ASSEMBLY-SETUP VERIFICATION AND QUALITY CONTROL USING MACHINE VISION WITHIN A RECONFIGURABLE ASSEMBLY SYSTEM

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DECLARATION OF INDEPENDENT WORK

I, *Thabo George Bihi,* hereby declare that the project entitled *Assembly-Setup Verification and Quality Control using Machine Vision within a Reconfigurable Assembly System*, completed and written by me is my own independent work and has not previously formed the basis for the award of any degree or diploma or certificate.

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T. G. Bihi Date

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ABSTRACT

The project is aimed at exploring the application of Machine Vision in a Reconfigurable Manufacturing System (RMS) Environment. The Machine Vision System interfaces with the RMS to verify the reconfiguration and positioning of devices within the assembly system, and inspects the product for defects that infringe on the quality of that product. The vision system interfaces to the Multi-agent System (MAS), which is in charge of scheduling and allocating resources of the RMS, in order to communicate and exchange data regarding the quality of the product.

The vision system is comprised of a Compact Vision System (CVS) device with fire-wire cameras to aid in the image acquisition, inspection and verification process. Various hardware and software manufacturers offer a platform to implement this with a multiple array of vision equipment and software packages. The most appropriate devices and software platform were identified for the implementation of the project. An investigation into illumination was also undertaken in order to determine whether external lighting sources would be required at the point of inspection. Integration into the assembly system involved the establishment communication between the vision system and assembly system controller.

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1 INTRODUCTION TO THE STUDY

Manufacturing means to make by hand and is a practice almost as old as mankind itself dating back to the cottage industry- when products were manufactured by artisans from their homes, and extends into today’s mass production for mass consumption, which is done in huge factories. Throughout history skilled labourers have made what others needed; goods were custom made to meet the demand of others or built at home for the farm or household. This process lasted until the **Industrial Revolution** (1760 – 1850), which introduced Machine-based manufacturing, steam power and thus the production of items at a profit. Manufacturing was overhauled through improvements of the steam engine, several inventions and the production of interchangeable parts. Agriculture advanced to the point where fewer farms could feed more cities, and transportation was enhanced by a network of canals and railroads [1].

Modern manufacturing includes all the intermediate processes required for the production and integration of product components. Semiconductor and steel manufacturers use the term fabrication instead. The manufacturing industry is closely connected with engineering and industrial design [2]. Manufacturing industries represent a wealth-producing sector of an economy. These industries use various technologies and methods widely known as manufacturing process management. Manufacturing industries are categorized into engineering, construction, electronics, chemical, energy, textile, food and beverage, metalworking, plastic, transport and telecommunications industries. A huge share of the labour force is employed by these industries, and they produce materials required by sectors of strategic importance, such as national infrastructure and defence. The world manufacturing industry has geared up and incorporated several technologies within its scope, and so generates employment, introduces new techniques and presents the economy with real earnings from shipments [3].

The manufacturing industry is a global interest and countries such as the Republic of South Africa and other developing African countries are interested in growing their manufacturing scope. South Africa has developed an established, diversified manufacturing base and has shown its resilience and potential to compete globally. Manufacturing in South Africa is dominated by the agricultural-processing, automotive, chemical, ICT and electronics, metals, textiles, clothing and footwear industries [4].

Changes in manufacturing has resulted in several key developments in the techniques employed to produce a finished product, and one such development is the assembly line, a manufacturing process in which parts are added to a product in a sequential manner to create a finished product, which increased the speed of manufacturing and over the years has been adopted by many manufacturing companies and also improved upon [5]. This has led to modern day mechanised processes of assembly; assembly systems, and production in varying sizes of factories and workshops.

Assembly systems are made up of various components that contribute to the function or purpose of the system. Whether the system is meant to assemble an automobile or something as small as a padlock, the performance of the system depends on the design used - which determines the order of the actions to be taken in the process. The design is often supported by simulation software which allows a user to construct the system virtually and simulate the actions until an acceptable design and assembly process are reached and then physically implemented. This physical implementation results in a design that is fixed, meaning the assembly system can only manufacture/assemble what it was setup for initially. This presents a problem in the current rapidly changing and competitive manufacturing industry. Reconfiguration comes forth as a solution to this, and that is where Reconfigurable Manufacturing Systems (RMS) and Reconfigurable Assembly Systems (RAS) feature in modern manufacturing.

An RAS is said to be a component of RMS which is not only a system that can adapt to product change and regulation changes, but is also meant to be cost-effective. A Reconfigurable Assembly System, on the other hand, is an assembly system which consists of sub-systems that can change or reconfigure on demand in order to perform another function or action (e.g. from drilling to welding to pick-and-place).

Reconfiguration of the sub-systems needs to be verified and the quality of the product that comes from the system must also be checked at all stages of the process in order to prevent defective products. The performance of the system after reconfiguration is dependent on the correct behaviour of the sub-systems and the number of non-defective products.

1.1. Problem Statement

Since the performance of a Reconfigurable Assembly System (RAS) depends entirely on the correct configuration (or reconfiguration in this case), of the assembly-stations within the system, and the quality of the product that comes out of the system, the problem thus lies in checking whether the assembled products are of an acceptable quality and changes in the assembly system configuration that needed to take place, have done so correctly.

Machine Vision Systems should be utilized to enhance and verify the correct operation of reconfigurable assembly systems.

1.2 Methodology

Machine Vision is the application of computer vision to industry and manufacturing. Vision systems do not just identify faulty products; they control and monitor processes and play an important part in the manufacturing process. The design of a vision system depends on the requirements of the system (assembly or automation) it will be part of.

The Machine Vision System in development will work in unison with the assembly system, which will communicate the need for reconfiguration. The vision system, utilizing cameras and vision software packages, will monitor the changes and movements of the different components and, hence, the reconfiguration of the assembly system. Proximity sensors will be in place to alert the system if any component is in an appropriate position for quality control to be administered by the camera allocated to the specific task.

1.3 Hypothesis

Machine Vision systems can be used to monitor rand verify the correct configuration of different assembly stations in a Reconfigurable Assembly System (RAS), and monitor the quality of the product assembled by the system. Information gathered by the vision system during the monitoring and verification process is provided to the assembly system and predetermined actions are taken.

1.4 Objective

The objective of this project is to realize a vision system that will work in unison with a Reconfigurable Assembly System, to produce top quality or fault-free products. This vision system must thus verify that all changes to an assembly cell or station has occurred correctly, and that the product is assembled as desired. In order to achieve this objective the following must be achieved:

- The appropriate hardware needs to be identified; i.e. cameras and processing hardware as well as programming computer.
- Vision software needs to be investigated and the one that caters to the problem of the study needs to be obtained.
- A solution regarding illumination problems has to be developed.
- The vision system has to be integrated physically into the assembly system. This will be done by mounting the different components within the assembly system framework.
- A program that scrutinises assembly-setup has to be constructed using the software package identified for the project, and the necessary information required for the validation of the inspection process also has to be identified.
- A program dealing with quality verification has to be constructed and incorporated with the assembly-setup program. Information needs to be gathered from the pallet during the inspection to aide in the assembly process.
- Decisions regarding communication have to be taken and the information gathered during the inspection has to be transmitted to the Assembly System Controller.

1.5 Dissertation Overview

The dissertation contains the following chapters:

- Chapter 1: Introduction to the Study

  This chapter introduces the reader to the manufacturing industry, and gives a general explanation and background information on the project.

- Chapter 2: A Review of Machine Vision and Machine Vision Systems

  The history of Machine Vision and the developments that have led to the growth of vision system applications are discussed in short, in order to present the findings of the literature review that was done.

- Chapter 3: Methods and Techniques of Implementation

  This chapter explains the methods and implementation strategies that are involved in the machine vision industry, and also discusses the different components that make up a vision system.

- Chapter 4: Results

  Results are discussed and observations, based on those results, are made in this chapter.

- Chapter 5: Conclusion, Contribution and Recommendations for Future Research

  A conclusion is reached; the contributions of the project are discussed, while possible future research is also discussed.

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2 A REVIEW OF MACHINE VISION AND MACHINE VISION SYSTEMS

Machine Vision was first applied as an image analysis military application of artificial intelligence in the late 1940’s. Then, during the period between 1960 and 1970, the Massachusetts Institute of Technology (MIT) developed the first real use of image processing in an industrial context with the Block Micro World project driving a robotic arm [1].

In the 1900’s massive growth of the Machine Vision industry was fuelled by the availability of industrial camera and support systems. Smart cameras became available using proprietary processing chips, and the accelerated use of standard PC technology and Windows OS for Machine Vision took place. In the early 1980’s, the commercial use of Machine Vision technology, for manufacturing quality control, began to emerge. These early systems were complex in programming and maintaining, difficult to install, limited in performance and, on top of all that, they were very expensive. In the 2000’s, development of ergonomic system solutions for factory integration started, and firewire (IEEE1394) was adopted for digital camera technology [1].

Advances in microprocessor and software technologies dramatically reduced these barriers in recent years, causing Machine Vision to emerge as a powerful process control technology that enables manufacturers to improve quality and increase productivity [2].

The market for Machine Vision is continually growing, and improvements are being added onto the application of Machine Vision on a daily basis.

2.1 Development of Machine Vision

Over the years, many descriptions for Machine Vision have come up. To mention a few, Machine Vision has been described as: the art of using computer-controlled cameras to maintain high levels of quality control in industrial processes [3], a subfield of computer vision [4], or the application of computer vision to factory automation [5]. What can be derived from this is that Machine Vision is used in different environments or applications in order to ensure correct operation and thus elevate quality standards, and that image analysis is the main function of Machine Vision.

Research in the Machine Vision field continues to grow, dealing with the processing and analysis of image data. Its key role is in the development of intelligent systems [6]. These intelligent systems are referred to as Machine Vision Systems. They use digital cameras, lighting/ illumination equipment and image processing software to perform inspections that would be traditionally undertaken by human inspectors [5]. The reason for the use of these systems is to develop machines that have the ability to see, make decisions, act upon those decisions, and learn from experiences [6].

These systems are rapidly being adopted as a standard in assembly systems and other areas of manufacturing due to their high accuracy and consistency. The other reason is to remove human beings from situations or sites in the manufacturing environment, which might be hazardous. Some systems include the attachment of a camera to a robotic arm in order to perform a certain function that a human would usually be responsible for.

2.2 Machine Vision Applications

Machine Vision has become an important constituent of industrial processes as diverse as semiconductor manufacturing, pharmaceutical packaging, film container printing and automobile manufacturing [1]. So, it has simple applications such as counting parts/components, ensuring correct orientation of products to be packed away or stored, to more complex ones such as monitoring bacterial development, stellar alignment to product availability in storage.

There are more complex applications than those mentioned, though. These include the guidance of a robotic arm in welding, sorting and pick-and-place systems. To explore a few of these applications would require one to venture into projects undertaken by companies that utilize Machine Vision.

In the automobile driver assistance area of the Machine Vision industry *Iteris*, which is situated in Santa Ana, California develops lane departure and collision warning systems for trucks and cars; these are used in over 100000 vehicles (2009), and also creates traffic monitoring systems.

For the Sports analysis area *Hawkeye* from Winchester in the UK uses multiple cameras to precisely track tennis and cricket balls for sports refereeing and commentary. And *Sport Universal* in Nice, France develops systems for tracking sports players and the ball in real time, using some human assistance.

There are also general purpose vision systems from companies such as Cognex; from Natick, Massachusetts, which is one of the largest Machine Vision companies (700 employees in 2009), that develops systems for inspection and localization tasks, people counting, and many other areas [7].

Several others exist but here are just a few that deal with Industrial automation and inspection, from the automotive industry to electronics and food and agricultural applications:

- BrainTech (Vancouver, Canada) produces systems for vision-guided robotics in the automotive industry and other robotics applications. The company Perceptron (Plymouth, Michigan) creates 3D laser scanning systems for automotive and other applications.
- Orbotech (Yavne, Israel) develops automated inspection systems for printed circuit boards and flat panel displays.
- Dipix Technologies (Ottawa, Canada) develops vision systems for the baked goods industry that monitor bake colour, shape, and size of bread, cookies, tortillas, etc. and Ellips (Eindhoven, The Netherlands) creates systems for inspecting and grading fruits and vegetables.
- Claron Technology (Toronto, Canada) uses real-time stereo vision to detect and track the position of markers for surgical applications [7].

As explained before, these are but a few of the companies that provide Machine Vision Systems to the different areas of industry. Many systems exist that range in application and complexity, and many others are being commissioned for development as Machine Vision grows in popularity.

2.3 Methodologies Used Within The Machine Vision Industry

These vision systems are mainly concerned with the matching of an array of pixels to another array of pixels under certain lighting conditions; this is referred to as image processing. Commercial and open-source Machine Vision software packages typically include a number of different image processing techniques such as the following:

- Pixel counting: counts the number of light or dark pixels in an acquired image.
- Thresholding: converts an image with gray tones to simply black and white.
- Segmentation: used to locate and/or count parts – usually in a single image.
- Inspecting an image for discrete blobs of connected pixels as image landmarks. These blobs frequently represent optical targets for machining, robotic capture, or manufacturing failure.
- Recognition-by-components: extracting geometric icons (simple 3-dimensional forms) from visual input.
- Pattern recognition: location of an object that may be rotated, partially hidden by another object, or variations in size.
- Barcode reading: decoding of 1D and 2D codes designed to be read or scanned by machines.
- Optical character recognition: automated reading of text such as serial numbers or nowadays even handwriting.

- Measurement of object dimensions in inches or millimetres.
- Edge detection: finding objects’ edges.
- Template matching: finding, matching, and/or counting specific patterns.

A vision system will, in most cases, use a sequential combination of these processing techniques to perform a complete inspection, e.g. a system that reads a barcode may also check a surface for scratches or tampering and measure the length and width of a machined component [8].

2.4 An Ideal Machine Vision System

As explained before, a vision system is made up of a few components and not just a camera. If one had to group these constituents they would fall into three categories; Hardware, Software and Illumination. Another would say that illumination should be classified as hardware, but because of its importance, I choose to discuss it separately.

2.4.1 Hardware

The camera is the most important component or aspect, and will be the most discussed in this section, there is a need to talk about the Processing Hardware (PH) as well. The processor is, after all, the platform on which the software will run.

The PH is a key element of a Machine Vision system and the faster it is, the less time the vision system will need to process each image. It is advisable to use an industrial-grade or ruggedized Personal Computer (PC), due to the vibration, dust, and heat often found in manufacturing environments. The PH in the current case is the Compact Vision System (CVS) that is programmed and/or setup using a PC.

2.4.1.1 Cameras

The focus can now be on the camera which will be used in the vision system. To begin with, let us consider the primary aspects of a camera:

- Resolution: The higher the resolution, the more processing will be done by the host. The advantage of a high resolution is that there are more pixels to work with, if your system can handle the processing load. A high resolution image is also less degraded when magnification is applied to it.
- Processing Hardware: It must be a rugged device that can interface with the necessary hardware (PC, Cameras, and Ethernet and system controller(s)) either through conventional Input/ Output (I/O) ports or an Ethernet port.
- Personal Computer: It must be relatively easy to interface the PC to the PH, and has to have the capacity to accommodate peripherals.
- Sensitivity: Camera sensitivity refers to how much light a camera requires to operate at its best. Higher sensitivity is better - especially where illumination is either not available or is inadequate. Higher sensitivity means shorter exposure times, lower gain settings, and lower-cost optics. Shorter exposure times mean less blur in imaging a moving system.
- Colour: Monochrome cameras produce less data than colour cameras and thus less processing is required. Colour cameras also complicate the system and should be used only if the application prescribes it.
- Interface: There is a need for the camera to interface with a system or processing hardware, and the more options that are available, the better chances there are that a

camera is compatible. Firewire and Gigabit Ethernet are associated interface standards.

- Software: The choice of software package is between using third-party or a Software Development Kit (SDK) to interface to your application [10].

The camera that is utilized depends on the application of your vision system, since software packages have made it possible to use the simplest low-cost camera available. Alternatively, there are a variety of cameras available on the market for Machine Vision purposes, these range from and include smart cameras (supplied by National Instruments, Sony, SOFTHARD, Emerald, LightWise, etc.) to image sensors (Allen Bradley, Cognex, etc.).

Cameras used for digital image processing consists of or are made up of two parts [11]:

1. The Image Sensor, referred to as the Image Acquisition Unit. This refers to Charge Coupled Device (CCD) and Complementary Metal-Oxide Semiconductor (CMOS) technology [12].
2. The Output Unit which generates the signals suitable for image-processing devices.

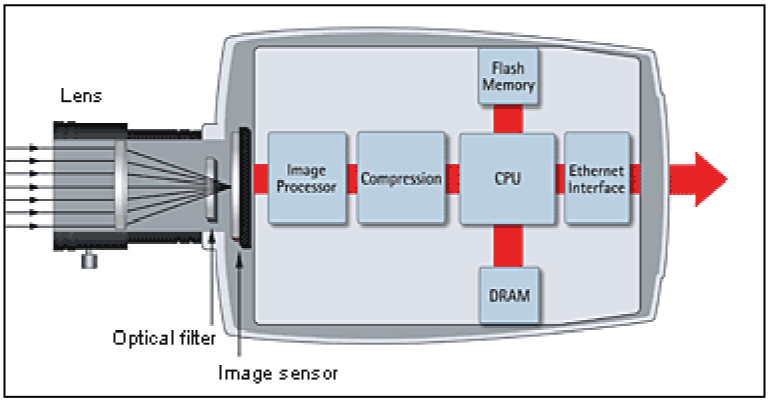

Figure 2.1: Placement of Image Sensor in a Network Camera [12]

2.4.1.1.1 CCD vs. CMOS

Image sensors are responsible for the transformation of light into electrical signals. In the construction of a camera, these two technologies (CCD and/or CMOS) are used for digitally capturing images. These technologies have their respective advantages and also disadvantages, and so far neither one has been proven as superior to the other.

In a CCD sensor, each pixel charge is transferred through a limited number of output nodes, converted to a voltage, buffered, and sent off-chip as an analogue signal.In a CMOS sensor, each pixel has its own charge-to-voltage conversion and the sensor often includes amplifiers, noise correction and digitization circuits, so the chip outputs digital bits [13].

2.4.1.1.2 CCD Advantages and Disadvantages

CCD technology is used for the following reasons:

1. It has better light sensitivity, which translates to better images in low light conditions.
2. It is produced using technology developed specifically for the camera industry.

The reasons to avoid them are:

1. They are more expensive because of the process of making them and they are complex to incorporate into a camera.
2. The CCD tends to “bleed” when a very bright object is part of the scene/image to be captured. This causes vertical stripes below and above the object, called smears.

2.4.1.1.3 CMOS Advantages and Disadvantages

The advantages of CMOS technology are:

1. Image quality is very close to CCD quality.
2. They provide a lower cost for cameras because they allow cameras to be easily built around them, making it possible to produce smaller cameras.
3. Large sensors are available to provide Megapixel resolution.

The disadvantage is that the 'Lower Light sensitivity' of CMOS sensors places a limitation on this technology as compared to CCD sensors. Further comparison of the two technologies is presented in Table 2.1.

Table 2.1: Feature and Performance Comparison[14, 15]

Feature	CCD	CMOS
Signal out of pixel	Electron packet	Voltage
Signal out of chip/sensor	Voltage (analogue)	Bits (digital)
Signal out of camera	Bits (digital)	Bits (digital)
Fill factor	High	Moderate
Amplifier mismatch	N/A	Moderate
System Noise	Low	Moderate
System Complexity	High	Low
Sensor Complexity	Low	High

Camera components	Sensor + multiple support chips + lens	Sensor + lens possible, but additional support chips common
Relative R&D cost	Lower	Higher
Relative system cost	Depends on Application	Depends on Application
Performance	CCD	CMOS
Responsiveness	Moderate	Slightly better
Dynamic Range	High	Moderate
Uniformity	High	Low to Moderate
Uniform Shuttering	Fast, common	Poor
Uniformity	High	Low to Moderate
Speed	Moderate to High	Higher
Windowing	Limited	Extensive
Anti-blooming	High to none	High
Biasing and Clocking	Multiple, higher voltage	Single, low-voltage

2.4.2 Software

Software application packages have developed or evolved to the point where one can use a webcam partnered with a standard processor to produce a Machine Vision system. The other advantage, nowadays, is the simple point-and-click interface that simplifies the programming process. What sets software packages apart, though, is the following:

- Inexpensive Vision Application
- Links Vision to Motion
- Interactive Graphic User Interface (GUI) [Simplicity is key]

- Socket-based Server Application Programming Interface (API) [The more interaction with useful software packages (from other vendors) that is possible, the greater the benefit for the software package]
- Multiple Interfaces [Disk, Web, File Transfer Protocol (FTP), Email, etc.]
- Plug-in Framework for Custom Modules
- Active Online Community [16].

Machine Vision software with graphical user interfaces are usually easier to use than specialized code (C++, C#, visual Basic) packages, although the code-based packages can be more flexible and faster even if they do need specialised programming knowledge. The software packages that offer both graphical user interfaces and code-level development have an advantage over the ones that only offer one option, and leave the decision of which platform to use up to the user. The users then determine which is best suited for their specific vision requirements [17].

2.4.3 Illumination

The level of ambient light is normally not constant and changes without prior notice, so alternative forms of artificial lighting are used in a vision system to provide a controlled level of illumination. Uneven object illumination is a source of degradation of the image [18].

The best or ideal illumination system is the one that yields the best results by enhancing the features that are important to the vision system and hides those features less likely to be used in the particular quality control system. The methods in Table 2.2 all have their unique illumination sources and the features they enhance in an image are listed in the table for each.

Table 2.2: Illumination Methods and the Features They Enhance in an Image [19, 20]

Method of Lighting	Feature Enhanced
Back Lighting	Edges
Bright Field Illumination	Contrast
Co-Axial Illumination	Less Reflection, Minimizes Shadows
Dark Field Illumination	Bumps, Ridges and Coarseness
Diffuse Lighting	Reduces Specular Reflections

2.4.3.1 Illumination Techniques

Two factors determine the effectiveness of an illumination source used in an inspection configuration:

1. The direction at which the light strikes an object.
2. The direction of the reflected light into or away from the camera

There are also three factors that qualify illumination as suitable:

1. The illumination must cover the required field of view uniformly.
2. There must be a consistently measurable degree of contrast.
3. Illumination must not cause reflected glare [19].

The above leads to the investigation of the types of reflection one will encounter and the different types of illumination in Machine Vision.

2.4.3.1.1 Reflection Types

Reflection can be said to be a change in the direction of a wave-front at an interface or point that hinders it from travelling on the original path.

The reflection off of objects by light can be classified as specular (e.g. light reflecting off a mirror) and diffused (e.g. light reflecting off a copier paper). There are objects that give off reflections that have both specular and diffuse properties. This relates to those objects with shiny, specular surfaces, and dull, diffuse surfaces.

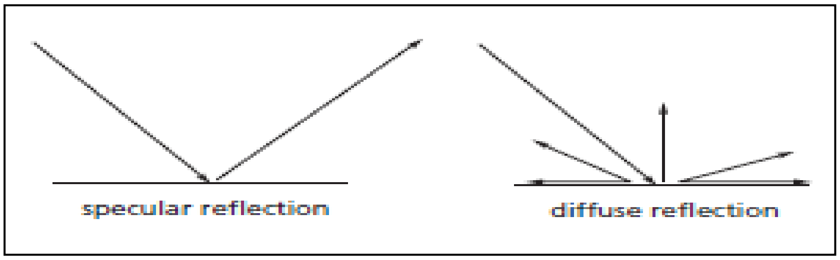

Figure 2.2: Types of Reflection of Light Incident on a Surface [20]

2.4.3.1.1.1 Specular Reflections

The properties that best describe a specular reflection are:

1. Bright: The intensity of the reflection is equal to the intensity of the illumination source, which tends to saturate the camera.

2. Unreliable: A small change in the angle of the illumination on the object may cause the reflection to disappear from the view. The angles need to be well-controlled or they are not of use to the inspection process.

2.4.3.1.1.2 Diffuse Reflections

Properties that best describe diffuse lighting, on the other hand, are:

1. Dim: The intensity of the reflection is less than that of the illumination source even though the reflected light in any direction will be less than the incident light, because it changes slowly with the angle of the light on the object.

2. Stable: A change in the angle affects the intensity slightly and does not cause the reflection to disappear completely from the view of the camera [20].

Derived from this is that diffuse lighting is the best choice in illumination whether one illuminates objects which give off a specular or diffuse reflection. Of course there are other factors such as the influence of shadows on the object that also have to be considered when formulating the best method of illumination.

2.4.3.1.2 Illumination Types

In the illumination of an object that is to be inspected it is at times apparent that more than one type of lighting is required to successfully capture a good quality image, or more to the point, to capture an image that highlights all the features needed for the inspection process to take place. That is why the discussion of the different types of illumination/ lighting was necessary.

Machine Vision illumination can be classified into five categories; namely bright field, dark field, back lighting, diffuse lighting and co-axial illumination, as illustrated in Figure 2-3 below.

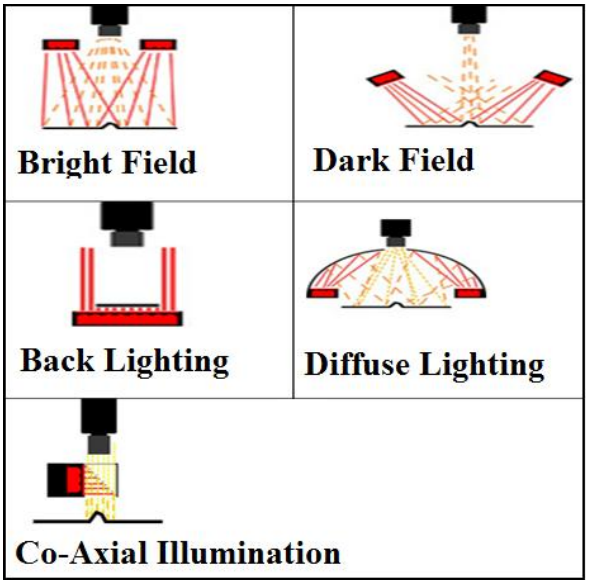

Figure 2.3: Types of Illumination Techniques [19]

2.4.3.1.2.1 Bright Field

In Bright Field Illumination:

- The light is aimed directly at the object.
- Distinct shadows are created because of the angle of illumination.
- Specular reflections are created on shiny objects.

This lighting type is effective when used on objects that require a high degree of contrast.

2.4.3.1.2.2 Dark Field

In Dark Field Illumination:

- The light is at an angle to the surface.
- Any variation deflects light into the camera.
- Bright spots are created on a dark background or field.

When using this type of illumination, nothing will be seen or captured by the vision system if there are no abnormities (bumps, ridges or coarseness) on the object under inspection.

2.4.3.1.2.3 Back Lighting

In back lighting:

- The field of illumination is even and projected from behind the object, in the direction of the camera.
- The object is seen as a silhouette by the camera.

Back lighting is used, in most cases, for taking measurements and to determine the orientation of an object.

2.4.3.1.2.4 Diffuse Lighting

In diffuse illumination:

- The light is reflected onto the object under inspection. This reflection is of a diffused nature.

- The light onto the object is soft/not so intense and does not cause harsh shadows.

This type of illumination is suited for shiny objects prone to specular reflections.

2.4.3.1.2.5 Co-Axial Illumination

In co-axial illumination:

- A variation of diffuse light is aimed at an angled beam splitter which reflects light down onto the object.

- The object is viewed through this beam splitter.

This illumination is useful when dealing with highly reflective surfaces and objects, and inspection areas that are bothered by shadows [19].

2.5 Chapter Summary

The first application of Machine Vision was for military image processing purposes in the 1940's, and it was only applied industrially between the 1960's and 1970's. Then the industrial application of Machine vision grew from the 1980's onwards, encouraged by industrial systems, new camera technology and personal computers.

Machine Vision systems are expensive to implement initially, but because of the long term benefits they are slowly assisting more humans in avoiding tasks that place them in dangerous situations within certain industries. Applications utilizing Machine Vision form part of more and more industrial processes in different environments such as biology, packaging, and manufacturing.

A Machine Vision system uses a combination of different processing techniques to perform a complete and correct inspection. Some of these processes are pixel counting, barcode reading, edge detection, template matching and segmentation. Machine Vision Systems consist of hardware, software and illumination devices. Hardware does not only have to do with the camera, but also the personal computer. Software packages have evolved to a point where they are not only easy to use, but are also becoming cheaper to acquire.

When dealing with illumination devices, one has to look at the different techniques, as well as the reflection characteristics - such as specular and diffuse reflection, displayed by the type of illumination chosen. There are five illumination types or categories; bright field, dark field, back lighting, diffuse lighting and co-axial illumination.

In the next chapter, the methods and implementation strategies that are involved in the machine vision industry are discussed, and the different components that will be involved in the development of the project are evaluated.

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3 METHODS AND TECHNIQUES OF IMPLEMENTATION

This chapter was written with the intention of formulating a strategy that assisted in the development of the Machine Vision System, by combining methods commonly used in industry and exploiting the tools available in the software chosen to be used in the implementation of the project/system. This involved presenting questions that were necessary to resolve the problems that were faced in the project: asking questions and finding answers that helped in the completion of the project. The chapter is compiled in such a way that it informs and gives a background on the thoughts that went into the process of developing the Machine Vision System. The aim was to present a comprehensive piece of literature that explained and/or clarified the decisions behind the project.

The Machine Vision system was aimed at resolving two matters, which are categorized as Quality Control, and Assembly-Setup Verification. Quality Control involved the checking of the product developed by the assembly system at different stages of the assembly process, i.e., at the sub-cells of the system. Assembly-Setup Verification on the other hand was more concerned with the behaviour of the system and the function of the sub-cells. Sub-cells consist of components in the assembly system, which are rearranged in order to satisfy the demand of the system to produce a different product.

In order for the previous paragraph to make more sense, an overview is given of all the different components that contribute/form part of the project; i.e. the assembly system, the product, and the machine vision system developed for the assembly-setup verification and quality control within the assembly system. The other element of the project that needed clarification is Reconfiguration, which is a constituent of the assembly system. Clarification is given in the different discussions surrounding the project components.

3.1 The Assembly System

The first step towards explaining the implementation of the vision system as well as the integration of it into the assembly system is to consider the assembly system, identify the areas that the vision system will be working in (i.e. looking at where the inspection areas are) and the position of all the components that make up the assembly system (i.e. conveyors, sensors, gantry systems and robotic arms). Figure 3.1 below illustrates the layout of the assembly system under discussion and the components that make up the system. Focus was given to Section Two of the assembly system wherein the vision system operates, and thus Section One highlighted by the yellow-rounded rectangle does not form part of the discussion on the assembly components. The areas of inspection are located below the camera positions, and the cameras are numbered according to which one was mounted and worked with first, instead of the order that they are placed in; from left to right.

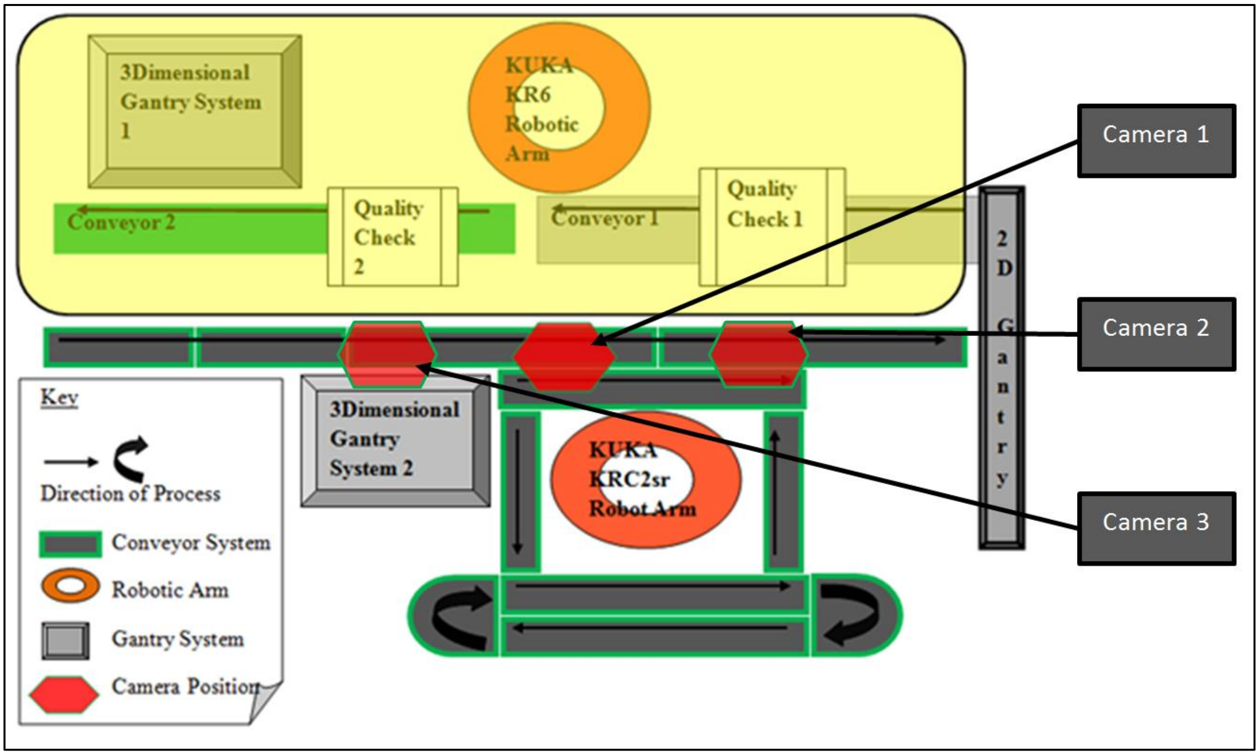

Figure 3.1: The Layout of the Assembly System

More on the significance of the cameras will be discussed under Machine Vision System; section 3.3. All the other components of the assembly system are discussed hereafter in order to understand their function in the system, and their significance in the system's reconfiguration capabilities.

Seeing that the conveyor is responsible for transporting the product as it goes through the assembly process- making assembly possible - it was ideal to start there before any other component was discussed. Figure 3.2 shows the conveyor system and the direction of travel of the different sections of it, as well as highlighting the areas of inspection which the product passes during its journey through the assembly process. Between Quality Check 1 and 2, two conveyors run parallel to each other; this was intended to increase productivity: by possibly having the robotic arm work on assembling two products concurrently. The conveyor belt, seen in the image to be moving in the direction of the Rework Conveyor, is used in cases where a pallet needs to be removed from the main assembly line: i.e. the conveyors between the three-dimensional gantry system and the two-dimensional gantry system. This removal is done in cases of ‘rejected’ or ‘Failed’ products. This rejected product then goes on to the rework conveyor belt system to be manually reworked; the specified pattern of blocks is placed in the pallet, and then fed back onto the main assembly line; towards the final quality check area. A final verification then takes place to ensure that the product is of a good quality.

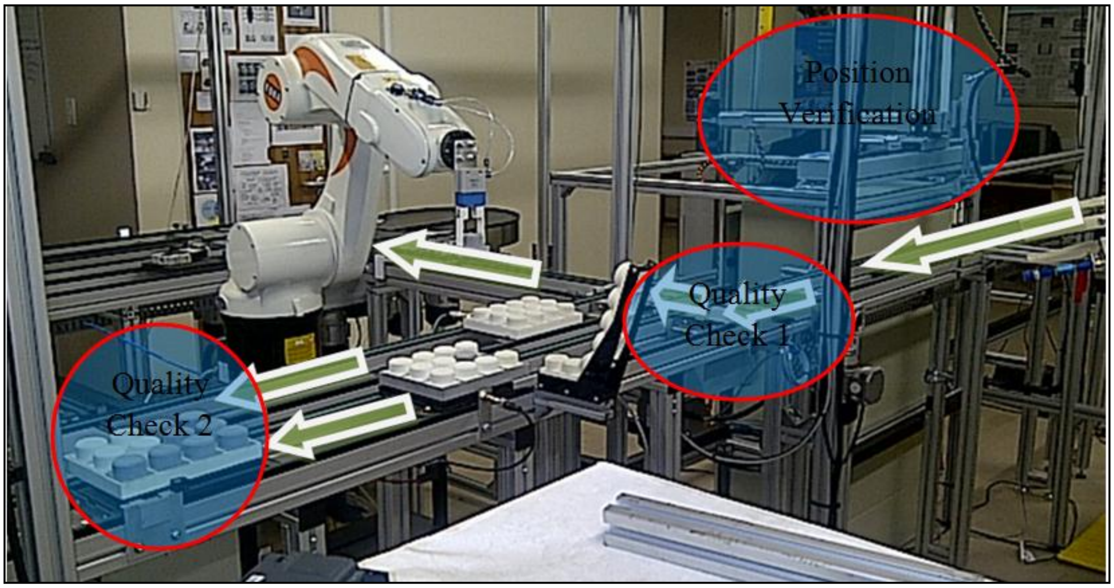

Figure 3.2: The Respective Directions of Travel of Different Conveyors within the Conveyor System

As mentioned, the conveyor moves the product through the different stages of assembly and each section of conveyor is bidirectional; moving in two directions, dependent on the control system of the assembly system. Different positions on the conveyor can be set up to allow a product to be stationary whilst the conveyor is running; i.e. at the inspection areas. These two capabilities make the conveyors integral parts of a flexible transport system, and this contributes to the flexibility of the assembly system. This flexibility allows the product to be moved around within the system as needed to complete assembly.

Tracking, or rather identifying the presence of an object as it is transported through the system, is necessary in such a system and the assembly system is not exempt from the need to know if a product is where it needs to be at any point in time. Simple applications such as using sensors at the inspection areas to initiate an action when a product is detected can be the key in a successful product assembly process. This being said, proximity sensors were employed in the assembly system at the different points where a product stops in order for some action of assembly to be executed. Figure 3.3 shows a proximity sensor mounted at the point of assembly with a product in front of it.

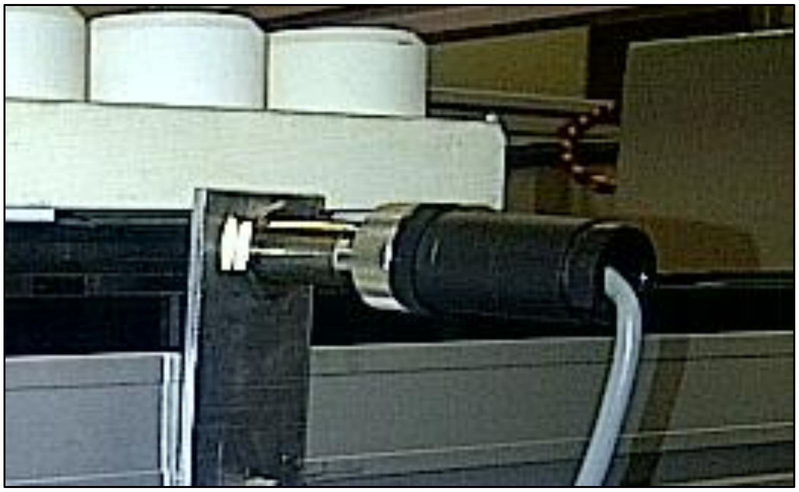

Figure 3.3: Proximity Sensor to Detect Product at Assembly Point

There are two gantry systems on the assembly system layout; a three-dimensional gantry system at the position of Camera 3's inspection area, and a two-dimensional gantry situated on the far right in the layout image. A gantry system is a number of motion devices that create straight-line motion, arranged in such a way that they can take an object from one point and place it at another; some arrangements make it possible for up-down, forward-backward, and left-right movement of objects (three-dimensional). An example of a three-dimensional gantry system is shown below in Figure 3.4. The arrangement of the different motion devices in the gantry system is inspected before the initialisation of the assembly system, but this will be covered under the machine vision system discussion. The markers indicated in the figure refer to small stickers placed on the gantry that aid in the inspection process by providing a reference point in the image when the use of measuring or position tools is considered. Since the three-dimensional gantry system is responsible for the initial work on the product it is placed right at the beginning on the assembly system.

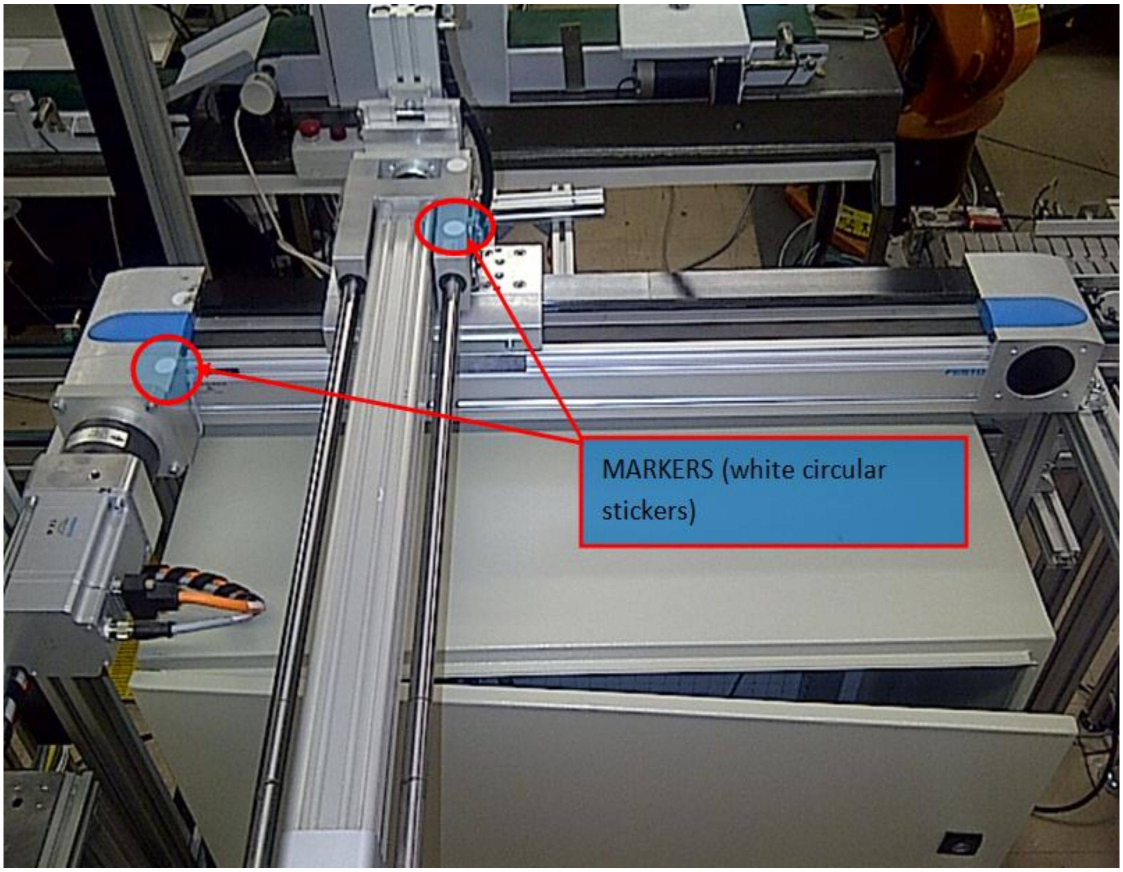

Figure 3.4: The Three-Dimensional Gantry System at Camera Three's Inspection Area with Markers

The pick-and-place process of assembling the product is supported by the gantry system as well as the robotic arms within the assembly system. The robotic arm is a mechanical instrument which is capable of performing the same functions as a human arm, like moving through X-Y-Z coordinates and picking up an object to move it to a different destination. The arm is programmed to perform these functions and the weight that it can pick up is limited according to design specifications thereof. Below, in Figure 3.5, is an image of a Keller Und Knappich

Augsburg (KUKA) Robotic Arm in the process of picking up a part and placing it in the pallet to complete a specified product arrangement. The Robotic Arm works on pallets moving on both conveyors; running parallel to each other, concurrently picking blocks from the magazine and placing them in the pallet.

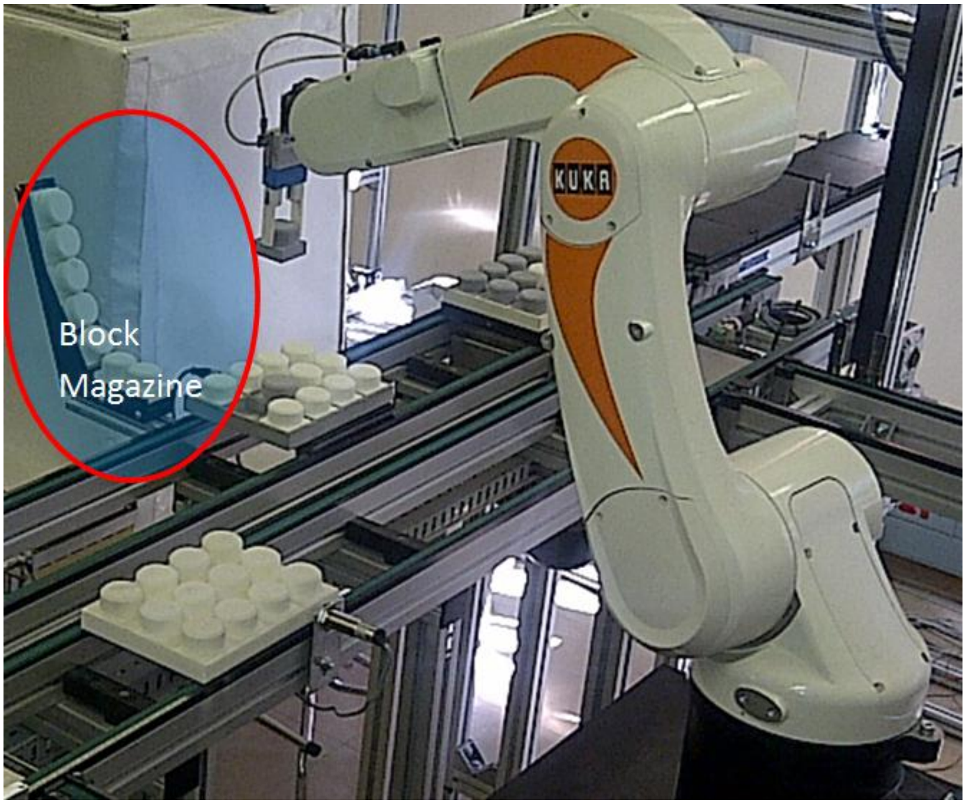

Figure 3.5: KUKA Robotic Arm Picking and Placing a Part into a Pallet

The robotic arm and all the other components of the assembly system work together to accomplish the assembly of a product, and the synchronicity of this process is controlled by a

Programmable Logic Controller (PLC). The PLC is responsible for distributing the instructions to the components in order to accomplish the assembly tasks necessary in the system.

Reconfiguration of the system has more to do with the fact that the system is capable of changing the route that the product takes through the process of assembly by relying on the flexibility of the conveyor system mentioned previously, and can be instructed to change the type of product that it assembles. This reconfiguration is accomplished with the aid of all the different components that make up the system and the control logic of the PLC.

It is important to mention that the Multi-Agent Control System is responsible for scheduling the assembly tasks that result in a completed product, i.e. the route that the pallet should take and the actions that are taken at each stage of assembly.

3.2 The Product

When dealing with engineering endeavours, it is always an advantage to become familiar with the main component/problem or test object. So before attempting to solve the current problem or develop a system, it was best to take a look at the product developed by the system in order to find a Machine Vision solution. The product is a rectangular tray; referred to as pallet herein, with a length of 200 millimetres, a width of 153 millimetres and a height of 20 millimetres when empty, and twice as high when filled with parts.

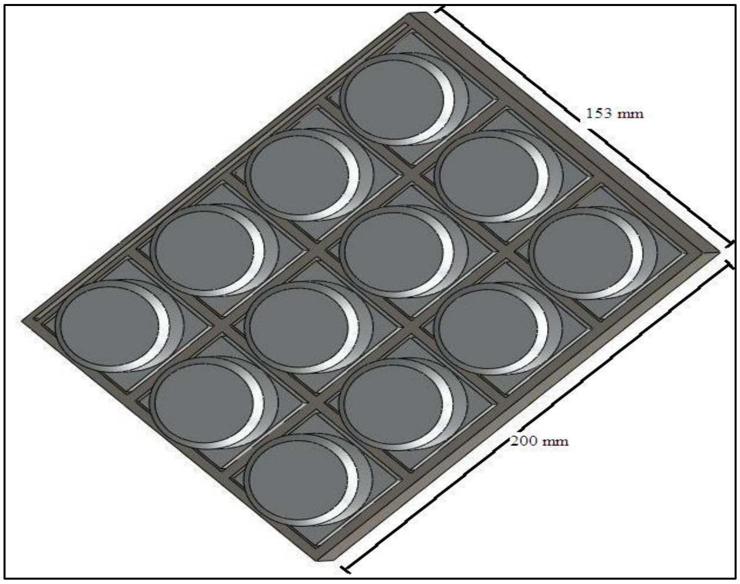

Figure 3.6: Gray Pallet Filled with Parts

The tray was moulded to accommodate twelve parts which are square-based 40 millimetre (length and width) in size. So there was a need for the machine vision system to identify the tray and determine whether it was empty, partially full or fully packed, despite the orientation of the pallet.

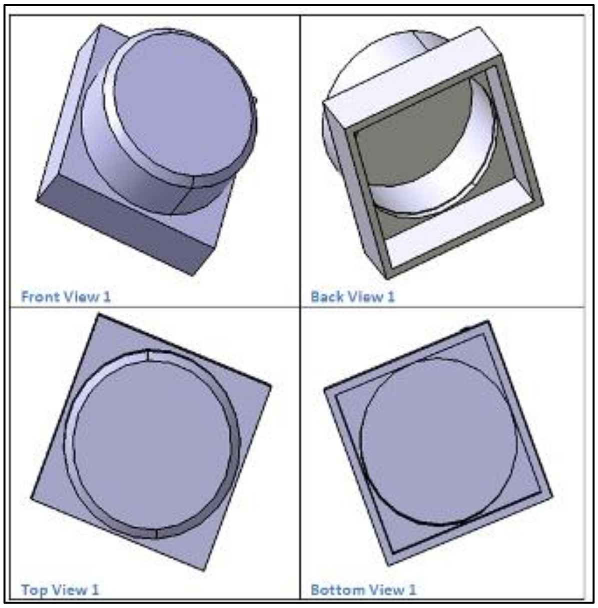

Figure 3.7: The Part to fit into Pallet

The quality of the final product assembled by the system is determined by the arrangement of gray or white parts, as seen in Figure 3.7, inside the pallet in a specific pattern, namely white parts in the shape of the letter ‘A’ (uppercase) or alternatively the letter ‘b’ (lowercase) in a gray pallet. The decision taken was that these arrangements in the gray and white pallet would constitute the number of products that the vision system has to identify and check for quality; i.e. four products: white pallet with gray letter ‘A’, white pallet with gray letter ‘b’, gray pallet with white letter ‘A’, and gray pallet with white letter ‘b’.

The remaining (empty spaces) in the pallet should be filled with blocks of the same colour as the pallet itself. A representation of this is given in Figure 3.8; pattern A, on the left, and b, on the right, are shown in a gray pallet.

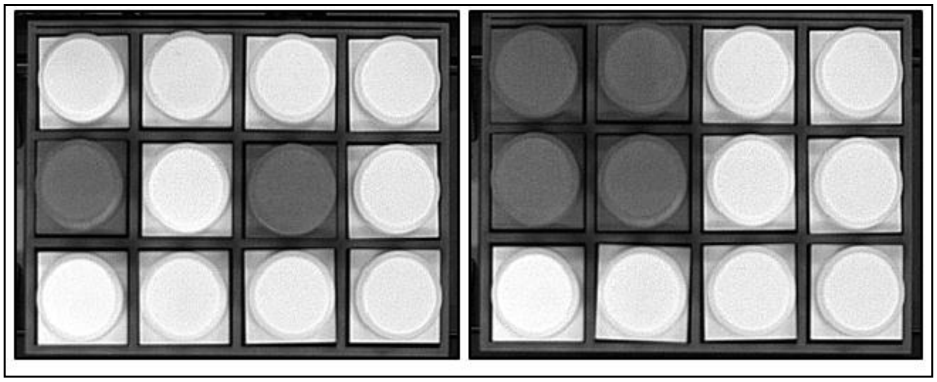

Figure 3.8: Two Products that are assembled by the System (Patterns A and b on a Gray Pallet)

The vision system is tasked with identifying these arrangements despite the orientation of the product, or whether they are in a white or gray pallet. So even if the pallet is rotated 180° the vision system should be able to identify it. Other pattern arrangements can be introduced and the vision system should have some level of flexibility to enable the identification of new products, but for the purpose of this project only the four products mentioned form part of the discussion in this thesis.

3.3 Machine Vision System

The Machine Vision System is a combination of software and hardware devices that work together to complete a task. In order to develop a Machine Vision solution, an understanding of the problem is important and the tasks that needed to be completed by the System had to be laid out clearly; i.e. ‘assembly-setup verification’ and ‘quality control’ had to be understood in order to have a satisfactory output.

Assembly-setup Verification has to do with verifying the arrangement of the gantry system's different parts, meaning how the moving and non-moving parts are orientated with respect to each other. This process requires a visual verification and communication with the assembly system controller. Visual verification refers to image acquisition and processing, and the results from this can be communicated to the assembly system controller (PLC).

Quality Control involves the visual identification of the correct, as well as complete, product that the system assembles.

The discussion that follows deals with the decisions taken with regard to the components that were used in the development of the Machine Vision System that will conduct the abovementioned tasks.

3.3.1 Hardware

The discussion here is focused on the type of camera to be used in capturing the images necessary for the inspection process.

The Personal Computer (PC) did not form a major part of the discussion and/or any investigation that was conducted before. The reason for this stems from the aim of the project, which was to end up with a standalone Machine Vision System, or rather a vision system that is independent of a PC, once the vision system has been programmed via the PC. The PC, however, was important for two reasons; it housed the software needed to develop the inspection program and configure the tools within that program to suit the needs of the project.

The hardware that is important to mention, however, is the Compact Vision System that houses the processing hardware which is vital to the standalone operation of the vision system. The CVS can operate on its own after programming and reconfiguration by the PC, and can also communicate with the assembly system controller.

3.3.1.1 Types of Cameras

In order to motivate the choice of camera that was used in the system, the different cameras that were considered in the beginning of the project had to be presented and then evaluated accordingly.

3.3.1.1.1 Fire-wire Camera

A fire-wire camera is a widely used standard camera that transmits video data. These cameras use the IEEE 1394 bus standard of communication, which is a serial bus interface standard for high-speed communication and regular real-time data transfer. The type of fire-wire cameras used in the automation industry are specialized and do not provide audio data. Fire-wire cameras are based on Charge-Coupled Device (CCD) or Complementary Metal-Oxide-Semiconductor

(CMOS) chips which have small light-sensitive areas divided into pixels. The camera that was available for incorporation into the assembly system was a Basler A601f [1].

3.3.1.1.2 Gigabit Ethernet Camera

Gigabit Ethernet (Gig-E) vision is a recent standard of interface used for high-performance industrial cameras, based on the Internet Protocol standard. This means the data acquired from the camera is transmitted in packet form through a network. Some of the features of a GigE vision camera include fast data transfer rates (1000 Megabits per second), data transfer lengths of up to 100 meters, networking with other Ethernet devices, and it delivers a standardized environment for the delivery of new-generation, networked video applications. This is also a low-cost solution because it uses low-cost cables and standard Ethernet connectors which allow low-cost integration [2].

3.3.1.1.3 Vision Sensor Camera

Allen-Bradley Multi Sight cameras are optical multi-pixel sensors with a pass or fail PNP output that uses three different methods of evaluation (pattern matching, contrast, and brightness) to detect or differentiate. The advantage of the 48MS Multi Sight is that it is easy-to-use and economical, allows multiple inspections using one sensor, and setup is simple using a PC and configuration software [3].

3.3.1.2 Comparison of Cameras

After investigating the different cameras that are available and those that can be acquired easily and quickly, the next issue that needed a resolution was choosing the right camera for the task at hand. An ideal camera for this project would be one that can change accordingly to satisfy the needs of this project and any future changes that might be implemented. This decision was taken by comparing the cameras, and thus looking at their features as well as the advantages of each as opposed to the others. The above method of selection is just the first that will be employed in this study, the second will involve looking at some of the features that make a camera useful, such as the resolution, sensitivity and the maximum frame rate, and looking at the options relating to colour, interface and the software each can accommodate. The next step would then involve comparing these features to the specifications that are ideal for the Machine Vision currently under investigation. A discussion will ensue after the assessment to determine the best camera choice.

Table 3.1: Comparison of the Three Cameras That Were Considered

Type of Camera	**Features**	**Advantages**
Fire-wire Cameras **[4]**	• Small and rugged casing • Up to 100 frames per second (fps) at Video Graphics Array (VGA) resolution and up to 25 fps at 1.3 megapixel	• Real-time communication between the camera and remote PC (400 Megabits per second) • Easy integration

	resolution • CMOS global shutter image sensor • Plug-and-play IEEE 1394 interface • Calibrated for consistent performance and reliability	• Cost-effective and standardized • No need for a frame grabber
Gig-E vision Cameras [5]	• Small and rugged • VGA to 2 megapixel resolutions • CCD sensors that are precisely aligned • Easy connection with gigabit Ethernet Interfaces • Calibrated for consistent performance and reliability	• Perfect fit for vision applications such as component inspection • Provide outstanding image quality for precise imaging results • Fully tested Gigabit Ethernet drivers for reliable and flexible image data exchange • Compatible with the latest vision industry standards
Vision Sensors [6] [7]	• Industrial Housing (IP67)	• Easy handling and setup • Short evaluation time

	• High resolution CCD sensor • Ethernet Interface to store images in a PC or Server • Designed for standalone operation • Built in LED lighting	• 10 virtual detectors • 3 evaluation methods

Table 3.1 shows that several similarities can be found between the cameras, but in order to determine which of these is suitable for the Machine Vision System a discussion will be carried out focusing mostly on their differences. Cameras rely on their image sensors to function and thus a discussion relating to the sensors is appropriate. The Allen-Bradley (AB) 48MS Multi Sight sensor and the Basler Scout scA640 camera both depend on a CCD image sensor. CMOS image sensors; used by the Basler A601f fire-wire camera, also produce good quality images similar to the CCD. The other difference between the image sensors is the data output format; the CCD produces an analogue signal which is converted to digital bits off chip, however, the CMOS sensor outputs digital data. Analogue signals tend to be less tolerant to noise than digital signals and the conversion of analogue to digital data results in the loss of information.

Table 3.2: Camera Resolutions and Frame Rates

Type of Camera	Resolution	Maximum Frame Rate
Basler A601f (fire-wire camera)	656 x 491 pixel	60 frames/ second
Basler Scout scA640 (GigE vision camera)	659 x 490 pixel	70 frames/ second
Allen-Bradley 48MS Multi Sight Camera (vision sensor)	640 x 480 pixel	N/A

Looking at the resolution column of Table 3.2 one conclusion that came forth was that the AB 48MS Multi Sight is a better choice, due to the fact that a higher resolution in a camera results in the need for more processing power from the PC or interfaced inspection device. The reality, however, was that a vision sensor lacked the flexibility of the cameras under discussion that rely on software packages for image processing tasks. The vision sensor, albeit easy to configure and setup, only has limited inspection functionality due to its on-board software system and could only offer pass or fail information.

3.3.1.3 Reason for Selection of Camera

The selection of the camera, although it had to do with the type, features and advantages did not stop there, because the environment that the system was to operate in also contributed to the choice. Other factors that were kept in mind included possible future improvements on the vision system and the assembly system - which were unknown at the moment of development, but influenced the choice to be made. Since the question of what the changes might be could not be answered, an assumption had to be made that there will be changes and that these changes will require the vision system to adapt or be replaced. An adaptive vision system will require a camera that is able to work with any software or additional hardware that might be added to the system as improvements are made, and one that is able to interface with the new hardware.

The previous discussion on the image sensors used by the three categories of cameras was taken into consideration in order to choose the best camera for the vision system. CMOS sensors; utilized by the fire-wire camera, were highlighted as the best choice for a camera that will operate in an environment with varying light conditions. The digital data provided by the CMOS image sensor chip also tipped the scale in favour of the fire-wire camera. The other cameras were not disqualified because they are designed for use in a Machine Vision System. Gig-E vision cameras are designed to work in an industrial environment and vision sensors are designed as standalone devices that communicate the state of inspection (pass/fail) to a Programmable Logic Controller (PLC) or another type of control device. In the end, the fire-wire camera was chosen for use in the implementation of the project.

3.3.2 Software

Software packages considered as ideal for a Machine Vision System had to conform or satisfy certain criteria, such as being inexpensive or if expensive the software had to be able to work with inexpensive hardware (cameras and illumination sources). The software should present the user with the option of both a graphic user interface and a code-based configuration platform.

The selection of the software to be used involved answering the following questions:

1. Which software packages can be used to solve the Machine Vision problem?
2. How will the software package fit into the assembly system under development? Does the system use other products that might benefit from the use of a particular software package?
3. Looking forward, will the software have the necessary support it needs to stay beneficiary to the assembly system?
4. Will the software satisfy the current needs of the system and any changes that might need implementation later? How flexible is the software when it comes to change?
5. Is the software affordable?

The software selection process normally involves the short-listing of software packages, and testing their respective capabilities by acquiring demos from the various vendors. On top of this, the vendor’s service record, in respect to support would have to be evaluated as well as the type of user training on offer [8]. This process, however, was not employed in this project because of the availability of a particular software package that might meet the requirements of the system under development. However, for the sake of the study other software packages were investigated in order to present the differences and similarities that exist between vision software packages.

3.3.2.1 Types of Software

Machine Vision Software allows one to combine a camera and/or other vision devices into a system that can be integrated into an assembly system or production line. The software works as an interface between the vision system and the assembly system to perform analysis and inspection on an image. Machine Vision Software can be categorized into General-purpose and Application-specific software packages. General-purpose Machine Vision Software packages cater to the industrial engineering environment that is always changing and requires a number of inspection tools offered as a single package. Application-specific Machine Vision Software, on the other hand, offers users a single specific tool that can be incorporated into a predefined application. Different Machine Vision Software manufacturers exist and the methods they use to design and develop these software packages has resulted in the existence of three known types of software systems within the aforementioned categories, namely Library-based, Closed, and Component-based systems.

Library-based systems are designed for PC-based vision systems that consist of libraries that enable users to develop their own applications by using functions that are archived in a library. The drawback, and also the advantage, is that the user has to develop a Graphic User Interface (GUI) and also program the interaction between the GUI, the vision solution and the production line.

Closed systems are executable programs housed on a manufacturer's hardware and cater to users that dislike or want to avoid programming their own Machine Vision applications. The user is instead tasked with the duty of configuring the system.

Component-based systems make use of the Component Object Model (COM), a binary-interface standard for software components introduced by Microsoft in 1993. COM enables inter-process communication and dynamic object creation in a programming language. Component-based systems encapsulate certain task-oriented Machine Vision functionality and have standardized interfaces that support network usage [9].

3.3.2.2 Comparison and Selection of Software Packages

There are many manufacturers of Machine Vision Software and thus many software packages, and this means that comparing all these software packages is possible yet impractical because some are so similar to each other. The aim in this section will be to look at and compare the types of software available instead of the numerous software packages. General-purpose and Application-specific software types were the first to be scrutinized in a table, highlighting the advantages and disadvantages.

Table 3.3: Advantages and Disadvantages of Different Types of Software

Type of Software	Advantages	Disadvantages
General-Purpose Software	• Performs a variety of tasks • Has multiple tools • Larger Return on Investment (ROI) because Multiple solutions can be developed [10]	• Time is needed to learn the software • Dependence on the software • Lack of knowledge relating to the hidden theoretical applications [10] • Expensive initially
Application-Specific Software	• Ease of use • Not as time consuming to learn • Cheap initially	• Developed for a specific task • Has only the tools necessary for that task • Increase in expenses when a different solution is needed

Based on Table 3.3, General-Purpose Software emerged as the ideal software product for a user with a big budget and enough time to learn and get familiar with the software environment. This being said it offered many tools and the ability to render multiple solutions for a single purchase price. Application-Specific software, on the other hand, offers the user a single solution and is not expensive, but this means for every solution needed in the future another purchase will be made to satisfy the problem. So both software types are useful depending on the user's needs.

The comparison of specific software packages available on the market has proven to be a difficult and daunting task because software manufacturers market their packages wisely and avoid highlighting the faults or drawbacks of their software packages.

The key here lay in defining a different evaluation strategy by looking at the proposed methods that were selected by other users. There are, for instance, those users that evaluated software packages according to ease of use and this involved purchasing different software packages or downloading demos or trial versions that some software manufacturers avail to users [10]. The novice user might be advised to adopt this method in order to get him on the road to finding a working vision solution.

The other method that can be used is looking through user feedback and comments from the forums that some manufacturers have on their websites and then seeing which software package has the least complaints and, on assumption, the least faults with it. The problem or shortfall with this selection method is that previous users might not have used the software to solve the same problem as the one you are faced with. This might result in the acquisition of a software package with inadequate resources and tools, leading to the failure of developing a functioning vision solution.

So, in order to choose the software package used to solve the Machine Vision problem, a comparison according to Compatibility, Flexibility, Affordability and Support was done. The software package purchased by the institution; namely National Instruments Vision Builder for Automated Inspection, and two other Machine Vision Software packages were compared; all of this was done in the form of a table.

Table 3.4: Comparison of Software Packages

	Machine Vision Software		
Criterion of Evaluation	National Instruments Vision Builder for Automated Inspection (NI VBAI) [11]	MVTec HALCON	MicroscanVisionscape®
Features	• Delivers complete vision solutions • No programming • Communication	• Large library for low, medium and high level image processing	• Comprehensive Machine Vision software for multi-platform use

	with PLC and other industry devices • Reads and Writes image files • Colour image processing • Makes complex decision making from inspection results	• Easy programming in C, C++, C#, Visual Basic .NET (VB), and Delphi • Colour image processing • High accuracy measurement • OCR and OVR [13]	• Point and click environment • Colour imaging • Optical Character Recognition (OCR) and Verification (OCV) [16]
Compatibility	• Compatible with IEEE 1394 cameras and GigE vision cameras, and National Instruments Compact Vision System (NI CVS)	• Supports industrial cameras and frame grabbers (GenlCam, GigE vision, IIDC 1394, USB 2.0, Camera Link) • Supports multi-processor and multi-core PCs [13]	• Can be used on GigE vision cameras, smart cameras (VS-1), and Machine Vision boards [16]
Flexibility	• Can run as a	• Intuitive	• Creation of custom

	standalone application • Can be embedded into an application (ActiveX)	development tool *HDevelop with code export feature, to C, C++, C#, or VB [13]	user interface in VB 6, VB.NET, and C# [16]
Affordability	• Initially expensive but the package makes up for the price: full features for development, benchmarking and deployment • Discount for academic institutions • Return On Investment: Develop multiple solutions using one package	• Initially expensive but worth the cost considering what is included: a development and deployment software for multiple solutions • Return On Investment because of the number of solutions that can be developed	• Initially expensive • Return On Investment, caused by multiple solution development from the same software package [16]
Support	• NI Online help and forums • Worldwide	• Comprehensive documentation • Smart online help	• Self-Help Technical Support • Worldwide partner

	Support with local staff (RSA included)[12]	- Worldwide Support (RSA excluded)[14]	network to offer support (RSA excluded)[17]

* HDevelop is a highly interactive environment that enables you to build image processing solutions, fast and efficiently, while acquiring images from the camera/capture device [15].HDevelop exports your Machine Vision program code as C++, C, C# or Visual Basic source code, which can be integrated into your application.

In Table 3.4 three software packages from three different Machine Vision Software manufacturers are compared under five criteria in relation to the five questions proposed at the beginning of the software discussion. A quick look at the table reveals what the respective software packages have to offer a user in need of a Machine Vision solution. However, a closer look and research shows that not all these software packages are created equal. Manufacturers of Visionscape® and HALCON fail to provide local support in the Republic of South Africa. The software manufacturer chosen by the institution NI, on the other hand, does have a local sales and support team in South Africa.

3.3.2.3 Reason for Selection of Software

The previous discussion compared two other vision software packages from Visionscape® and HALCON, with National Instruments' Vision Builder for Automated Inspection (NI VBAI) to see how similar and different software packages are. Although the main reason behind the use of NI VBAI is because it was readily available and did not require any additional administration tasks to acquire it, it was also a good thing that local support was available in case of any problems that might have come up. Another reason is the number of tools that are available in the software package and the researcher’s familiarity with using National Instruments software products (e.g. LabVIEW). These tools enable a user to not only acquire an image, but also save and manipulate the image. Manipulate refers to handling an image and using the tools, in the software package, to enhance the image and extract details necessary for quality control. A tool that also presents itself as being very useful is the calculator tool, which computes numerical, Boolean, or string results from existing measurements.

3.3.3 Illumination

Lighting is very important, if not the most important part, in a Machine Vision System and thus is discussed here to determine the proper lighting to be used in the project.

The need for a constant frequency light source that cancels out the effect of the changing ambient light immediately came to mind. Dimensions of the pallet; i.e.; length and width, also needed to be obtained from the acquired image as the camera is mounted to have a top view.

Another feature that needed attention was the contrast in the acquired image. There was a need for the gray and white parts to be clearly recognizable and to distinguish between the gray and white pallet.

3.3.3.1 Comparison of Illumination Types

One of the best approaches to the illumination problem was to acquire cheap light sources such as a 12 volt, 20 watt halogen lamp and LED lamps and use them to illustrate the different methods, the focus being on simulating the methods that will benefit the project; i.e. lighting that enhances the edges of the pallet and the contrast of the colours. Back lighting and bright field illumination are the two methods that were the focus of the simulations.

Back lighting was simulated by projecting the light from an LED lamp through a sheet of Perspex and a white A4 page positioned beneath the object to provide a silhouette of the pallet, which helped in identifying edges with the software, but there was an issue with bright spots that interfered with the acquisition of other data such as colour and shapes of the blocks in the pallet.

To simulate bright field illumination two halogen lamps were used, positioned on either side of the camera and aimed at the pallet; they were supplied with a variable power supply, between 9 and 12 volts, to cause a dimming effect.

The illumination in the lab was also taken into consideration; i.e. simulations were run without the back light and bright field illumination. Tweaking some of the configurations of the inspection program gave good results. The results of these will be presented in the next section.

3.3.3.2 Reason for Selection of Illumination Methods

The project needed an illumination source or method that would enhance certain features that would enable the camera to take a viable image. This image would make it easier for the inspection program to extract the necessary information to determine whether the product under inspection is of good or acceptable quality. Edge detection and colour contrast arose as the features necessary for the successful processing of the image and assessment of quality. Back lighting and Bright field illumination are the two lighting methods that, respectively, bring out these two features and that is also the reason they were chosen for the illumination process during the simulation phase.

Initial programming of the vision system involved getting familiar with the tools of the software package, and making use of a stationary experimental inspection station which was built using aluminium profiles, as seen in Figure 3.9.

Figure 3.9: Experimental Inspection Station Built to Develop Vision Solution

The other reason for the building of the inspection station was to help in the identification of key tools that will lead to a working vision solution for the assembly system problem. So, the inspection station itself is a tool that aided the investigation and application of the tools and was fitted with a backlight to highlight the edges of the pallet in the acquired images. This was only used at the beginning to gain familiarity with the software package and determine which tools should be considered in the development of the vision system.

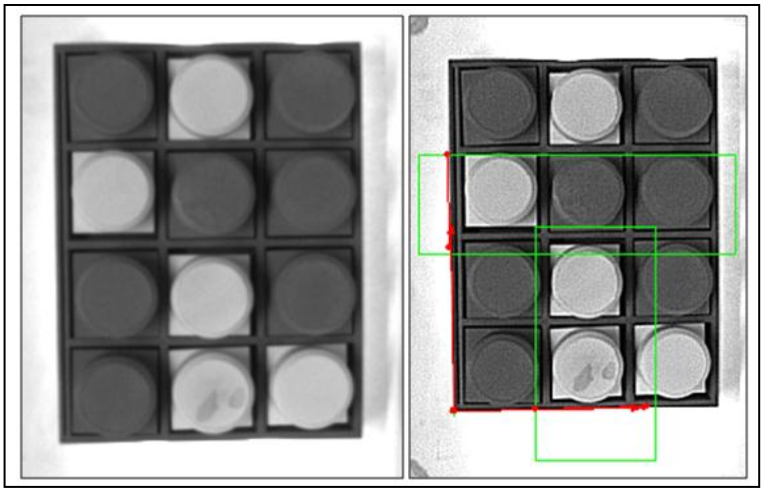

Figure 3.10: Back Lighting in Room and the Resulting Image Processing (Good Edge Detection Results)

The first method experimented with, in Figure 3.10, shows the effects of back lighting in a room with a single light fixture; and the result of edge detection on the image is presented by the image on the right. However, the use of back lighting for the pallet in the assembly system at the inspection point failed to render similar results, as seen in Figure 3.11 below. An attempt at adjusting the brightness was made, and the brighter the lighting, the worse the image quality got; i.e. edge detection deteriorated and bright spots became prevalent on the image.

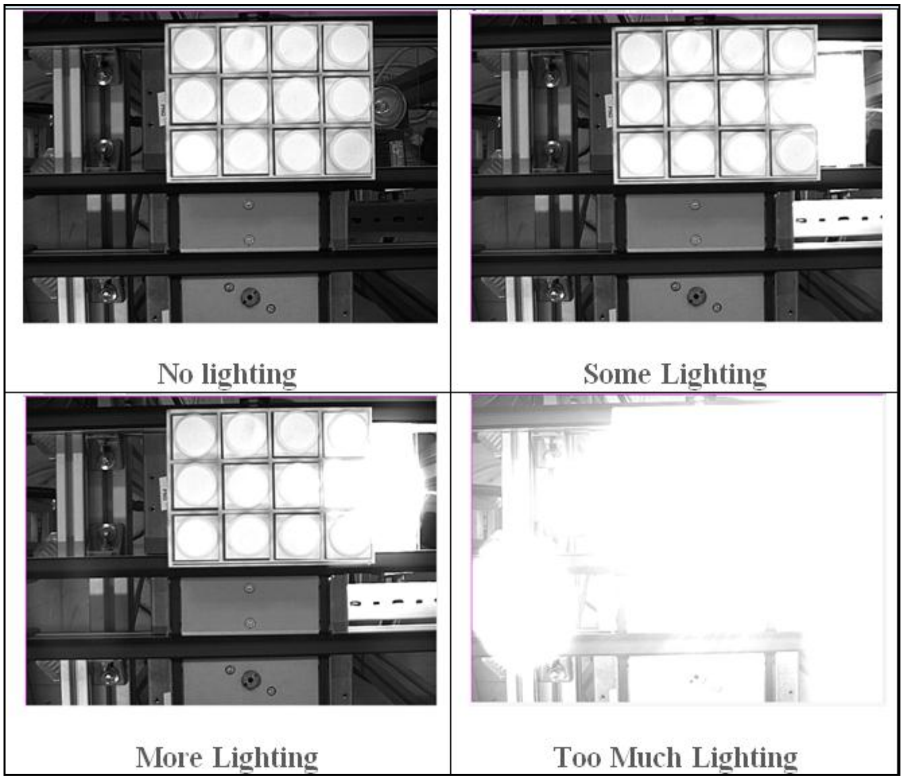
No lighting
Some Lighting
More Lighting
Too Much Lighting

Figure 3.11: Application of Illumination at the First Quality Inspection Area

Positioning a light source at the back of the object under inspection in order to enhance the quality of edge detection and to simulate the possible effects of back lighting is illustrated in Figure 3.11. The position of the light source leads to the degrading of the images captured by the camera due to the light shining directly into the lens. The factor that determined the location of the light source was the structure of the conveyor system around the area of inspection, which hindered the ideal positioning of any light source that might help in enhancing edge detection. Some other structural hindrances are shown below in Figure 3.12.

Top View Side View Bottom View

Figure 3.12: Mechanical Structure of the Conveyor System at the Point of Inspection

The implementation of Bright-field illumination, which involves lighting up an object from the sides to eliminate shadows and enhance geographic differences on the object surface, was also hindered by the physical construction of the conveyor system and the need for the robotic arm to get in and out of the area without causing damage to any other device of structure. The method was sound, but not for this particular project; it would require special mounts and/or brackets to attach to the assembly system.

The final decision was to exclude additional lighting since it only hindered progress and adjusting inspection programs proved the ability to circumvent the need for it. The introduction of built-in tools such as a software filter that applies a convolution function, in order to enhance details of the acquired image, and changes to some of the tool settings assisted in reducing the effects of the environment lighting sources.

3.4 Vision System Layout

The Machine Vision System is a combination of software and hardware devices that work together to complete a task. Hardware devices include the CVS; processing hardware, three cameras for image acquisition, the programming PC, and the display monitor that serves as an output for the inspection process taking place within the CVS. Figure 3.13 better explains the relationship between the different hardware devices.

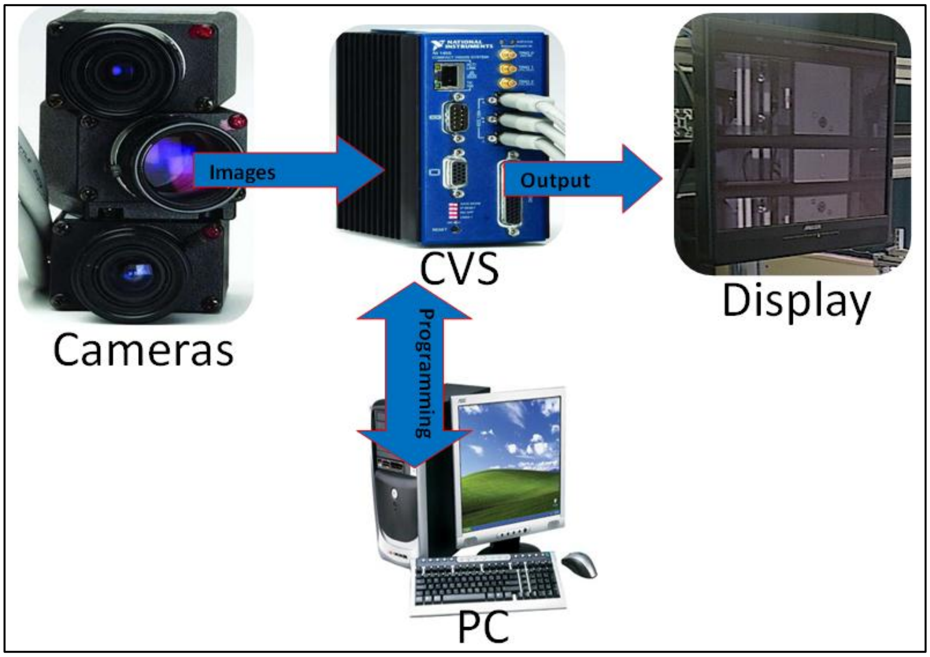

Figure 3.13: Vision System Component Relationship

The CVS acquires images through the cameras and then processes the images using the inspection program while showing this inspection process on the display. The PC has a bidirectional relationship with the CVS, meaning while programming, it can download to the

CVS, initialise the program and act as a display so that the programmer can observe the inspection process. The PC monitor shows the user which stage of the program is being processed as well as the results of the image processing, unlike the CVS’s monitor which only shows the resulting image processing. The user can also see some statistical data on the programming PC monitor when the software application is instructed to switch from the configuration to inspection interface. The software used for programming the CVS is NI Vision Builder AI 3.6, installed on the programming PC.

3.5 Integration Into The System

This section deals with how the vision system was integrated into the assembly system and in order for this to be clear the location of the different components of the system needed to be highlighted. The layout of the assembly system has already been discussed as well as the components that make up the said system, so what follows is a visual presentation of the vision system layout within the assembly system, and a brief explanation of the system operation.

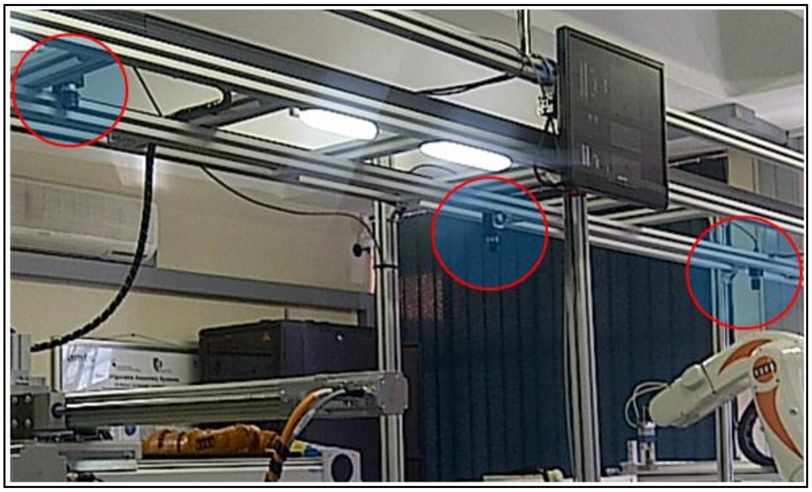

Figure 3.14: Position of Cameras within the Assembly System

The vision system uses three cameras which are connected to the CVS and these cameras are located above the three inspection points as shown in Figures 3.1 and 3.14. The location of the cameras gives the vision system a series of top views of the pallet as it passes through the system. Camera Three, located on the left in the above image, is responsible for the verification of reconfiguration of the gantry system which performs the initial assembly process. This process will also be referred to as Position Verification. Camera One, which is located in the centre, is then tasked with verifying if the initial placement of part within the pallet has completed correctly; this is Quality Check 1. Camera Two, rightmost in figure 3.14, performs the final quality check on the pallet/product, herein also referred to as Quality Check 2.

Figure 3.15: The Position of the CVS in the Assembly System

The images above and below, Figure 3.15 and 3.16 respectively, show the positions of the CVS and the display monitor connected to it. The CVS is the processing hardware of the vision system and the display monitor is simply an output of the inspection process; showing an observer what is happening throughout the quality verification process; this means that the three images from the three cameras are displayed one at a time depending on which camera the inspection program is accessing. When in operation the system programs will execute within the CVS without interaction from the programming PC, except when initialising and during maintenance or improvement.

Figure 3. 16: The Position of the Monitor

The cameras acquire images of the pallet, and these are processed by the inspection program running on the CVS; the status of the quality of the pallet will be determined and a response from the program will be communicated to the system in control of the assembly.

The primary purpose of the vision system is to work together with the assembly system and verify that assembly is done correctly and produces quality goods. Communicating with the assembly system to ensure that everything is going according to plan, is secondary to this but also important. Communication will be both to and from the vision system in that a proximity sensor will trigger the system at the different points of inspection, with a digital input to the CVS, so that the camera can capture an image at the right moment; i.e. when the pallet is at the point of inspection. Camera Three is triggered at the initiation of the system; before any movement of conveyor belts and/or placement of pallets onto the assembly system take place, to ensure that the gantry is properly positioned. This is the verification that happens before the pallet moves into the conveyor system to ensure that the gantry system is prepared to engage with the pallet. There are two placements that take place in the system; the first is dedicated to placing gray parts on the pallet, and the second places the white parts onto the pallet: this is done to form the desired pattern, namely the resulting product that the system assembles. Camera One is triggered when the pallet is moved into the inspection area by the conveyor system after the first placement of parts by the gantry system into the pallet is complete, enabling the quality inspection of initial assembly. This prompts the movement of the pallet, by the conveyor system, to the next point of inspection where Camera Two is triggered to verify the second placement of parts onto the pallet by the robotic arm. The feedback from these inspection processes concludes whether assembly is done correctly or not. A graphic representation of this process is found below in Figure 3.17.

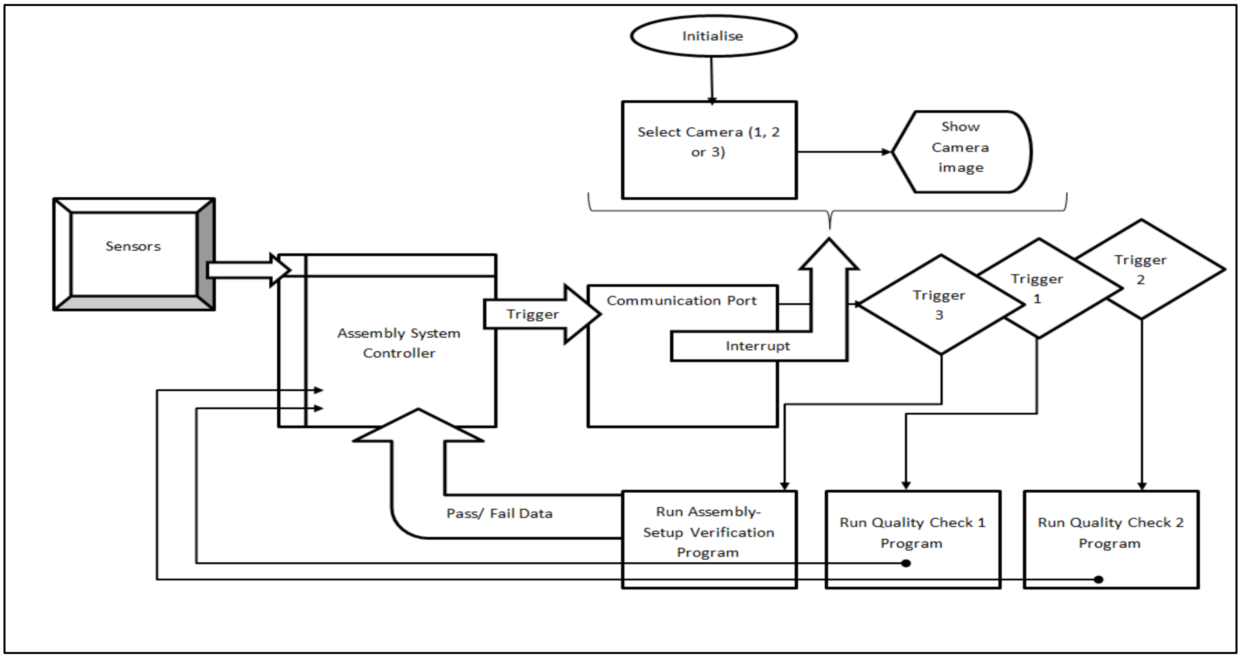

Figure 3. 17: Process of initialisation and Communication between the Assembly System Controller and CVS

3.6 Data Acquisition and Communication

When considering the data that was required from the vision system three questions came to mind:

1. What information does the vision system gather from the relevant pallet?
2. How can this information be made available to the assembly system if there is a problem with the pallet?
3. What should happen if an error occurs?

Information gathered from the pallet during inspection included XY coordinates, for the position of the pallet, and other data such as colour intensity, object edges and the distance between those edges, which determined whether the product passed or failed the quality verification; and this pass or fail status was also important. The x and y coordinates assisted in locating the centre of each space on the pallet where a gray or white block could be placed. The coordinates of the spaces in the pallet helped in determining the orientation of the pallet. The pass and fail status is determined by the inspection program in relation to predetermined requirements of the system; colour contrast and arrangement being the most important. Figure 3.18 below shows the interaction of the vision system with the assembly system controller, highlighting the integration, and an explanation is given thereafter.

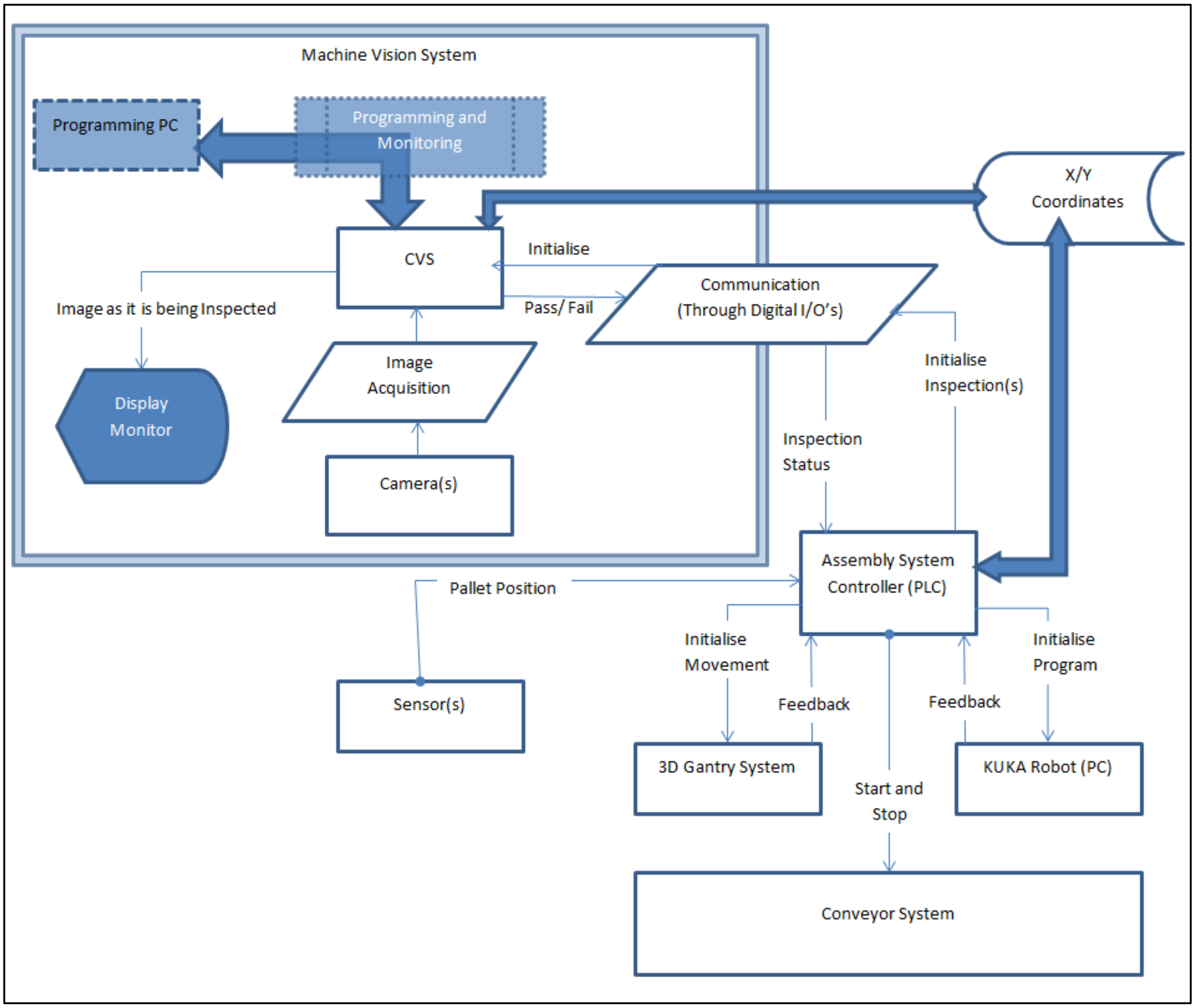

Figure 3. 18: Integration and Communication of the Machine Vision System

Making the information available to the assembly system controller (PLC) meant considering the communication capabilities of the CVS. The basic means of communication by the CVS is done through the digital Input/output port situated on the front panel of the CVS device, which is in the form of a 44 pin DSUB terminal which consists of 2 Transistor-Transistor Logic (TTL) inputs, 10 TTL outputs, 13 isolated inputs and 4 isolated outputs. This port can be accessed and used to establish a digital communication link between the CVS and the controller of the assembly system. The other means of communication that was employed is Ethernet communication, whereby the information can be exchanged through the network. The CVS, using the Ethernet port, and the assembly system controller are both connected to the network using Ethernet. This structure proved to be less of a hassle and required less wiring. Communication between the CVS and the assembly systems controller is thus established through these two means; Ethernet and digital I/O's. The assembly system controller then avails the information to the Multi-Agent Control System which allows it to make informed decisions.

3.7 Chapter Summary

The assembly system is responsible for the assembly and arrangement of a product that involves two parts; the pallet and the blocks. There are two types of pallets, some gray and some white, which have to be filled with white and gray blocks as requested by the product manager within the Multi-Agent System. The arrangement of blocks within the pallet, in a predefined pattern, constitutes a product.

Within a vision system the camera is an important if not the most important hardware and three types of cameras were investigated namely GigE vision camera, Fire-wire camera, and vision sensors. This yielded results that concluded that the camera best suited to the project would be the Fire-wire camera. This was due to the fact that it required less processing power, it used an image lens that would be better able to assist in the image capturing of the project, and it is flexible to work in a number of vision systems.

Software can be grouped into two types, General-Purpose Software and Application-Specific Software. General-Purpose Software is suitable for an environment that needs a customized solution for the vision problem. Application-Specific Software, on the other hand, is tailored to solve a specific problem, to the satisfaction of the user or some industrial process.

General-Purpose Software, which is flexible to change with the growing needs of a system, and can be customized to satisfy those needs, was seen as the best software type to employ in the development of the Machine Vision System. This decision resulted in the use of National Instruments' Vision Builder for Automated Inspection (NI VBAI) to develop the inspection program of the vision system. NI VBAI stood out because it met the requirements for a General-Purpose Software and it belonged to a company which offered local support in the Republic of South Africa. This also prompted the decision to use National Instruments' Compact Vision System (CVS), a hardware device that enables the development of an independently operating vision system. The inspection program is downloaded to it and initiated by the programming computer, but afterwards the inspection runs on its own within the CVS.

Illumination in a vision system is a crucial element and vision systems cannot work without proper lighting. Illumination assists the camera when it is capturing images, often enhancing features necessary for successful inspection and good results. Different illumination methods exist and those that were identified as possibly helpful in the image acquisition of the inspection process were experimented with.

The Machine Vision System integrates into the assembly system by checking whether the process of assembly is carried out as required. The information gathered from the inspection process is shared with the system through different means, such as digital inputs and outputs and through the Ethernet via the Compact Vision System.

The next chapter presents a complete picture of the project and discusses the work that went into the development and testing of the vision system, and the test results are presented in various forms.

3.8 Chapter References

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4 BENCHMARK AND PERFORMANCE RESULTS

This chapter deals with the results that followed the setup and integration of the vision system into the assembly system. A short discussion on testing and benchmarking is undertaken to present the state of mind behind the process that went into the testing of the system, as well as to clarify some of the procedures that are involved in the Machine Vision industry. Some testing scenarios were deemed necessary to serve as a guide to the results that follow; thereafter, a short observation is given on the results.

4.1 Performance Testing and Benchmarking

Machine Vision Systems consist of different parts that each undergo testing to ensure that they satisfy or adhere to industry standards, which means a benchmark had to be set for the software, hardware, cameras and communication protocols that contribute to the development of a vision system, and some were specifically designed to work in the Machine Vision Industry. In this regard the system developed by integrating the different parts also had to be tested to ensure that it would function as envisioned for the project.

Machine Vision Benchmarking is more software oriented; i.e. the focus is not on the hardware but rather on the software that is responsible for most of the inspection, because “Any successful machine-vision benchmark (MVB) should evaluate only the software and how it performs on various types of hardware” [1]. Benchmarking revolves around testing the fundamental aspects of a tool, as well as how that tool generates data for the purpose of fulfilling a previously defined task.

Keeping the above in mind, the task of testing and benchmarking the Machine Vision System had to be focused on the tasks that needed to be completed; namely, Assembly-setup Verification and Quality Control, and the data that can be provided by these functions. In this regard Figure 4.1 gives a basic outline of the procedure that the inspection program takes to fulfil the task of inspection.

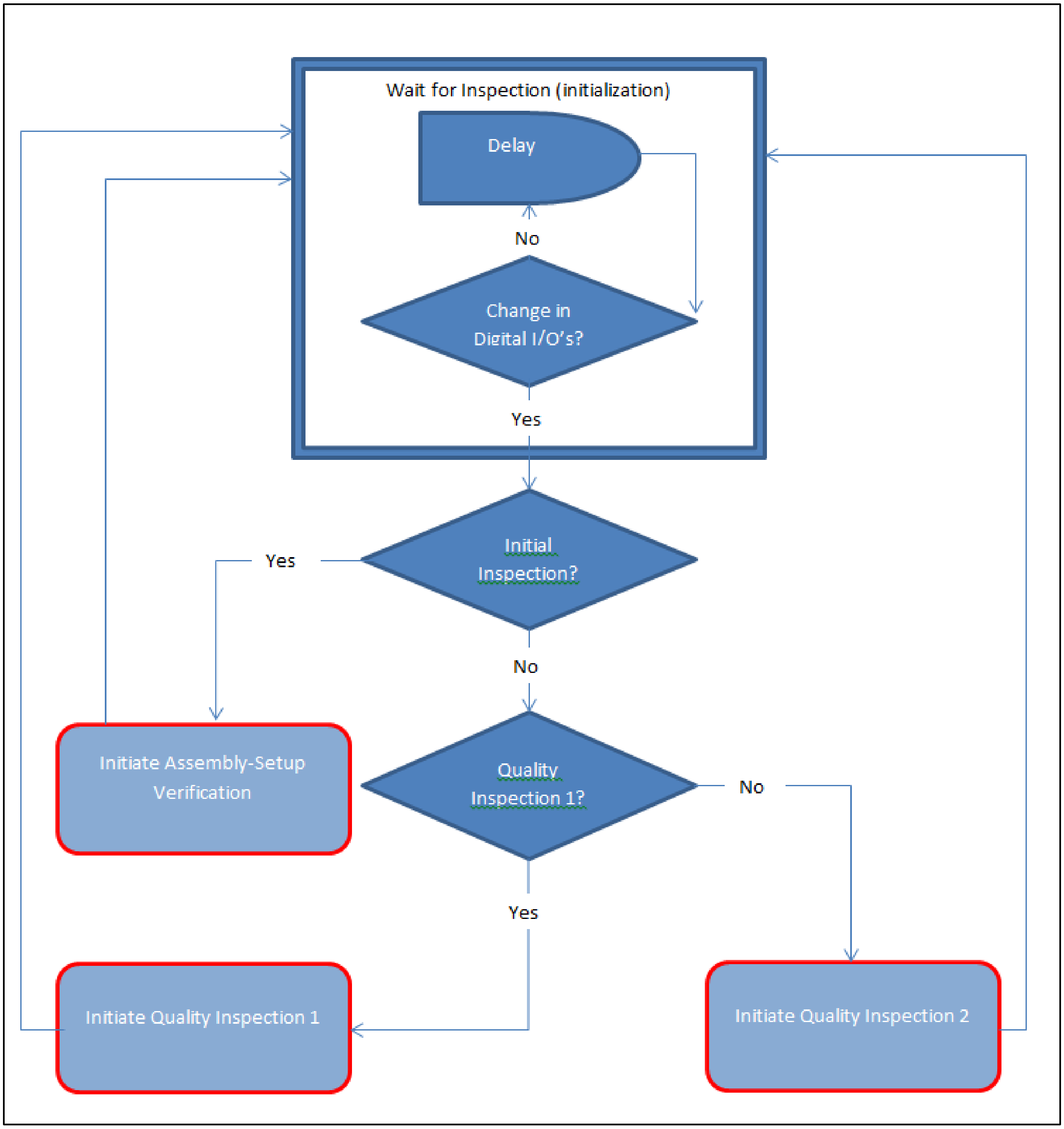

Figure 4.1: Initial Inspection Program Structure

4.2 Testing Procedure and Results

4.2.1 Initialization of the Assembly Process

Initialization of the assembly process required the verification of the three-dimensional gantry system; this meant that an inspection of the gantry system was initiated by the assembly system controller and then the controller waited for feedback from the vision system before it initialized the assembly process; i.e. started moving the pallet to the gantry for the first placement of parts. The Verification process involves:

- The capturing of an image by Camera Three: the gantry system as viewed from the top
- Then the inspection of the image follows to determine where the mobile arm of the gantry system is located;
- Measurements are performed in the vision program to verify that the mobile arm is at the Home position or initialization position;
- An inspection result of ‘Pass’ is when the mobile arm is at this Home position, and a ‘Fail’ when it is not; and
- The assembly system is triggered to let it know what the inspection result is, through the outputs from the DSUB connector of the CVS.

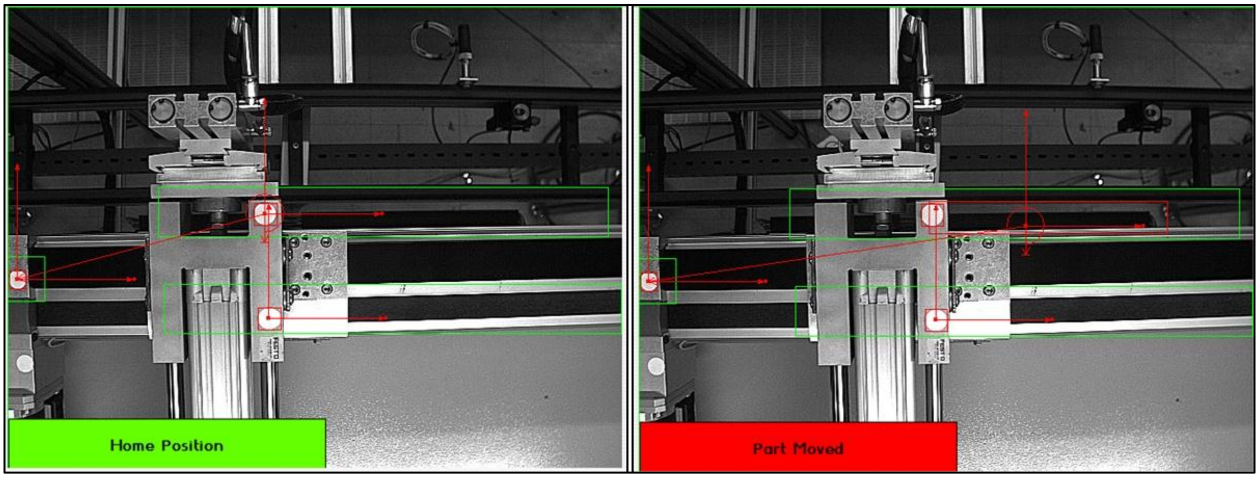

Figure 4.2: The Result from Assembly-Setup Verification Conducted on the Three-Dimensional Gantry System

Figure 4.1 shows the resulting feedback to the user for a passed inspection; represented by the image on the left, and a failed inspection; shown on the right. The image on the left is of the gantry system's mobile arm at the home position, and the arm has moved in the image on the right. The decision taken to resolve the matter of the gantry system's mobile arm being out of position was to have the assembly system controller move the arm around until the vision system can verify that it is back in home position. A positive feedback ('Pass') from the vision system to the assembly system controller signalled the commencement of the process of assembly.

When the position of the gantry's mobile arm is verified, the assembly system controller proceeded to move the pallet into the first assembly position, using the conveyor system. The gantry was then tasked with the placement of the first blocks, gray or white, into the pallet.

4.2.2 Product Quality Verification

The process of assembly needed to be verified at two points; herein referred to as the inspection areas, located at Camera One and Two. Ensuring that the product is correctly assembled verifies that the assembly process completed or took place correctly. The process of inspection involves:

- A trigger from the assembly system controller when the pallet is in place; i.e. at Camera 1's inspection point;
- Image acquisition of the inspection area;
- Inspection of the image to identify if the correct pattern has been assembled, and to identify the XY coordinates of the empty spaces in the pallet; and
- If the pallet has the correct pattern then a feedback of ‘Pass’ is sent to the assembly system controller, if the pattern is incorrect then the feedback is a ‘Fail’.

This routine holds true for both quality inspection programs.

The inspection process involved a number of tasks such as edge detection, object detection, pattern matching and distinguishing colour intensity, which then resulted in a ‘Pass’ or ‘Fail’. A ‘Pass’, with regard to product verification, means that the current arrangement, under inspection, was a match to the desired arrangement of parts within the pallet. It is worth mentioning that the orientation of the arrangement can be 180 degrees either way. A ‘Fail’ on the other hand means that the current arrangement, under inspection, did not match the desired arrangement of parts within the pallet.

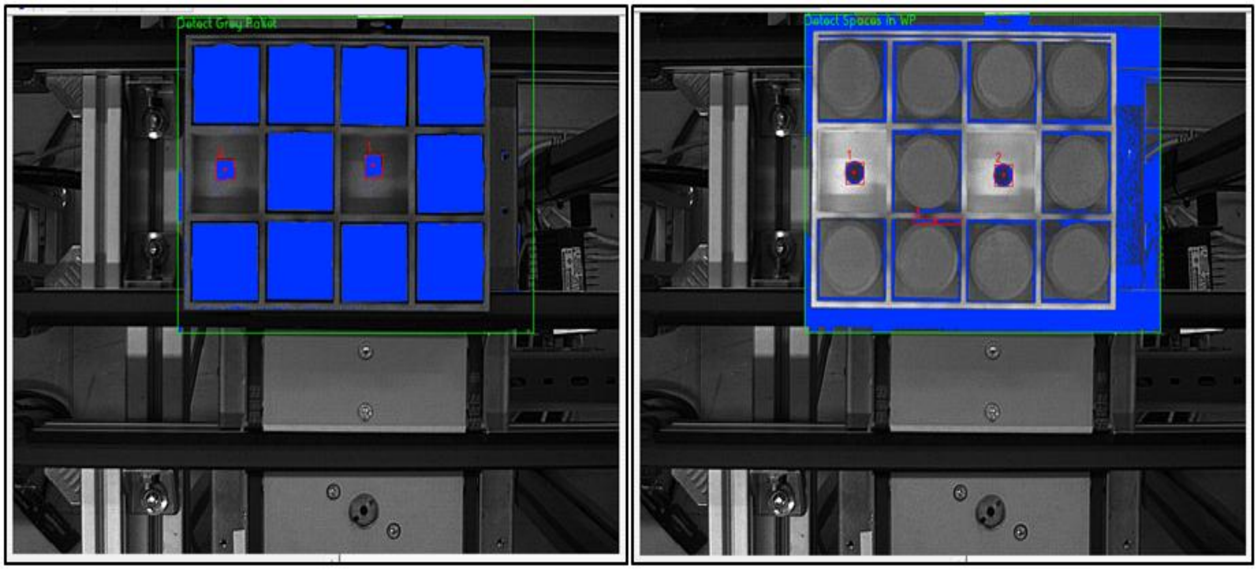

Figure 4.3: Positive Result from the First Quality Inspection

In Figure 4.2 the pattern A on both the white and gray pallet has been identified by the inspection program; i.e. gray pallet on the left hand side and the white pallet on the right. What is also identified are the spaces within the pallet where parts still have to be placed; this is represented by the red squares in the images. The program had to be put together so that it catered to both pallets; i.e. gray and white pallets, and the above images show this process of inspection. This result is a ‘Pass’ and this is communicated to the assembly system controller; through the DSUB connection, along with the XY coordinates of the empty spaces on the pallet which are sent through the Ethernet port of the CVS. The second placement of blocks follows hereafter to complete the product; this is done by the robotic arm. The robotic arm fetches the blocks from the Block Magazine (Figure 3.5) and places them in the empty spaces of the pallet.

The second process of inspection is triggered by the assembly system controller, initialising the quality inspection of the complete product, meaning that the arrangement of blocks in the required pattern is verified, as seen in Figure 4.3 below. The verification takes place for all the products in the same area of inspection and in the same region of interest within the acquired image and the information for every inspection cycle is sent back to the controller from the CVS.

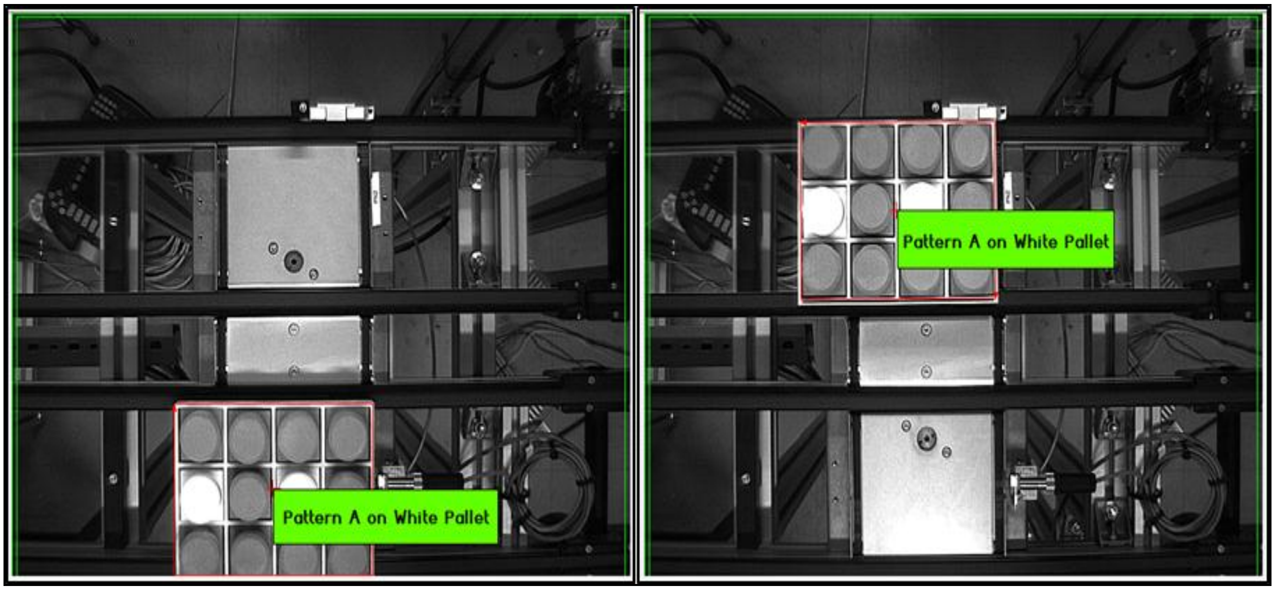

Figure 4.4: Positive Results from the Final Quality Inspection

Whenever an error, of whatever type, occurs in the assembly process and results in a product of inferior quality, then the vision system will report a 'Fail' to the assembly system controller and the assembly system starts a routine of removing the pallet from the system.‘Rejected’ pallets are moved onto the Rework conveyor, as explained under section 3.1.

4.3 Performance Testing

Looking back at some of the influential factors, time, lighting and communication were important to examine whether they have been taken care of. This resulted in a performance test for the assembly-setup verification process that included looking at the number of inspections that the system can execute within a set timeframe; e.g. five minutes, and an accuracy test for the quality control inspection process. In order to ensure that the combination of light incident through windows and normal lighting of the experimental area didnot have a negative influence on the Machine Vision System, the tests were completed during three different times of the day, namely morning, afternoon and night.

4.3.1 Camera 3: Assembly-setup Verification

This relates to the initialization process explained above. The information tabled below represents the findings obtained from the test to investigate how many inspections can be completed in five minutes when the program is run continuously for that period of time.

Table 4.1: Camera Three: The Number of Inspections Completed in Five Minutes

	26-09-12	**27-09-12**	**01-10-12**
Morning	172	208	197
Afternoon	197	196	220
Evening	199	183	207

Results in Table 4.1 indicate that the tests were conducted during three different days, and at three different times of those days. The tests were carried out as follows on the 26th, 27th of September and the 01st of October between 10:00 and 10:45 in the morning, between 14:00 and 14:45 in the afternoon, and between 18:00 and 18:45 in the evening. Each test lasted five minutes and the number of inspections that occurred in that time frame was recorded. These are three different times of the day when natural light affects the system to a certain degree. Figure 4.4 below is a graphical representation of the data collected.

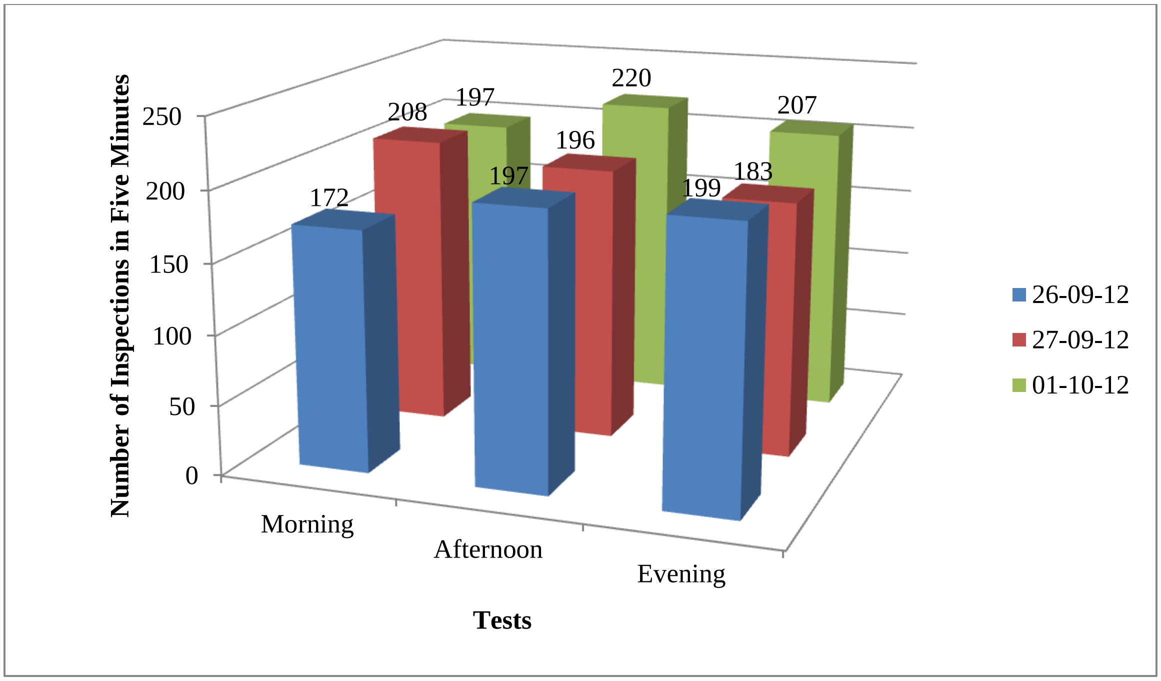

Figure 4.5: Chart Representation of the Number of Inspections Executed in Five Minutes (Camera Three)

Lighting plays a vital role in the vision system, at the moment of image acquisition and thus the number of inspections that can take place. On three different instances the tests yielded an optimal number of inspections, i.e. more than 200 inspections. In the morning test on the 27th of September and in two tests on the 1st of October, afternoon and evening, the system performed a greater number of inspections because light conditions were favourable.

4.3.2 Camera One and Two: Quality Control

The following data relate to the product quality inspection process.

Table 4.2: Camera One: Accuracy of the First Product Quality Verification

	Fail	**Pass**	**No. of Inspections**
Morning	3	44	47
Afternoon	5	41	46
Evening	0	52	52

In Table 4.2 the test results for Camera One show the data gathered when a comparison was done on the occurrence of failed and passed inspections in a five minute time frame in order to look at the accuracy of the system.

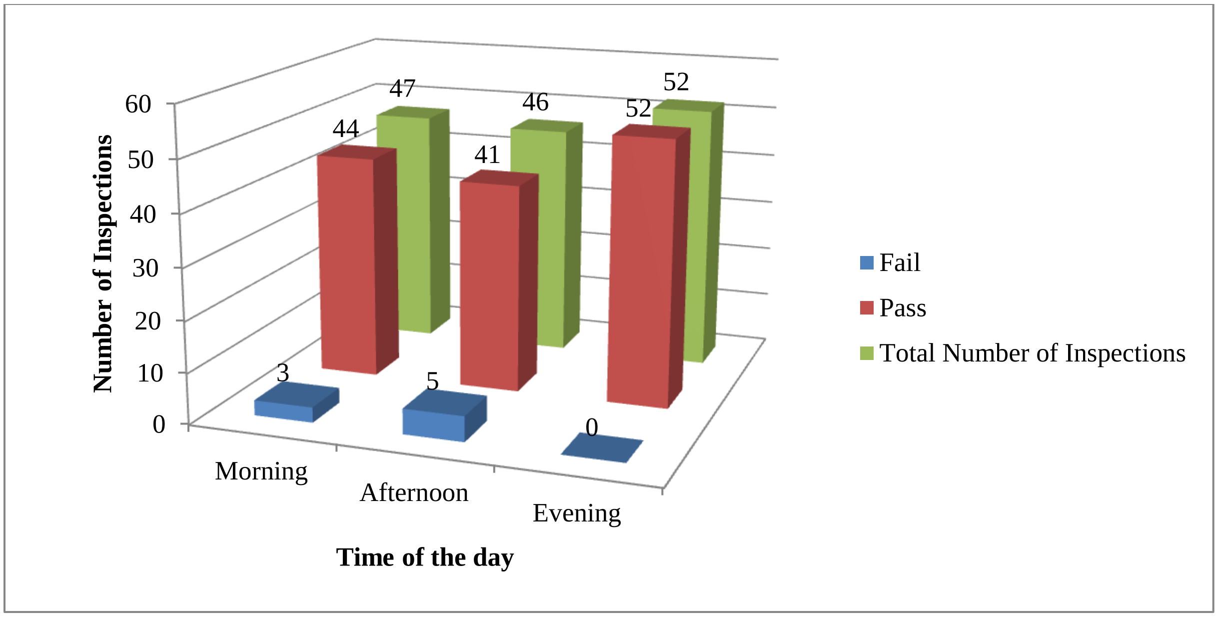

Figure 4.6: Camera One Accuracy Results of the First Quality Control Inspection

Figure 4.5 presents a picture of a system that has some errors in the testing phase when tests are conducted within a five minute loop; the difference is that tests done at random times offer up no failures when the conditions for a pass are met.

The second process of inspection, triggered by the assembly system controller, initializes the quality inspection of the complete product - ensuring that the arrangement of blocks in the required pattern is verified.

Table 4.3: Camera Two: Accuracy of the Final Quality Verification

	Fail	Pass	No. of Inspections
Morning	0	45	45
Afternoon	0	46	46
Evening	2	43	45

The results from the accuracy tests conducted on the final inspection of the product are presented in Figure 4.6 and convey a different image, where no failures occurred during the two earlier tests and only a small percentage occurred during the evening tests. This difference; in comparison to Camera One, might have been caused by the position of the inspection area, which was close to a window and thus more natural illumination.

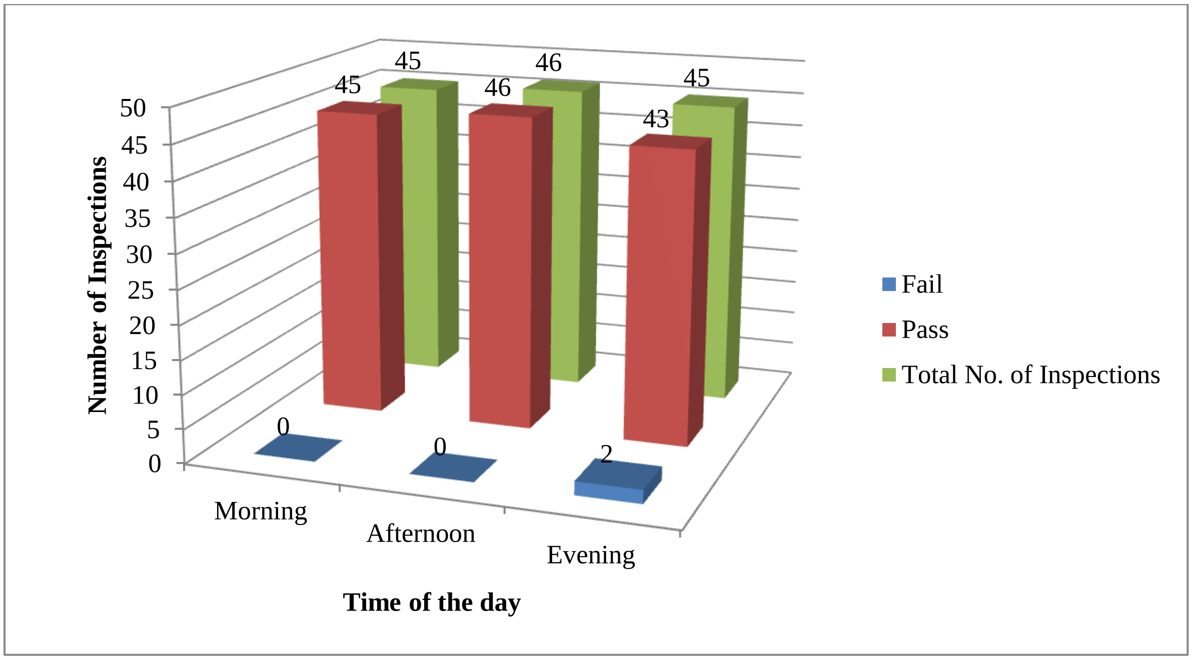

Figure 4.7: Camera Two Accuracy Results of the Final Quality Control Inspection

4.4 Observations on Results

The main aim of the project was to design and implement a vision solution that can be integrated into an assembly system in order to enable that system to verify any rearrangement of parts within the system, and to confirm that the product assembled by the system is done so correctly.

Whilst conducting the performance and accuracy tests the following was observed from the results:

- Markers used to assist the inspection program when dealing with position verification of the three-dimensional gantry system's mobile arm, proved to be helpful in increasing the accuracy of the vision system - especially in the inspection of geometrically shaped objects with very few defining features other than colour and size.
- Triggering the system at random to initiate an inspection instead of running an inspection in loop proved the accuracy of the system and represented the actual way the system works.
- Communication with other devices concerning information that conveys more than just a state of 'ON' or 'OFF' is best done through the Ethernet port instead of through the DSUB connection. This includes the XY coordinates of the spaces in the pallet that need to be filled after the first placement of parts.

The overall results of the testing suggest that the system is functional and can verify that the gantry is correctly positioned at the initialization phase of the assembly system, and both quality inspections work and give the correct results.

4.5 Chapter References

[1] Towards a Machine Vision Benchmark by Wolfgang Eckstein, sourced from http://www.vision-systems.com/articles/print/volume-14/issue-5/departments/leading-edge-views/toward-a-machine-vision-benchmark.html Accessed on: 08 September 2012, 10:13

5 CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

The following discussion aims to draw a conclusion in the project by looking back at what has been done and also re-examining the results gathered in chapter four. This means the preceding thoughts and ideas will be looked at and a discussion of whether the project has achieved the goal it set out on will be the main focus in this chapter.

The aim of the project was to develop a Machine Vision System that will be used to verify the position of a part working within an assembly system and to check whether the product being assembled by the system meets the required specifications to be declared as a product of good quality and for the system to be qualified as an accurately working system. A second underlying aim was to aid in the experimental development of a Reconfigurable Assembly System (RAS), and to nullify the need of human quality verifiers within the system and relocating them out of dangerous areas where robotic arms and other moving parts operate, to safer zones without necessarily replacing the workforce. RAS's are aimed at increasing the efficiency of a system rather than the eradication of the workforce as already explained, and the objective of the project was to ensure that an increase in efficiency did not have a negative impact on the men and women in charge of labour in the factories where vision systems such as this one would be implemented.

5.1 Conclusion

So much transition in the industry has taken place with regard to assembly systems and the conveyor belts used within them. Conveyors have changed from simple and slow point-to-point belt transport systems to more complex units with varying speeds, even the type of material used for the belts has become more rugged, e.g. stainless steel and aluminium belts. Technological advances have made it not only possible to incorporate different materials into conveyor systems, but have also contributed to the development of complex and efficient assembly systems that are made up of robotic arms, gantry systems, PLC's from different manufacturers, and cameras that monitor the process of assembly.

Vision systems of today do not only monitor, but are integral parts of an assembly system; they communicate with the system; save images on network servers for data logging purposes; and can also accept external triggers and requests from the control system. The Machine Vision System developed and under discussion in this study is important in the investigation of RAS's and the evaluation of the type of quality that can be produced by these systems. Communication and data exchange limitations can also be tested with the integration of a vision system that encourages bidirectional communication between the RAS, for instance, and whatever type of quality inspection system.

5.2 Goals and Objectives

The Machine Vision System had two tasks; to verify that the gantry system arm has adjusted itself in order to perform the tasks it is responsible for - Assembly-setup Verification - and to ensure that the product was acceptably assembled by the system. Using different tools and setting them up to identify the position of the gantry system arm was successful and the necessary information was then relayed back to the assembly system controller. This was true for the quality control function as well: the product was identified and the information that was obtained was communicated to the assembly system controller. All of this gave a conclusion that the vision system is capable of performing inspections within an assembly system and can be adapted to fit a different assembly system with minor changes to the program cycle, and by rather changing the vision software tools that were used.

5.3 Contributions of the Project

The vision system offers the following contributions:

5.3.1 Visual Verification and Quality Control

The development of the vision system added an element of visual verification and quality control to the assembly system and two-way communication cemented the relationship of the two systems. Visual verification and quality control was vital and enabled the assembly system to verify that the process of object-handling has been carried out properly by ensuring the product is of a high quality; i.e. meets all the requirements.

5.3.2 Portability

The combination of devices to make up the vision system enables the moving of the assembly system and integration into another system that requires a machine vision system. This means that it is a portable system that can be reconfigured to satisfy the needs of any assembly system that needs a visual verification and/ or quality control of the same level of intelligence as the current system.

This was proven when the system was relocated to the Stellenbosch University and setup within a day in order to add a function of visual control to an assembly system under development at the university. Although the functionality and accuracy was not at one hundred percent it proved that the vision system can be classified as a portable system.

5.3.3 Basic Vision Solution

The portability of the system, the communication capabilities of the CVS and the fact that other components of the system (the cameras) can easily be replaced and more advanced cameras used to improve the image acquisition makes it possible to use the same vision systemon a different vision problem. Improved image quality means more accurate data can be gathered.

Both these advantages and the fact that the vision system program, housed in the CVS, can be altered, makes the system a general solution that can be applied to other systems.

5.4 Recommendations for Future Research

Future researchers should look at fully utilizing the CVS by using all the communication capabilities available and looking at what more information can be extracted from the image processing stage of inspection and transmitted to the assembly system controller.

Another possible improvement is getting the vision system to assist the assembly system with reassembly when a product that is being assembled has only minor errors, rather than the rejection of a product at the last stage.

The acquisition of a camera with greater viewing capability and possibly an adjustable zoom distance would greatly improve quality control when smaller parts are under scrutiny, or another solution can be implemented with the current devices by altering the placement of cameras within the system.

5.5 Closing Statement: Development of System

- In the beginning, the system at the Central University of Technology, Department of Electrical, Electronic and Computer Engineering was an object-handling and identification system that consisted of a conveyor system with a lower level and a higher level conveyor belt, a KUKA robotic arm and two vision systems, one on each level. The KUKA robotic arm had a camera mounted on it to aid in the location of parts on the lower level conveyor belt, and then the arm would pick up the (Lego) block, and place it on the higher level conveyor belt. This system of conveyor belts and robotic arm is illustrated in Figure 3.1; it is the part of the system within the yellow ellipsis.
- An interest in Reconfigurable Assembly System (RAS) afforded the University an opportunity to partner together with Stellenbosch University on a project funded by the Department of Science and Technology (DST) under the Advanced Manufacturing Technology Strategy (AMTS).
- This endeavour encouraged the expansion of the conveyor belt arrangement mentioned above, and the introduction of the three-dimensional gantry system and the other KUKA robotic arm, mentioned in the thesis.
- The need to verify the integrity of the system, i.e. ensure the quality of the product assembly, made it necessary to involve visual confirmation of the product as it progresses

through the assembly process. Verification of the position of certain tools that contributed to the assembly process also had to be conducted.

- At the end the assembly system was a more flexible unit with a complex route of assembly and product verification, and needed a more intelligent control and command structure, which was handled by the Multi-Agent Control System, the assembly systems logic control programme (PLC) and the vision systems CVS. These components all had to communicate with each other in order to form a single unit, which is accomplished by different communication protocols.

Addendum A: Research Output

- Department or Electrical, Electronic and Computer Engineering Workshop: Presentation on Project
- DST, AMTS: Progress Presentation