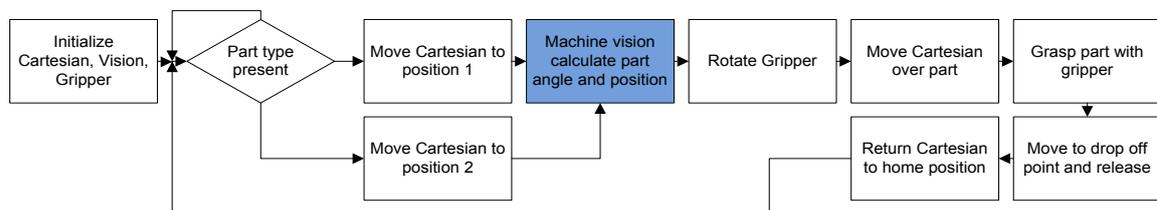


Figure 4.8 Steps of the flow diagram where Machine Vision is discussed

The step of the automated robot vision system that will perform Machine Vision is highlighted in Figure 4.8. The Machine Vision system determine the part's position and orientation.

4.4.1 Camera lens

For the camera to capture a focused image of the part under inspection, the camera lens must be positioned at the correct height from the part. This height is known as the working distance (see Figure 4.9) and was calculated by using the specifications of the camera's sensor, the lens and the inspection bay's dimensions.

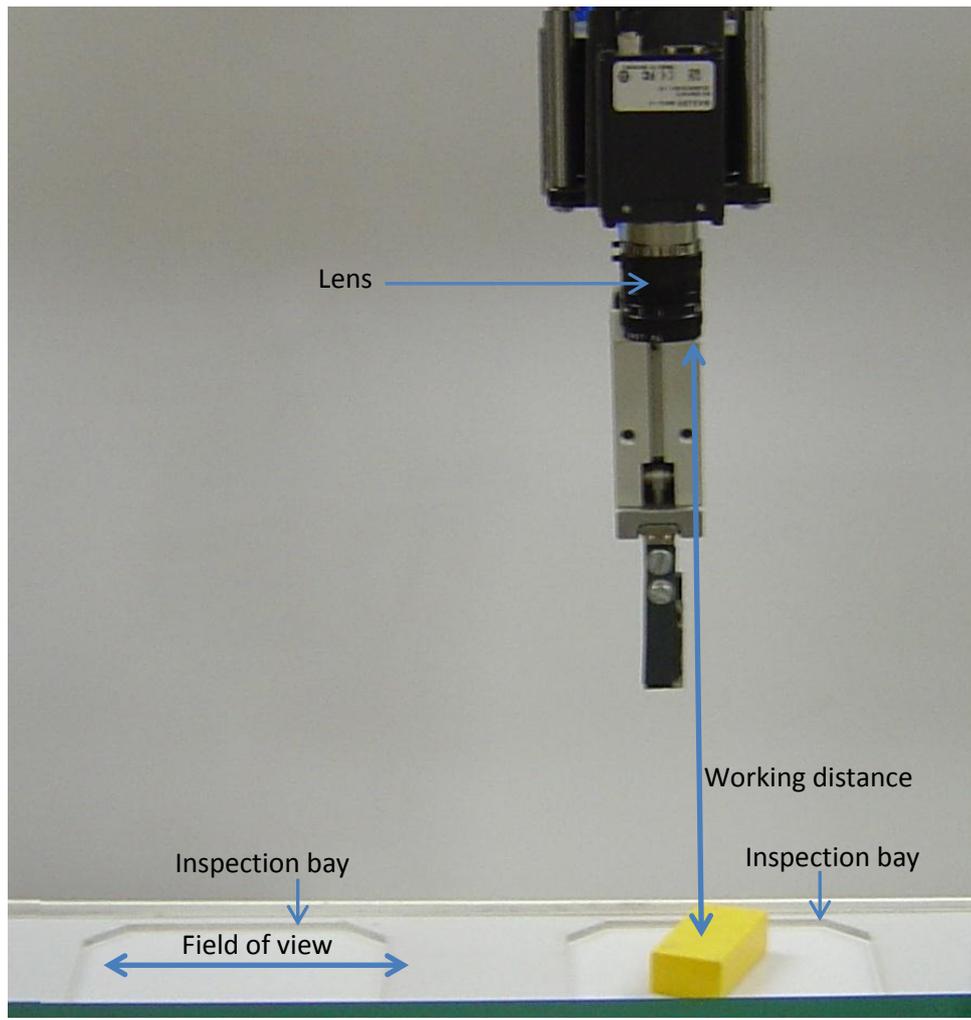


Figure 4.9 Camera working distance and field of view

The lens used in the system has a focal length of 12mm and the maximum aperture ratio is 1:1.4.

The Basler camera makes use of a (656 pixel X 491 pixel) 8mm CMOS sensor. The sensor length and width can be calculated as follows:

$$X = 656 \text{ pixels} \times 9.9\mu\text{m per pixels} = 6.494\text{mm}$$

$$Y = 491 \text{ pixels} \times 9.9\mu\text{m per pixels} = 4.861\text{mm}$$

A clear Perspex piece was cut and placed on the lighting box to restrict the inspection bays to a width of 130mm. The 130mm width of the inspection bay is used as the value for field of view.

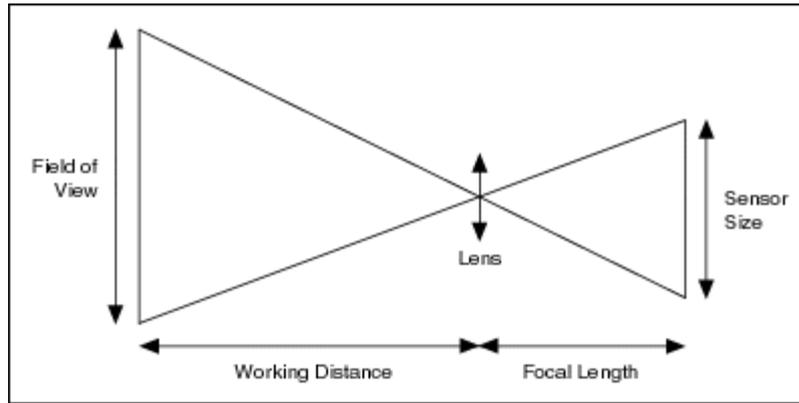


Figure 4.10 Calculating working distance [76]

The working distance (see Figure 4.10) was then calculated by the following formulae:

$$\text{focal length} = (\text{sensor size} \times \text{working distance}) / \text{field of view} [30]$$

$$\text{Working distance} = (12 \times 130) / 6.494 = 240\text{mm}$$

From the calculations it can be seen that the distance from the front of the lens to the part under inspection should be 240mm.

4.4.2 Machine Vision setup

National Instruments Measurement and Automation (MAX) explorer can be used to view the devices connected to the PC. MAX was used to setup the Basler camera's gain, brightness and exposure time. By using MAX it is very easy to view the video stream from the Basler camera while other experimentation or troubleshooting is done. In this study it was intensely used with the illumination setup and experimentation as the gain and brightness had to be adjusted for the different types of illumination setups. MAX was used in Figure 4.11 to take a snapshot of the rectangular part during the illumination setup.

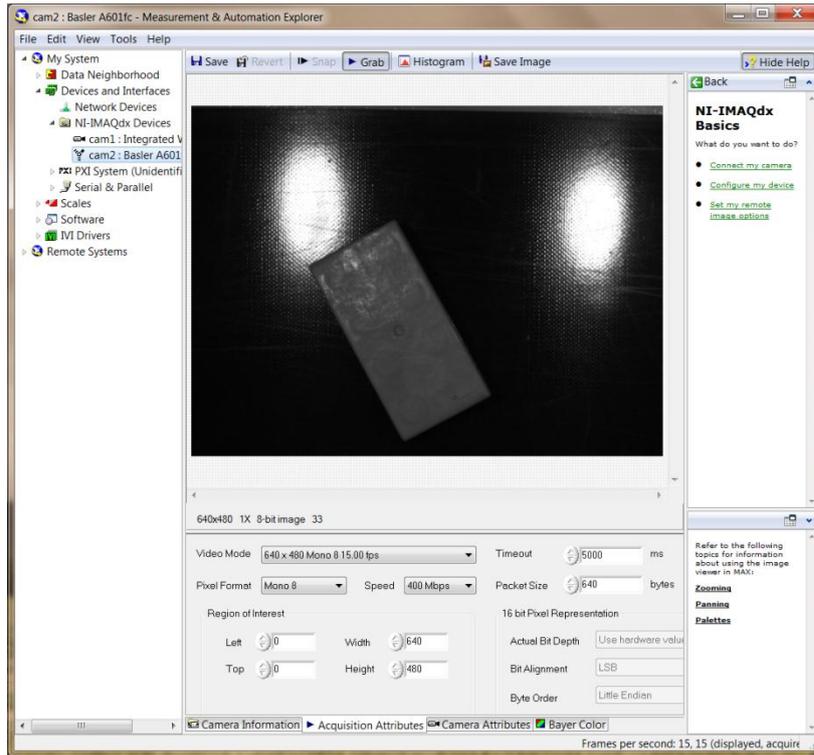


Figure 4.11 An image of the rectangular blocks is captured using MAX

In this system, the real world coordinates must be calibrated with the camera coordinates in order for the Cartesian robot to pick up the parts. MAX was also used to position the camera by the robot to get calibration values.

NI Vision Builder AI was used to configure and for the testing of the Machine Vision inspection. When the inspection in Vision Builder runs as expected, the inspection steps can be migrated to LabVIEW. Figure 4.12 shows the front panel and Figure 4.13 the block diagram created from the final inspection steps migrated to LabVIEW. An exchange student, Petri Leinonen, was involved in the implementation of the Machine Vision and Cartesian integration.

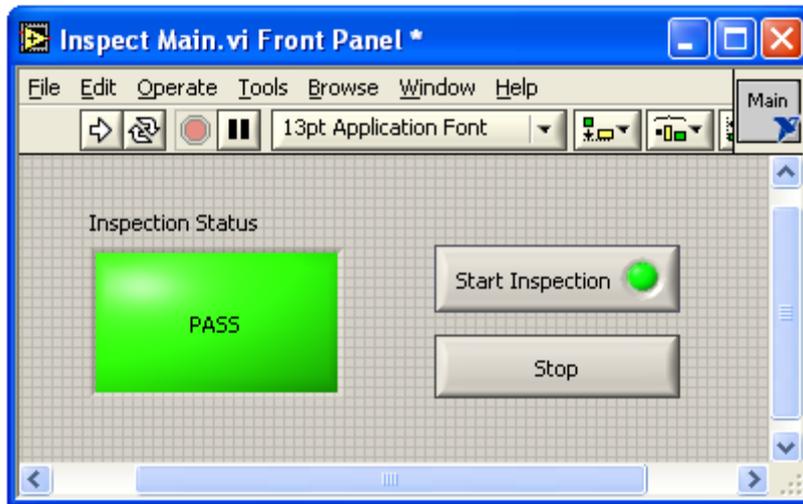


Figure 4.12 Front panel of the inspection steps migrated from Vision Builder AI to LabVIEW

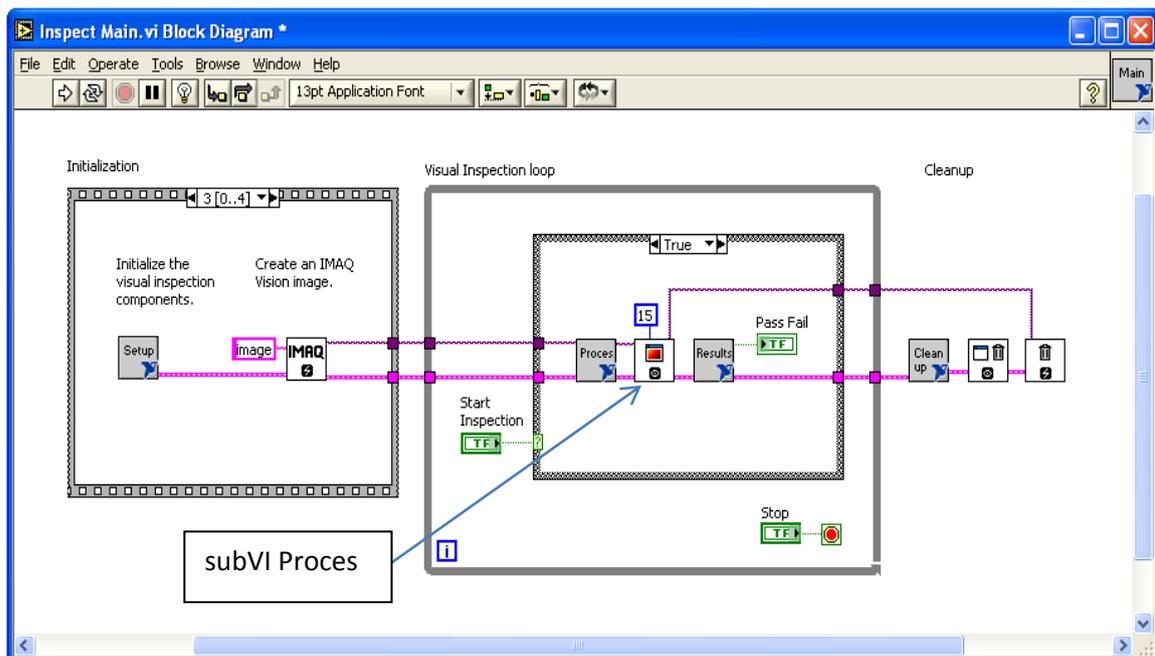


Figure 4.13 Block diagram of the inspection steps migrated from Vision Builder AI to LabVIEW

With this VI a pass or fail result was given as output. The subVI “Proces” is where the image processing steps are done as shown in Figure 4.14.

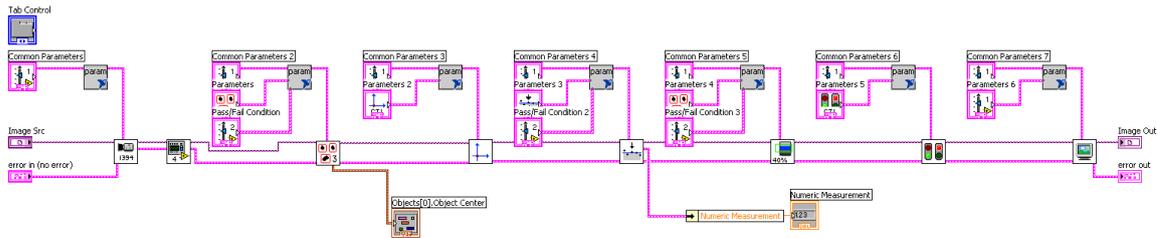


Figure 4.14 Proces subVI expanded

From the Proces subVI the results from the different image processing steps can be obtained. From *detect object* the position of the part can be read and from *find straight edge* the angle of the part is read.

4.4.3 Calibration

4.4.3.1 Rotator

A flowchart of the control program software is shown in Figure 4.15. The encoder used in the rotator has 128 discrete steps and the rotational value from Process subVI is given in 360 degree value. The control program for the rotator converts the 360 degree value to 128 steps in gray code. The values are then manipulated to ensure that the gripper move only in the desired 180 degree area as discussed in section 4.2.

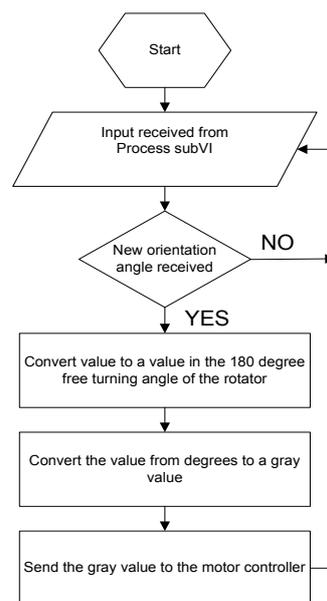


Figure 4.15 Flowchart of the controller's software for the rotator

The microcontroller's software, as used in the rotator controller, is shown in Figure 4.16. The rotator control units program compares the values received from the RS232 interface to the value of the encoder and step the gripper to make adjustments if necessary.

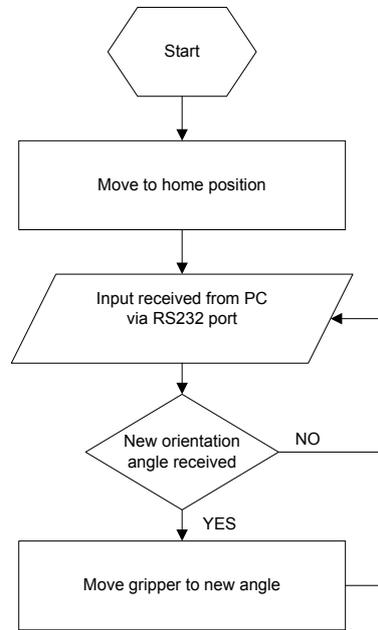


Figure 4.16 Flowchart of the rotator controller's software

4.4.3.2 Cartesian robot

There was no need for the Machine Vision system and Cartesian robot to be calibrated in metric units. The two systems just need to be calibrated to each other's coordinates. The result of the Process function for the part's position is given in pixels and the input coordinates of the Cartesian robot is a long integer.

The robot was moved to the coordinates where the camera captured the image of the part. The outside borders of the image were determined and the robot was manually moved to the edges while the robot coordinates were noted. This was done for both inspection bays and used as the robot's reference coordinate values. As the values of the Process subVI and the input to the Cartesian robot are both linear, a simple conversion formula was created to manipulate the pixel value to the correct long integer value.

4.4.3.3 Spatial calibration

Spatial calibration is the process of transforming pixel to real-world measurement units. In this study, it is important to know the real-world coordinates of the part under inspection for the robot to position the gripper and grasp the part.

The conversion ratio is calculated by dividing the 130mm field of view by the sensor resolution of 656 pixels. The real-world coordinates of the object under inspection is calculated from the vision system by using the 0.198mm conversion multiplier.

With the field of view of the inspection bays known, the gripper was moved to the four corners of each inspection bay's field of view. In Figure 4.17 is the presentation of the coordinates for the robot's region of interest for the inspection bays.

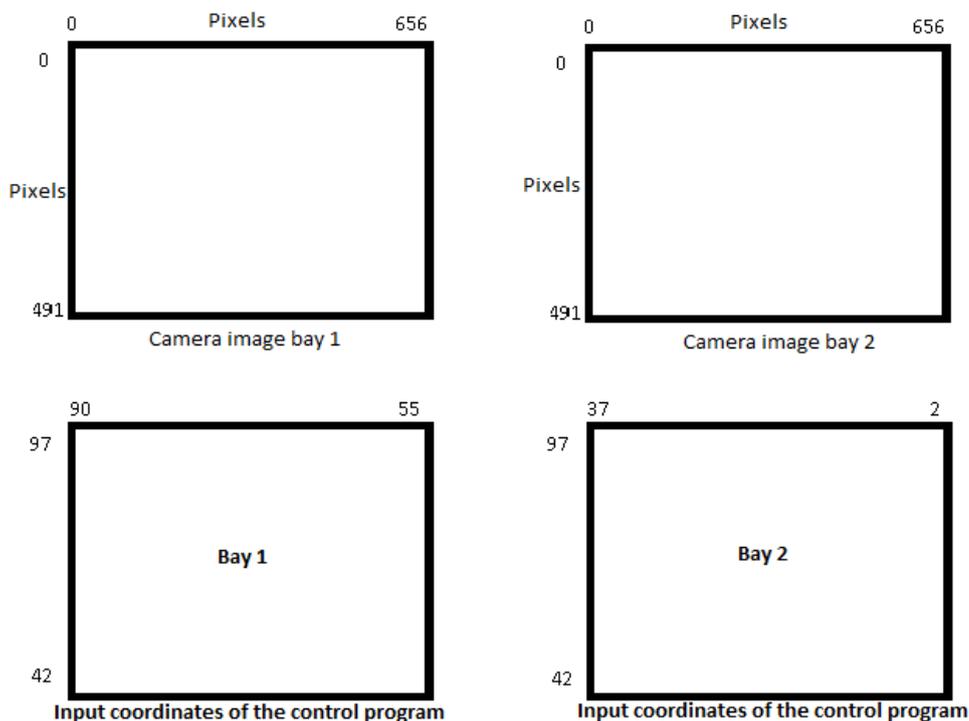


Figure 4.17 Coordinates of Machine Vision system and Cartesian robot for the inspection bays

The y range of travel is 55 (97 – 42) for both bays and the x range of travel is 35 (bay1=90-55, bay2=37-2). For x the scale can be calculated $656 / 35 = 18.743$

and the y scale $491 / 55 = 8.927$. These values represent the transformation factor between the Machine Vision system and the Cartesian robot coordinates.

4.5 Safety

Safety systems are used to protect humans from dangerous movements or actions from moving machinery and parts. Machines are designed to perform tasks at a high speed and force. The machine does not have the intelligence to sense dangerous movement. Sensing systems are integrated with these machines to protect mostly humans, but also the machine's environment from dangerous actions.

4.5.1 Safety Mat

A pressure-sensitive safeguarding mat is placed in front of the conveyor. The mat will detect people on the sensing surface and will stop the automation system to keep a person safe from hazardous conditions.

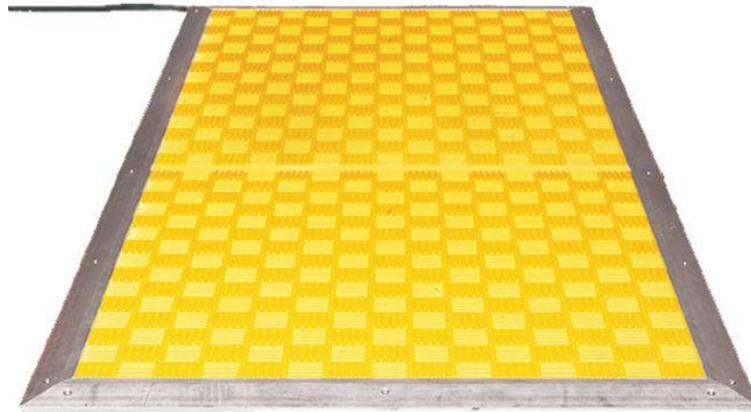


Figure 4.18 Matguard mat from Allen Bradley [77]

The mat is designed to operate at 24V DC and can be connected with other mats in series to form a floor-level guarding system in hazardous areas. When the mat is stepped on, the two internal plates will touch and the resistance will fall to zero. The mat makes use of a four-wire system to detect opens and shorts. The mat is

500mm wide and 1500mm long and is designed to detect people heavier than 30kg.

4.5.2 Light curtain

Safety light curtains are used to protect people from dangerous interaction with machines. A sender and a receiver is used to create a multi-beam “curtain” of light. When this “curtain” is penetrated, the safety light curtain detects the beam or beams that are being blocked, and sends a signal to the safety control circuit. The safety control circuit will send a signal to the machine controls and will halt the dangerous process of the machine [78].



Figure 4.19 Light curtain transmitter, receiver and controller [79]

The GuardShield Micro 400 as shown in Figure 4.19 is an economical light-duty safety light curtain system targeted to the semi-conductor, micro electronic and small assembly machine markets. The length of the unit used in this system is 1200mm with 120 beams and a resolution of 14mm. The maximum sensing range of the light curtain is 4.5m [79]. The transmitter and receiver are connected to the dedicated MSR41 safety controller.

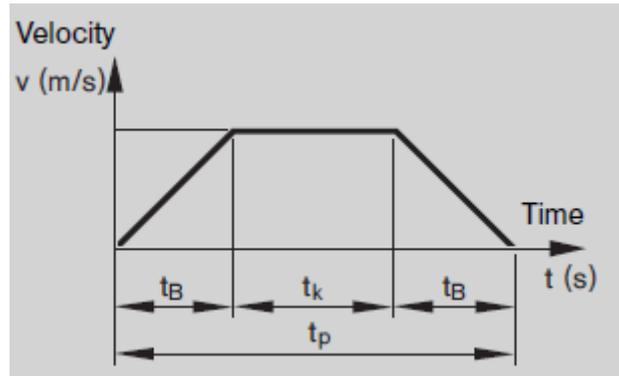


Figure 4.20 The positioning time for the Cartesian robot [80]

For the Cartesian robot, a linear module's positioning time is given in Figure 4.20. This is an indication of the time needed to reach a position under maximum load with maximum acceleration and velocity. It consists of the acceleration time, the time at constant velocity and the braking time.

To calculate the time it will take the robot to brake, the following formula can be used:

$$t_B = v/a = 1\text{ms} / 10 \text{ms}^2 = 0.1\text{s} [80]$$

The safety distance for a light curtain can be calculated according to the EN ISO 13855 standard with these formula [81].

$$S = (K \times T) + C$$

Where

S = safety distance

K = part of body speed in mm/s

$$T = T_1 + T_2$$

T₁ = the safety device reaction time in seconds

T₂ = the machine's reaction time in seconds

C = further distance in mm based upon the body's intrusion towards the risk area before the safety device has been activated.

With K = 2000mm/s for S < 500mm and K = 1600mm/s for S > 500mm

In this study, the safety distance was calculated as:

$$\begin{aligned} S &= (2000 \times T) + 8(d-14) \\ &= (2000 \times 0.15) + 8(14-14) \\ &= 300\text{mm} \end{aligned}$$

This distance represents the shortest distance from the light curtain to any part of the robot.

Figure 4.21 is the photo of the automated robot vision system with the safety curtain fitted to detect a person or object entering the hazardous area.



Figure 4.21 Light curtains mounted on the sides of the Cartesian robot

Figure 4.22 is the schematic representation for the safety system incorporated in the robot's emergency brake system.

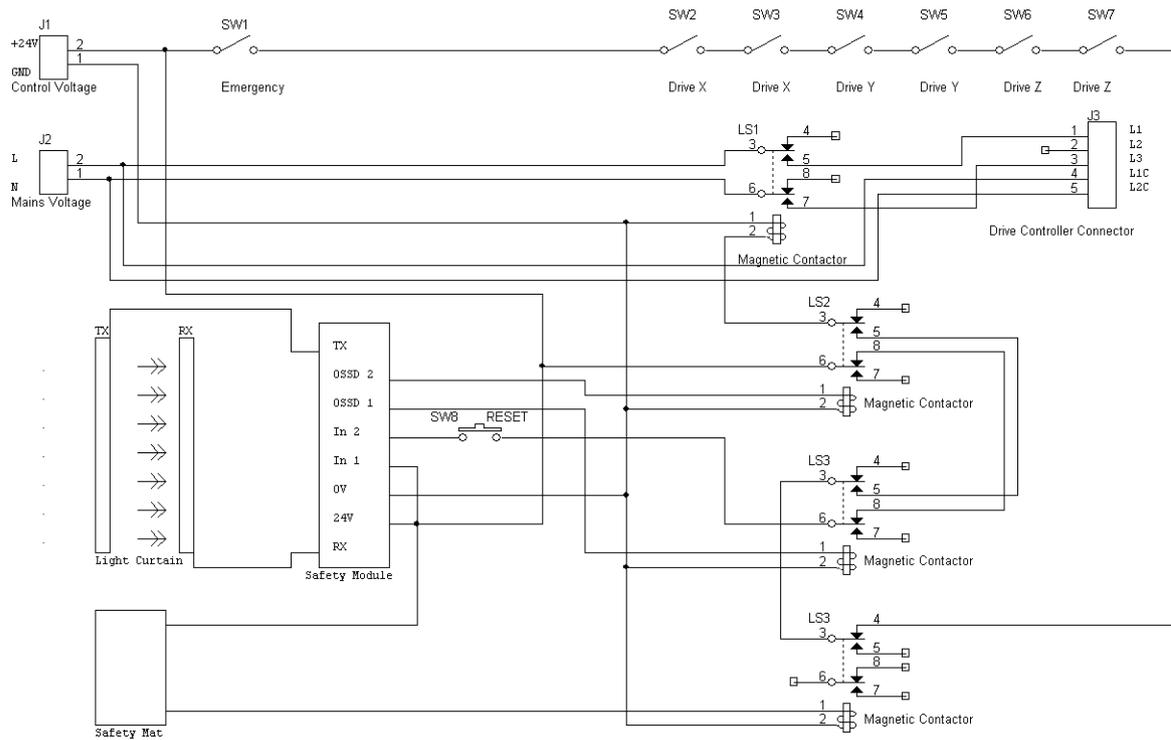


Figure 4.22 Schematic representation of the safety system

With this wiring configuration the GuardShield Micro 400 controller, as shown in Figure 4.22, is set for automatic start with start release.

When a PLC or a computer controlled system is used to control a automation process, a dedicated safety PLC have to be integrated in the system. In this project the safety system was hardwired into the system, therefore a safety PLC was not needed.

A cabinet was used to mount the control devices of the automation system as shown in Figure 4.23.

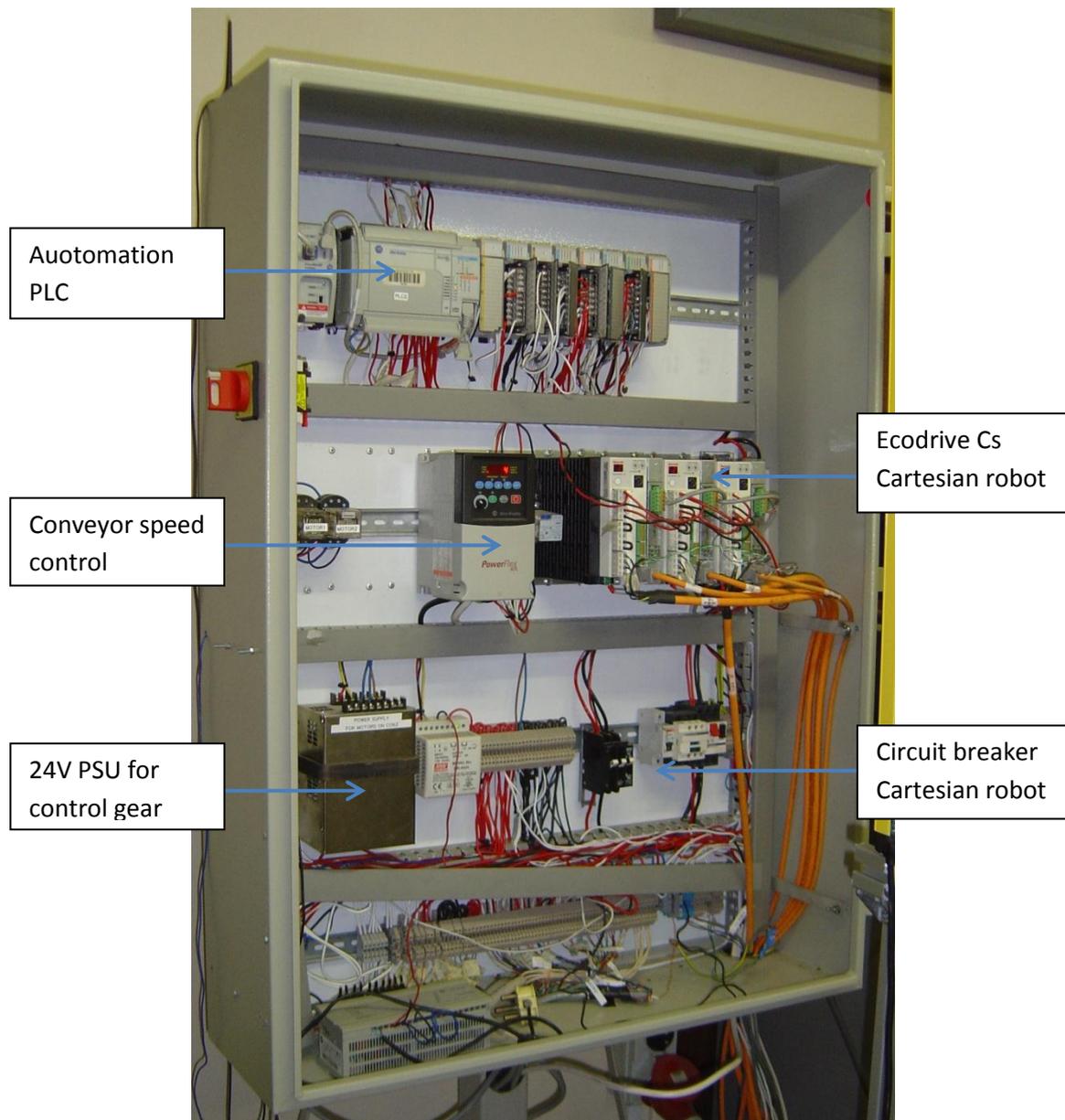


Figure 4.23 Control gear cabinet of automation system

This cabinet contains the control gear for the conveyor, Cartesian robot and the PLC.

4.6 Summary

The operation of the automated robot vision system was discussed. The parts used in the project were discussed and it was described how they are configured to operate optimally in the real-time system.

Chapter 5: Results

This chapter focuses on the setup and results obtained with different illumination techniques. Steps are discussed to identify a part and obtain the coordinates and orientation of a part using Machine Vision.

5.1 Illumination

5.1.1 Direct light

The photo in Figure 5.1 shows the two types of parts used in this system on the conveyor belt. The reflections on the conveyor belt surface are from the fluorescent lights in the laboratory and from this photo it is clear how reflective the conveyor surface is. The shadows from the parts on the conveyor are prominent and had to be addressed with the illumination setup.

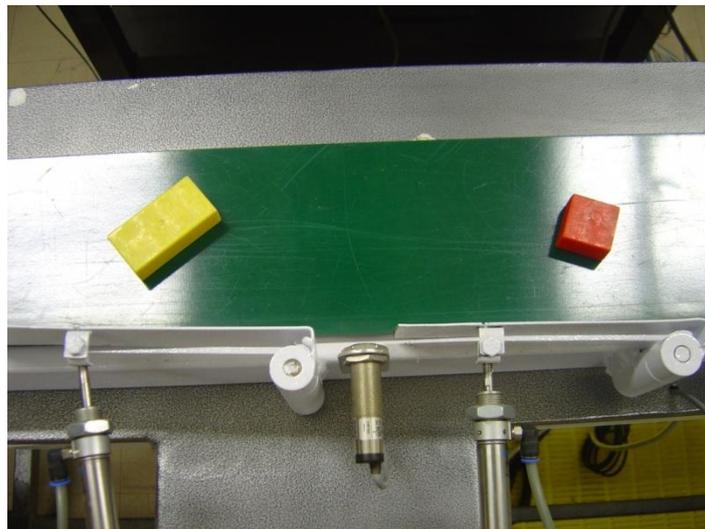


Figure 5.1 Ambient light on conveyor

From the results of the image in Figure 5.1 a system had to be designed to illuminate the parts in an effective way to minimize the shadows and reflections that could have an effect on the Machine Vision process.

The first tests were done with halogen lamps mounted in different positions to illuminate the parts. The idea was to use high intensity light to overwhelm the light from the fluorescent lamps in the laboratory.

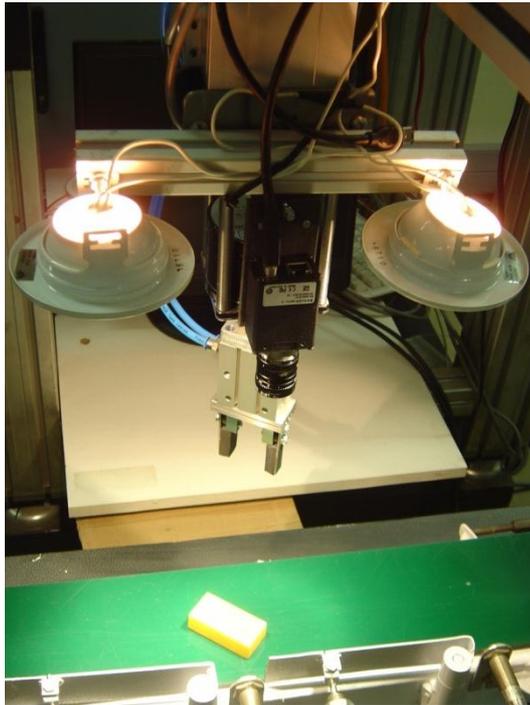


Figure 5.2 Direct lighting with halogen lamps

Figure 5.2 shows the setup with two halogen lamps illuminating the part. With this setup, uniform illumination was expected and therefore that shadows would be greatly minimized. Figure 5.3 and 5.4 show tests of this type of illumination.

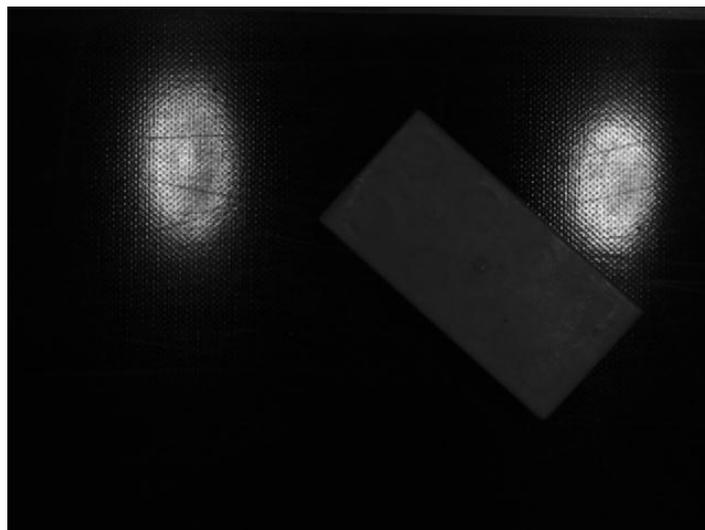


Figure 5.3 Image captured with Basler camera at low intensity

To test the setup with low intensity light, the halogen lamps were connected in series with a supply voltage of 9V at 2.52A. This is equal to a total input power of

22.68W or 22.68 % of the specified lamp input power. In Figure 5.3 the captured image from the Basler camera is shown. Here the light reflections and the deformities of the conveyor belt are more visible than the part.



Figure 5.4 Image captured with Basler camera at medium intensity

In Figure 5.4 the voltage was set to 15V at 3.48A which is equal to 52.2W or 52.2% of the rated lamp input power. Here the part is more visible and the reflections are bigger and brighter than the image captured at 9V. From this image it is clear that the part and its reflection are intertwined and will make the image processing unnecessarily complicated and prone to incorrect results.

5.1.2 Diffused ring light



Figure 5.5 Diffused ring light mounted on Machine Vision camera

As shown in Figure 5.5, a diffused ring light was mounted on the system. One of the advantages of a diffused ring light is uniform illumination. The expectation was to capture images with fewer reflections from the conveyor surface. As can be seen in Figure 5.6 the circular reflection from the LED ring light is very dominant in the captured image.

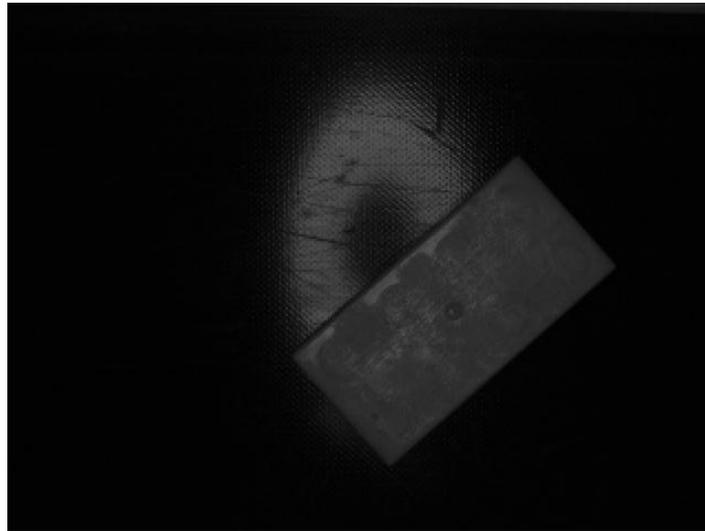


Figure 5.6 Reflective ring on conveyor from the ring light's illumination

The scratches and damaged areas of the conveyor belt are prominent using the ring light and made the image processing more challenging.

5.1.3 Ambient light box

Another option for the Machine Vision application only, would be to build an enclosure around the camera and illumination setup. With this method, only the light from the lights inside the box will illuminate the part and the ambient light is also blocked. This will give a perfect illumination setup for the vision system to take an image of the part. In this project, however, it was not feasible because the robot's gripper must be able to grasp the part and move it to a different location.

It was realized that the conveyor belt's surface could not be changed and the lights in the laboratory could also not be changed because in a typical factory

these will be real-world challenges and other methods had to be found to work around this.

5.1.4 Backlighting

For the Cartesian robot to pick up the component it only needs to know the position and orientation of the part. With this in mind, methods were searched for where these can be measured with a simple illumination setup.

By applying backlit illumination correctly, an opaque part is silhouetted and the outside dimensions can be determined easily. It was then decided to alter the conveyor system to push the parts from the conveyor belt onto inspection bays. These inspection bays are also used as an enclosure for the lamps of the backlighting system.



Figure 5.7 Two light boxes with 50W halogen lamps

Figure 5.7 is a photo of the two light boxes built and mounted to be used as the inspection bays. The parts are pushed off the conveyor onto these boxes by pneumatic cylinders. These boxes were built as a square with all the sides and bottom made from wood and painted white. A white Perspex cover is used for the top cover and act as a diffuser.

In order to achieve adequate light output, a 50 W halogen lamp with a fixed reflector was chosen as the light source. The light from this lamp is directed at

the bottom of the box. By reflecting the light from the white panels it was expected to achieve a more uniform light on the top cover.

With this setup, a high current power supply was needed because a 50W lamp with a supply voltage of 12V requires a current of 4.2A.

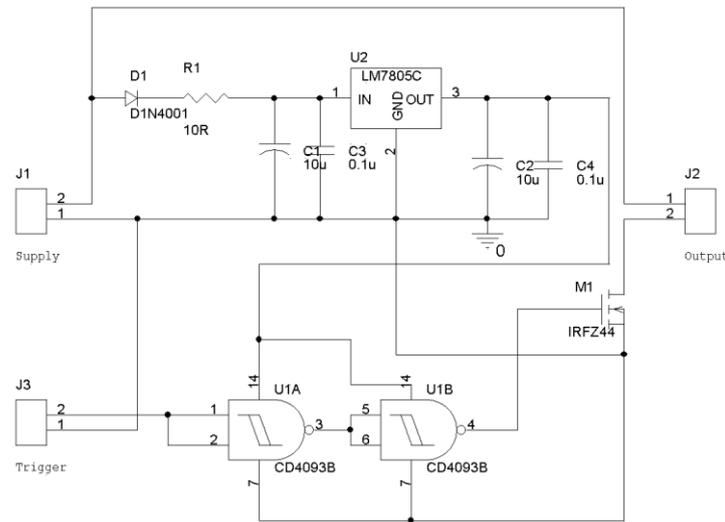


Figure 5.8 Halogen lamp switch

The 50W halogen lamp converts only about 10% of the consumed energy to light and the rest is wasted as heat [82]. The halogen bulb can reach temperatures over 200°C and when inside such a small box, the temperature inside the box rises very quickly [83]. The circuit in Figure 5.8 was built to switch the lamps on only when a part is on the light box. Switching the lamp on only when a snapshot of the component is taken minimizes the heat generated by the lamps. The heat of the PSU cooling system could be lowered as well.

After some experimentation, the light on the Perspex cover was still not uniform and the two enclosures were replaced by a single enclosure. Halogen lamps were placed at different positions to find a more uniform illumination on the Perspex cover (see Figure 5.9). The illumination was still not uniform on the Perspex cover, as can be seen in Figure 5.10. The problem was that the box was not deep enough to position the lights in order to focus the beam over a large area.

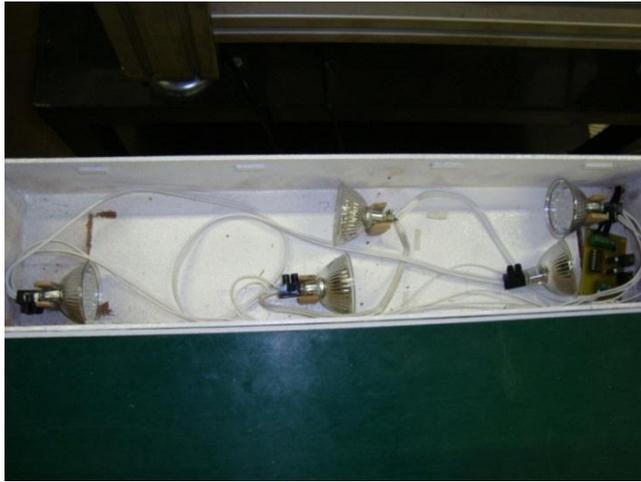


Figure 5.9 Inspection bay with 50 W halogen lamps as a light source



Figure 5.10 Bright spots on the inspection bay

Due to the high current consumption and heat generated by the halogen lamps, LEDs were identified as a different light source.

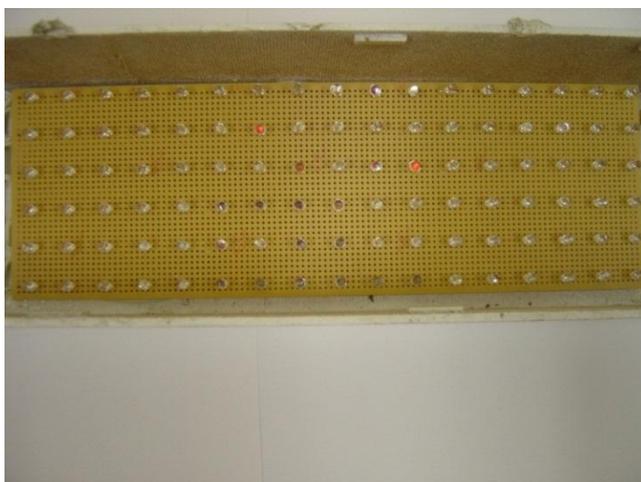


Figure 5.11 Inspection bay with LED array as a light source

An array of LEDs were built to fit inside the inspection bay box. By using this method as shown in Figure 5.11 it was found that the LEDs were too close to the Perspex platform and that there were still bright spots on the Perspex platform.



Figure 5.12 Diffuser placed over the LED array

A diffuser was placed between the LED array and the Perspex cover as shown in Figure 5.12. Using this method, a uniform light was achieved - as shown in Figure 5.13.



Figure 5.13 Uniform distribution of light with a LED array as a light source

By using this method, good results were obtained and it was thus chosen as a solution to the illumination problem.

5.2 Vision Builder

The purpose of the Machine Vision system is to determine the part's spatial properties and the part's orientation.

Vision Builder was used for the experimentation of the image processing and the following steps were used:

Step 1: Acquire Image (IEEE 1394)

This step was used to acquire an image of the object under inspection from the Basler A601f camera. In this step the camera's settings are also set.

Step 2: Vision Assistant

In this step the image processing steps, or functions, that will be performed are shown. When selecting the edit button, Vision Assistant will open up and the steps can be edited.

Step 3: The *Threshold* function was applied to the image as shown in Figure 5.14.

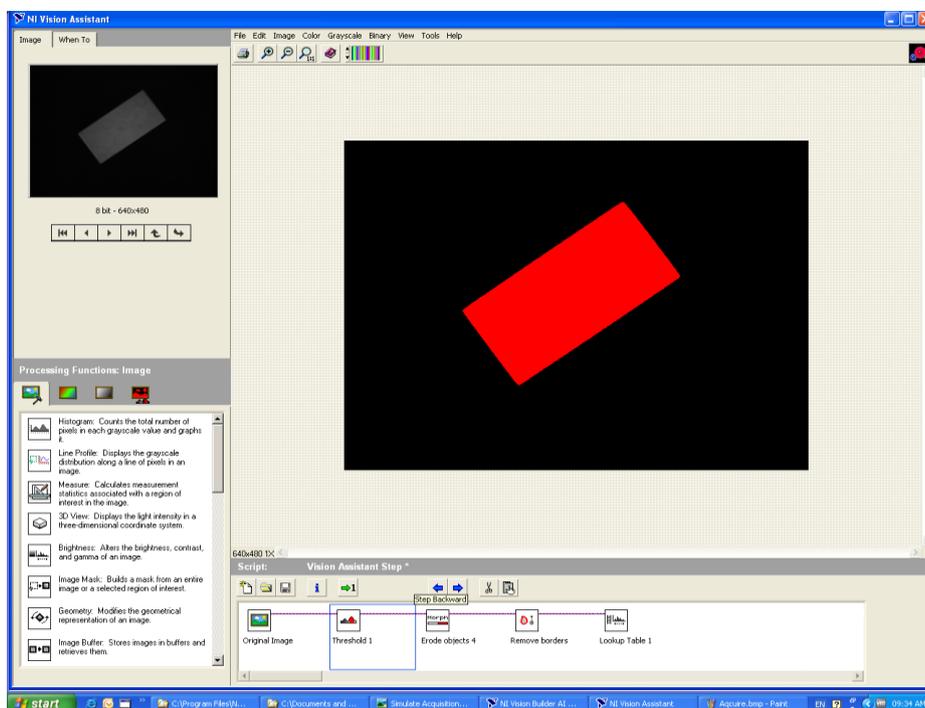


Figure 5.14 NI Vision Assistant Threshold function

With the *Threshold* function, objects were isolated and those of interest can be kept. The *Threshold* function also converts the grayscale image with pixel values ranging from 0 to 255 to a binary image with pixel values of 0 or 1.

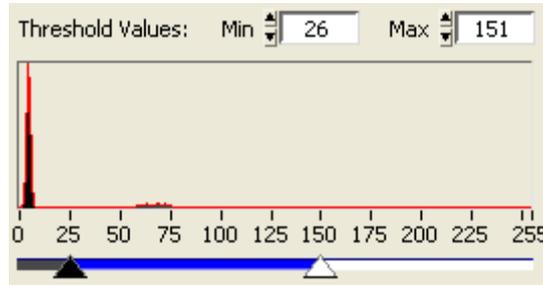


Figure 5.15 Histogram of the captured grayscale image

The manual *Threshold* function was selected. By analysing the histogram, Figure 5.15, of the captured grayscale image, the threshold values were set to a minimum of 26 and a maximum of 151. This function sets all the grayscale values that fall outside the minimum and maximum range to 0 and all the values in the range are replaced with a 1. The result obtained is a binary image with part pixels set to 1 and the background set to 0. This step is needed to convert the grayscale image to a binary image because the functions in Step 4 and Step 5 are performed on binary images.

Step 4: As mentioned in paragraph 2.4.2 the *Binary Morphology* function was used to remove unwanted noise. The erode objects function, shown in Figure 5.16, was used to isolate pixels in the background and pixels touching the contour of the objects. The default structuring element is set at 3 X 3 and iterations of 1 proved to be sufficient to remove the noise in the image.

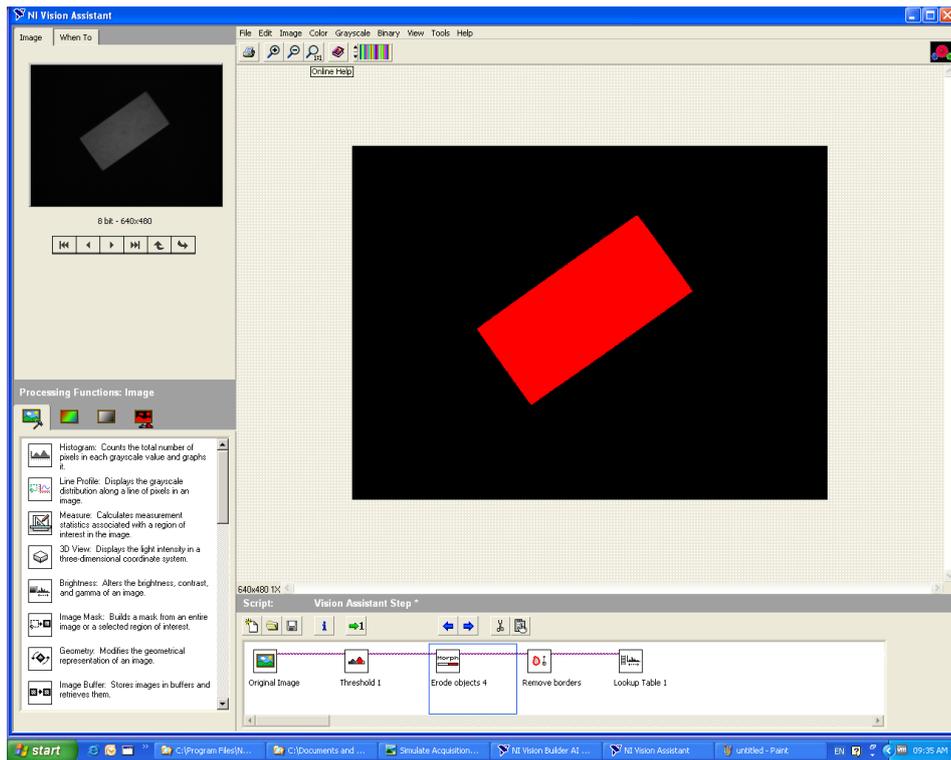
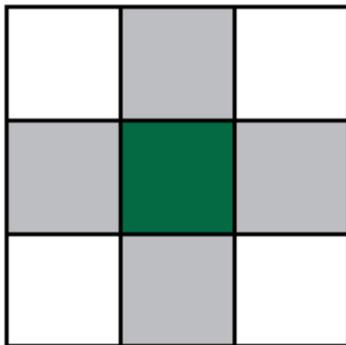


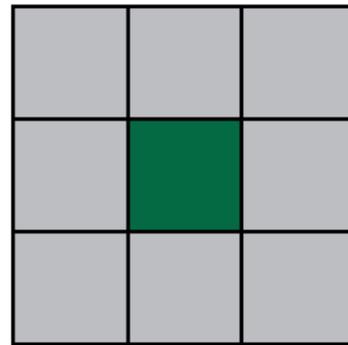
Figure 5.16 Erode objects function

Step 5: The *Remove Borders* (see Figure 5.18) function is used to improve the image information by eliminating particles that touch the border of the image.

By selecting connectivity 4, as indicated in Figure 5.17(a), two pixels touching horizontally or vertically are considered to be of the same particle and pixels touching diagonally are considered as different particles. By selecting connectivity 8, two pixels are considered to be of the same particle if it touches horizontally, vertically or diagonally as shown in Figure 5.17(b).



(a)



(b)

Figure 5.17 (a) Connectivity 4 (b) Connectivity 8 [42]

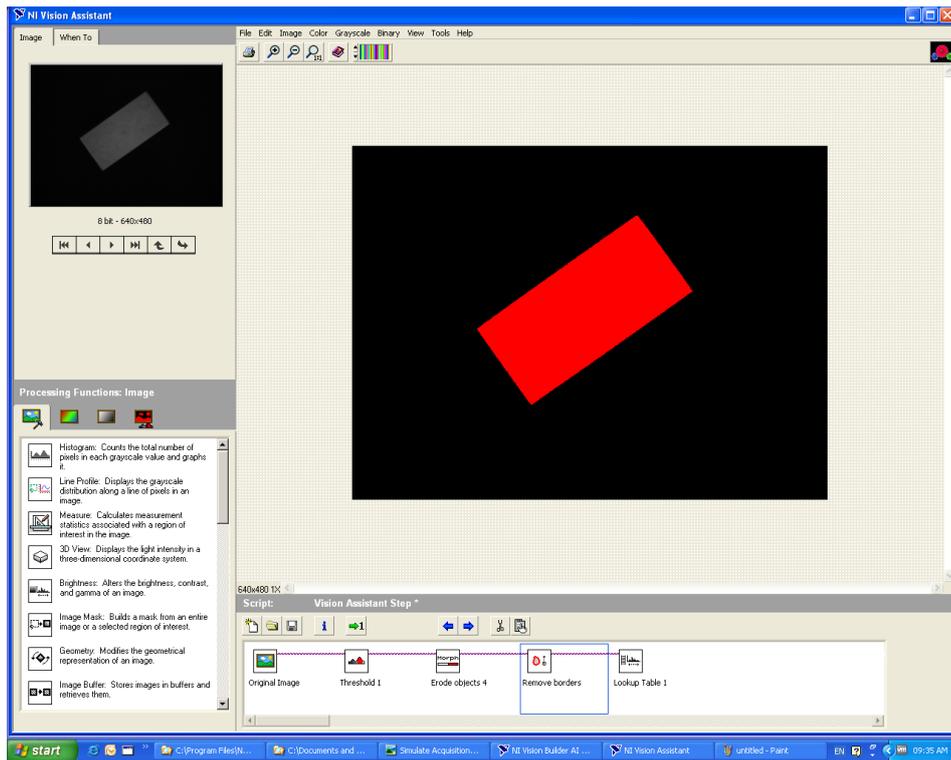


Figure 5.18 Remove borders

Step 6: The functions in Steps 7 to Step 11 operate on grayscale images. *Lookup Table 1* with the equalize function selected is applied to convert the binary image to a grayscale image. In step 1 the *Threshold* function was used to set the part pixels to 1 and the background pixels to 0. This image is transformed with the *Lookup Table 1* function to transform the image to a grayscale image with a value from of 0 to 255.

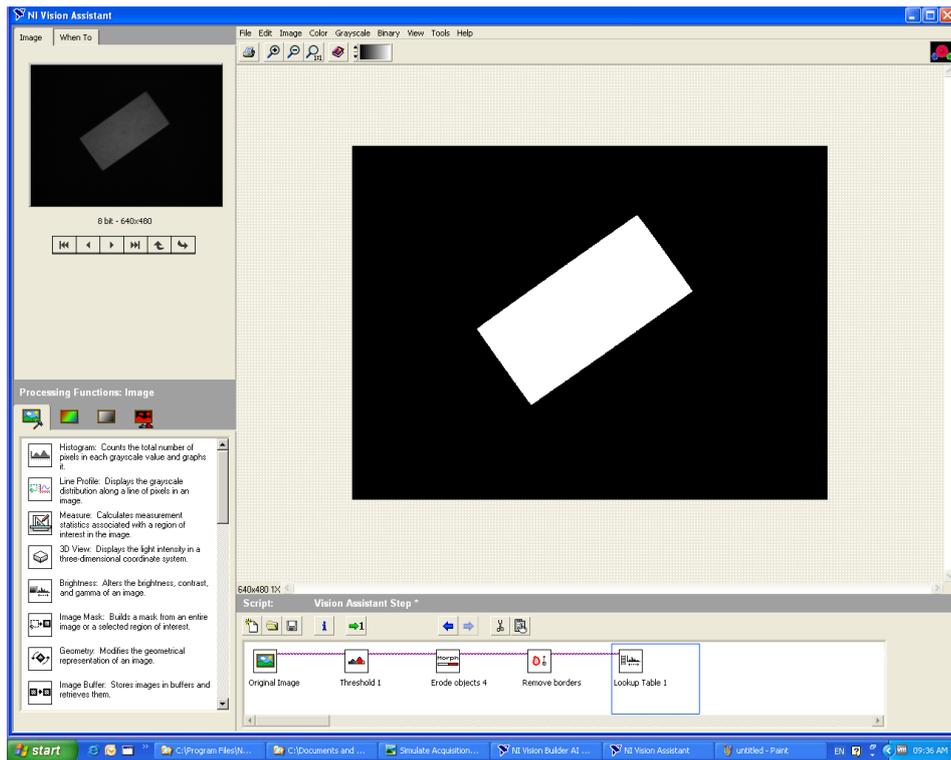


Figure 5.19 Lookup Table 1

Step 7: When the *Lookup Table 1* function (see Figure 5.19) finished, the *Detect Objects* function in Vision Builder is executed.

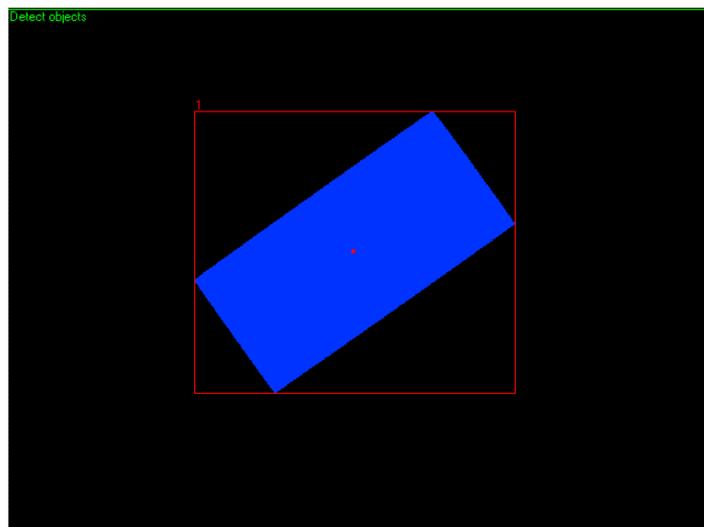


Figure 5.20 Detect Objects

The *Detect Objects* function searches for objects in the image and determines the x and y coordinates, the size and the orientation of the objects. This function is used in this study to ensure that there is only one component on the conveyor.

The threshold was set to an intensity of 97, and the function was set to look for *Bright Objects* because the intensity of the object pixels is greater than the surrounding pixels. A rectangle and square block was processed to determine their object size according to the function. From this data the minimum object size was set to 14000 pixels per square and maximum object size was set to 35000 pixels per square. The minimum and maximum number of objects was set to 1. A pass inspection result will only be given when all the criteria as mentioned for this function are within the correct limits.

Step 8: Set Coordinate System

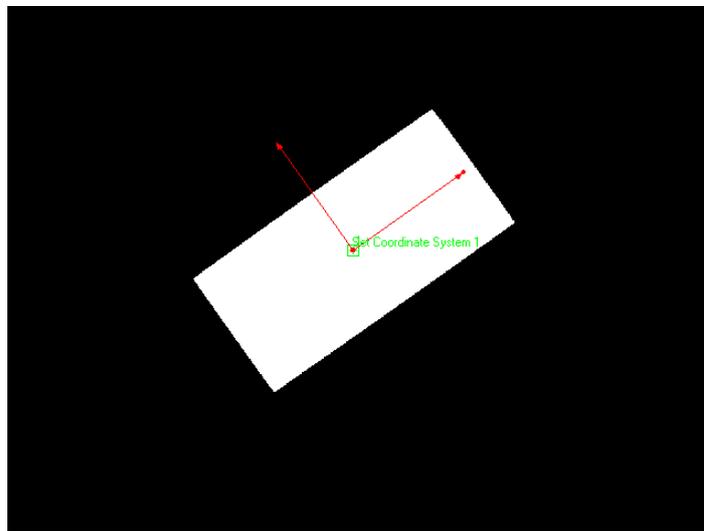


Figure 5.21 Set Coordinate System

In a typical Machine Vision inspection, a region of interest is set to avoid irrelevant information and to improve inspection speed. The setup of the region of interest is simple in an application where the object under inspection is always at the same location and angle. In this application, the object is not at the same location or angle and the region of interest needs to move and rotate according to the object's location.

Step 9: With the *Set Coordinate* function (see Figure 5.21) a coordinate system is determined according to a specific feature in the image. The mode selected is set for a variable horizontal, vertical and angular motion.

Step 10: With the *Find Straight Edge* function (see Figure 5.22) an edge of the object is determined. From this data the angle of the object is determined. This data can be used to rotate the gripper to an angle for grasping the part.

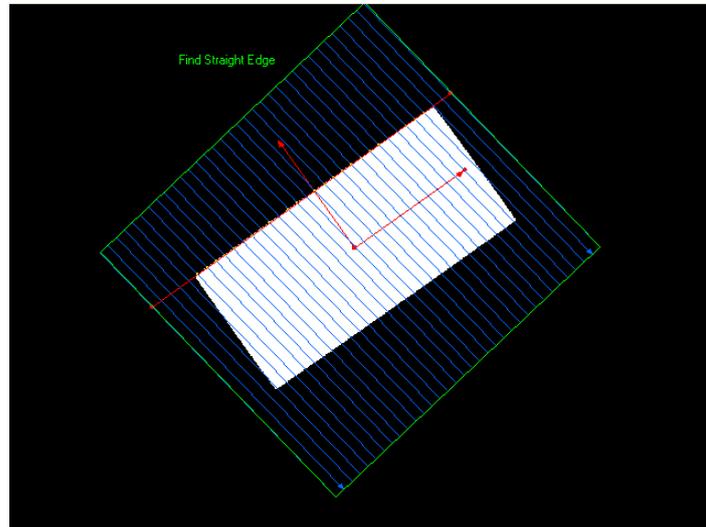


Figure 5.22 Find Straight Edge

Step 11: The *Count Pixels* function (see Figure 5.23) is used to determine the size of the part on the conveyor. The result of the function is given as a percentage of pixels in the region of interest that are within the range established for the current image. The limit was set at 4.5% minimum and 14% maximum to output a pass result.

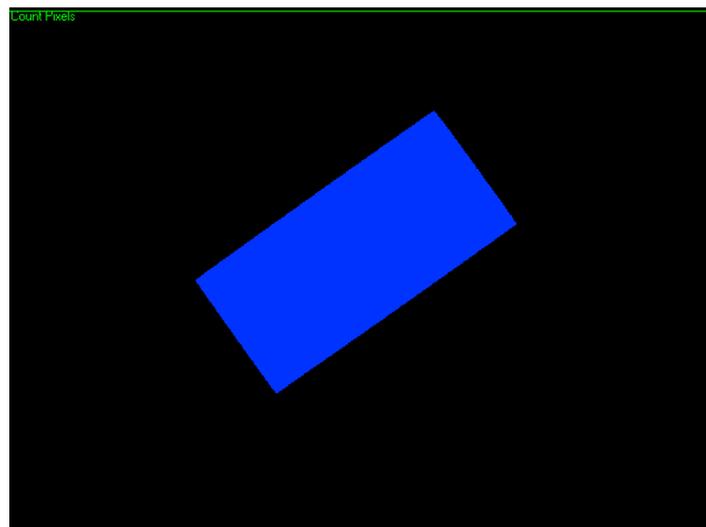


Figure 5.23 Count Pixels

Step 12: The *Decision Making* function determines if the inspection passed or failed. A pass result is obtained when all the criteria of *Detect Objects* (step 7) are true and the *Count Pixels* (step 11) value is within the specified range. Should either the *Detect Objects 1* or the *Count Pixels* be false, a fault condition will be given and the system will be stopped.

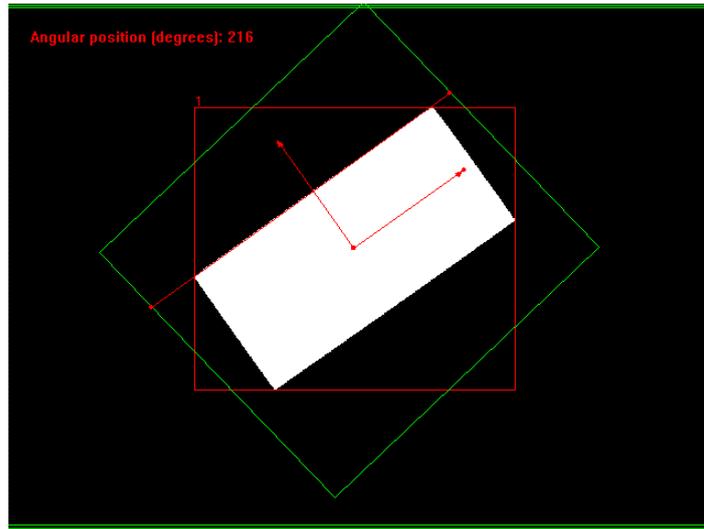


Figure 5.24 Decision Making output image

In paragraph 4.3.1 it was explained that the steps done in Vision Builder are migrated to LabVIEW. From the subVI's the orientation and coordinate data is read and used to move the Cartesian and gripper to pick up the part.

5.3 Summary

Illumination is very important part of a Machine Vision inspection, which can be time-consuming in certain environments. By the proper setup of the illumination, the vision inspection can be done using fewer image processing functions. The illumination must be properly set up before the software design and testing can be started.

Vision Builder AI provides a well-designed software platform to test and adapt a vision inspection. By using the histogram (see Figure 5.15) and other values read from the inspection results, it is easy to set values for the inspection at hand.

Chapter 6: Conclusion

6.1.1 Software platform

LabVIEW is a powerful program that worked well in the system where different software modules for the different hardware were developed. A software module and hardware can be developed, tested and improved without having any effect on the other components in the system.

6.1.2 Illumination

In this study it was realised how important illumination is in a vision application. Many hours were spent on the design and testing of the illumination setup. It was found that it is very difficult to correct a poorly captured image by the use of image processing functions. Ambient light plays a major role in the illumination setup and has a huge effect on the results of the Machine Vision setup. When the illumination is properly setup, the Machine Vision steps can be greatly minimized with consistent results.

Bright reflections were problematic when an image was captured on the conveyor belt. Two inspection bays were implemented to enable the system to use backlight illumination. This method of illumination proofed to work very good in this system.

6.1.3 Machine Vision

The Machine Vision system detects a part on the inspection bay. The position and the orientation of the part are determined by the Machine Vision system. The Machine Vision system will give a pass result when the part's size is within limits and there is only one part on the inspection bay. The initial testing and improvements in the Machine Vision software were done in Vision Builder AI. To use the result, the inspection steps were migrated to LabVIEW. From the VI and subVI's the results were manipulated and used for the control of the Cartesian robot and rotator.

6.1.4 Rotator

The initial finger design was not able to hold a part while the part is moved by the Cartesian robot. With the new finger design the part is properly grasped and does not slip out of the fingers even at high-speed movement by the Cartesian robot.

The rotator operates well and is consistent in moving the gripper to the angle as calculated by the Machine Vision system.

6.1.5 Safety system

The safety system consists of an emergency stop, limit switches on the Cartesian robot, mechanical brakes built in the Cartesian robot, a safety mat and a light curtain. The safety system will stop the Cartesian movement during a power failure or when one of the safety devices is triggered.

6.1.6 Purpose-specific software and equipment

When using high quality or purpose-specific software like LabVIEW and equipment like the Cartesian robot, Basler camera and safety systems from Rockwell, time is saved in respect of unnecessary troubleshooting. The high-quality equipment was also found to be consistent and reliable.

6.2 Possible follow-up studies

At the completion of the study, the AGV was not yet developed. When the development of the AGV is completed, the system will have to be reconfigured to load the components onto the AGV's in the loading area.

The current illumination works very well for the part under inspection. A challenge will be met when transparent parts need to be handled, as backlighting is not suitable in such contexts.

6.2.1 Smart camera

As an alternative option the camera, PC and control software can be replaced with a Smart camera for the Machine Vision part of the project. A smart camera is a self-contained unit that performs image processing on board [84].

Previously, smart cameras were used for basic projects such as reading barcodes. With the increased processing power, as technology advances, the smart camera can now manage a wider range of duties and compete with PC-based systems [85].

A smart camera is more reliable than a PC-based vision system because the smart camera generates less heat, has fewer components and has fewer moving parts. Its size and in many applications ease of use make the smart camera more attractive. The Smart camera is easily replaceable without the need to replace any of the other hardware, which makes more sense in an automation plant with many cameras.



Figure 6.1 Smart camera and robot integrated to pick cast parts from a pallet onto a conveyor [86]

Figure 6.1 is a photo of a smart camera integrated with a multi-axis robot to move parts from a pallet onto a conveyor. The smart camera offers smooth order

picking at high speed with up to 5000 profiles being evaluated per minute and the results are sent directly to the robot as position coordinates [86].

6.2.2 Industrial PC

In industry, industrial computers are used for the work the personal computer is performing in this study. The ideal applications for industrial computers are in industrial, mining, military, avionics or any field where normal a PC cannot survive [87].

The features of Industrial PCs are different from consumer PCs in terms of reliability, compatibility, expansion options, long-term supply and they can withstand harsh industrial environments [88].

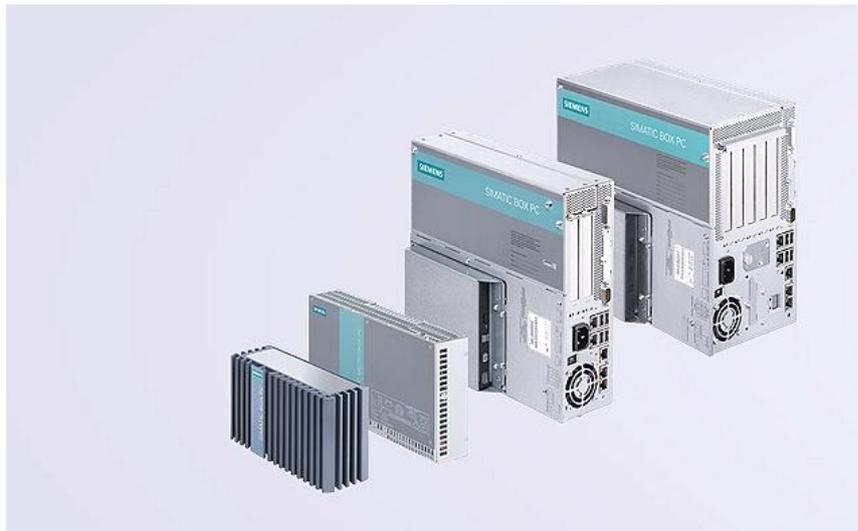


Figure 6.2 SIMATIC Box PC from Siemens [89]

The panel PCs from Siemens as shown in Figure 6.2 are maintenance free, offering different mounting, expansion and performance capabilities. They can be used for measuring, checking machine data and industrial image processing [89].

A subset of industrial PC's is the Panel PC where a touchscreen liquid crystal display (LCD) is typically built into the same enclosure as the other electronics and motherboard [88].



Figure 6.3 Panel PC from Advantech [90]

The panel PC as shown in Figure 6.3 is robust enough to withstand harsh environments on factory floors. This expandable panel PC has a die-cast housing that acts as a heat sink for protection against overheating [90].

6.2.3 Improve Pneumatic Gripper

The gripper designed for the blocks handled in this study works very well. Should the need arise to move different parts, the fingers need to be replaced. The fingers should be designed according to the part's shape, dimensions and weight.

While the part is moved, there are other forces besides gravity working in on the part and this should be considered in the new design.

With the current design of the gripper, a part will be dropped when the air pressure is lost. To correct for this, a retention mechanism should be designed to keep the gripper's claws closed when the pressure is lost [91].

6.2.4 Safety system

Safety is a very important factor of any automation system. As this study focussed only on one part of the automation system, the described safety system needs to be integrated into the larger automation systems safety.

The factors from the other machinery also need to be accounted for and a complete redesign of the safety system needs to be done, which is a project in itself. A possible solutions will be to add a safety PLC like the Allen Bradley Guardlogix with a SIL 3 rating.

List of Scientific Publications

The research work presented in this dissertation has been presented and published as indicated below.

1. R.J. Jansen van Nieuwenhuizen, P.S. Veldtsman and H.J. Vermaak, Development of an automated robot vision component handling system, CUT Interdisciplinary Journal, Interim, 2006.
2. G.D. Jordaan and R.J. Jansen van Nieuwenhuizen, "Machine Vision in an Automated Component-Handling System" in IEEE 3rd International Conference on Mechatronics, Budapest, 2006.
3. R.J. Jansen van Nieuwenhuizen, "Development of an automated robot vision component handling system", in Proceedings of: 15th Annual Research Seminar, Faculty of Engineering & Information Technology, CUT, Free State, SESSION C, 22 October 2012.

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