University of Southern Queensland

Faculty of Engineering & Surveying

SICK vs Intrinsic

A dissertation submitted by

Mr Adam Donnelly

In fulfilment of the requirements of

ENG4111 and 4112 Research Project

towards the degree of

Bachelor of Engineering (Honours) (Mechatronic)

Submitted October, 2022

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Research Project

Limitations of Use

CANDIDATES CERTIFICATION

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Adam John Donnelly

Student Number: [redacted]

Contents

ABSTRACT

This paper compares and contrasts the SICK and Intrinsic vision systems in order to identify which system James Hardie, Carole Park should invest in long term, to identify surface defects on their fibre cement boards. Currently surface defects are identified by operators standing by conveyor belts and visually inspecting the sheets as they pass by at high speeds. This method of quality inspection leaves James Hardy open to human error. Operators can be distracted or preoccupied while trying to maintain the general running of the machine or carrying out their other duties required by their position. It also leaves the quality checks up to interpretation by each individual operator resulting in different interpretations of the same quality criteria as set by James Hardies specifications.

After assessing the various methods of surface defect detection within engineering industries, it was found that an optical based machine vision system would be the most suitable for trials at James Hardie. SICK and Intrinsic were both chosen as businesses who can offer suitable trial systems for installation and implementation for such systems. The SICK system has been installed with successful trials conducted proving that the provided system can identify surface defects such as lumps, dents and debris within the accuracies outlined by the James Hardies specifications. The Intrinsic system is yet to be installed and as such a thorough and final comparison between the two systems has not been made. This dissertation highlights the important learnings from the SICK installation and identifies some key considerations for future decision-making between the two systems.

ACKNOWLEDGEMENTS

This research was carried out under the principal supervision of Mikael Andem & Craig Lobsey.

Appreciation is also due to James O'Connor (OPEX Eng. Rosehill) at James Hardie who has been of great assistance during the writing of this dissertation.

And lastly to my incredible wife who has supported me through my entire Engineering degree.

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICIES

NOMENCLATURE AND ACRONYMS (OR ABBREVIATIONS)

The following abbreviations have been used throughout the text:

APAC	Asia Pacific
OPEX	Operational Excellence
QA	Quality Assurance
QMS	Quality Management System
NDT	Non Destructive Testing

CHAPTER 1 – INTRODUCTION

1.1 Outline of the study

Quality Management Systems (QMS) are used by businesses and organisations to regulate their teams to produce outcomes or achieve goals that are aligned with a set of standards or specifications as outlined by the customers and the businesses or organisations expectations. QMS is a part of all engineering disciplines; Food & beverage, aerospace, automotive, medical, IT, services, production, manufacturing & fabrication, but its benefits and the way in which it is utilised differs.

Before the industrial revolution, the majority of Engineering quality systems were human based physical checks. Typically, through a human populated and completed paper based checklist system, where physical measuring done by humans, would then be compared to drawings and tolerances. Measurements may have been taken using incremental measuring devices such as rules, callipers, verniers, voltmeters, etc or they may have been in the form of Physical stop go gauges.

During the industrial revolution Engineering production rates became faster and the quantity of products being produced increase dramatically. As such a greater importance fell on ensuring that these high quantities of product were indeed manufactured and supplied correctly to their customers. The solution; sensors. Sensors can transmit real time data about conditions that may cause quality defects.

Sensors allow us to measure physical things i.e.; movement, waves, heat, light and quantify this information into a data set that can be analysed and interpreted to find trends and irregularities. These systems are extremely beneficial in manufacturing when large quantities of product at high speeds are being put through a process line. How do we know every product has been made to the correct specifications? How do we know if the manufacturing machine equipment is beginning to fail or operating incorrectly? When products begin to fail how can we go back and track what went wrong and why the finished product went out of spec, and how do we stop it from happening again?

In the modern era, these sensors need to be coupled with other hardware and a plc with software that can produce some useful outputs. The software can also assist with machine learning and internal machine development. At a high level overview of a sensor based quality system, there are three major components;

1. The sensor will send an analogue signal to the;
2. PLC that will use a written algorithm to interpret this data and transform it into;
3. Useful information or outputs.

This information may be displayed data on a screen in the form of images, graphs, and data sets. Or it may produce some physical output, like a machine command or raise a visible or audible alarm.

So, what already exists in the engineering world and what are some examples of these sensor based systems?

- Temperature sensor on a bearing, a spike in temperature means the bearing is failing in some way causing more friction and in turn higher running temperatures.
- Level sensor in a vessel full of product, if the levels are going above or below the required range an alarm can be raised which will let an operator know that something in the system isn't working as it should, like a valve failing.
- A flow sensor on a pipeline can detect if the flow rates is within range, again alluding to a leak or a restriction in the line. If multiple sensors are used, these sensors can also assist in fault finding the approximate location of the failure. It works here, but it doesn't work here, so the failure must be here.

1.2 Introduction

James Hardie is the world's largest manufacturer of fibre cement building materials and products in the world (James Hardie, 2022). James Hardie was a man who in 1888 founded his own import business in Melbourne, Australia (James Hardie, 2022). James came across a fibro-cement product while on a trip to London and decided that there was an opportunity to sell the product on the Australian market. James and his partner Andrew Reid worked together to build and grow the business over the coming years before James retired in 1911. At this point Andrew bought half of James' shares and continued to run the business through his Grandson, John B Reid (James Hardie, 2022).

Fast forward to the present day and James Hardie now has 19 manufacturing facilities across North America, Europe, Australia, New Zealand, and the Philippines (James Hardie, 2022). Each facility has their own mix plants, sheet machines and finishing lines, all slightly different but producing similar products. This global presence coupled with the businesses accelerating growth has made James Hardie the leader in delivering high quality fibre cement board products to customers around the world.

As such, there has recently been greater investment into the infrastructure and quality management systems of James Hardie. This focus shift has been important due to the high volume of product that James Hardie produces and the sheer size of the business itself on a global scale. It is important to manage this growth and maintain the businesses' ability to produce fibre cement products efficiently. Simply increasing the volume of product produced does not return a direct profit to the business if this product is not within specification.

At the James Hardie manufacturing facility in Carole Park, Brisbane, the creation of the fibre cement boards can be witnessed from the delivery of raw materials, right through to the distribution of the finished product. Sand is dredged in the Moreton Bay region and delivered via trucks to a sand bunker on site. The sand is then taking up conveyor belts, delivered to silos that distribute the sand into a ball mill. There are two Ball mills on site, both of which are horizontal rotating mills. Steel balls and lime water are mixed with the sand creating a silica slurry within the ball mill. This silica slurry is then transferred across into the mix plants.

Other raw materials such as Alumina, IMP, KM, and cement are delivered by trucks in the form of powder or dust. These other raw materials are also stored in their respective silos and transferred across to day bins in the mix plants when required. At Carole Park there are three sheet machines each with their own mix plant. Each mix plant is completely automated with a control system in an office where an operator sits and views a control screen. The screen displays the weights of products in the batch tanks, the operating state of valves, pumps and motors, flow rates in pipes, densities of product, and audible and visual alarms should the system fail to operate correctly in any way. Using this control screen, the operator can change or adjust any of this information based off the feedback from the sheet machine operator.

All of the raw material in a mix plant is fed into a primary mixer that stirs all of the products together. There is then a transfer pump that delivers this product mix to the sheet machine line. When the feed slurry comes into contact with a less permeable surface, the product will transfer from one surface to the other. The product is fed into tubs where a sieve roller spins, picking up the product and using the principle of permeability, sticks that product to a felt.

The felt is approximately 30 metres long and runs across each tub of the machine before coming into contact with the size roller. The size roller is less permeable again so as the felt comes into contact with the size roller, the product jumps again. The size roller will turn approximately two to three times, building layers of product on its surface before pneumatically actuated cut off arm, cuts the product, flicking the leading edge onto another conveyor belt.

The side of the sheet machine prior to the size roller is referred to as the, “Wet End,” while the side after the size roller is referred to as the, “Dry End.” The sheets then travel through a sheet thickness controller that uses lasers to detect the heights of the green sheet board. There are scrap doors along the conveyor system so if an operator can see that a board is damaged, they can react quickly and press a button to open the scrap door and scrap the damage sheets. The scrap sheets are fed onto a conveyor belt underneath the main sheet machine that drives this scrap into a shredder. The shredder then delivers the product to a scrap agitator which mixes the product with a water slurry. This product is then reused into the feed of the system minimalizing waste from damaged or scrapped boards.

The good sheets that aren't scrapped travel along the conveyor belt and into the stacker. An operator is located at the stacker entry point, where every ten sheets they are required to manually measure the length and width of the sheets, to ensure that they are within spec and square. Once the sheets go into the stacker a large vacuum pad powered by vacuum fans lifts the sheets and stacks them on top of each other. These large stacks weighing 5 to 10 tonnes (pending product thickness, length, width) are placed on trucks which are taken out to the autoclave ovens. These autoclave ovens use steam and pressure to cook and cure the green sheet boards. The ovens run at approximately 900kpa and each cycle can take 6 to 12 hours depending on the product.

After the boards are cooked, they are taken out of the ovens and delivered to the finishing side. At James Hardie in Carole Park there are two finishing lines; Trim line 4 & Trim line 8. On these trim lines the boards are cut to size, grooved, notched, sanded, and painted (if required) along a series of conveyor belts, before making their way to the final QA station. There are no online QA cheques on these finishing lines. The QA station is the last point of call, at which point the boards are already stacked and ready for distribution.

It is clear that there are many holes in the process that leave James Hardie open to supplying customers with out of spec product, which although infrequently, does happen. More so, the boards are often found to be out of spec after the finishing line, prior to distribution, at which point large volumes of finished product that are unable to be sold or reused must be scrapped. Once this quality issue is found, the quality management team need to trace back that product through the finishing line, the autoclaves, the sheet machine, the mix plant, and the ball mills. They must search through each part of the entire systems machines data history to understand what the cause was of the out of spec product.

This is a lengthy and elusive process as answers are not always immediate, wasting James Hardies valuable labour, machine, and material resources. The out of spec product may have been made by the sheet machine one or two weeks prior to the board being put through the quality cheques at the end of the finishing line. Although there is some traceability, it is clear that there is a need for an automated online quality system, giving more immediate feedback to the operators. If a board can be identified as out of specification immediately as it's cut its final size, faster decision making and fault finding can occur. An online automated quality system has the potential to save the company millions of dollars and radically decrease the finishing lines scrap rate.

1.3 The problem

James Hardie APAC OPEX Engineer, Mikael Andem, eluded that there is a big opportunity in the APAC region to develop and install a sensor based quality management system on both the green sheet and finishing lines. There are three main driving factors that stress the importance of such a system;

1. **As the global demand in product supply increases, the machines capabilities will also need to increase to produce the required product volume**. As capacity

increases the line speed will increase. Humans can only do so much, and the faster these lines move the less reliable and less efficient human error detection becomes (James Hardie board production is measured in linear meters per minute).

2. **The customer expectation has increased, from commodities to a high-end business.** James Hardie is now producing products that will be seen and not covered, i.e.; building exteriors with patterned finishes. Therefore, the business needs to be more stringent on its quality, as surface defects will not be able to be hidden by plaster, paint, or tiles.
3. **James Hardie is a global business, so they want technology that is worldwide**. James Hardie needs to be able to achieve consistency across its marketing. There is a lot of interpretation to the current quality specifications but using identically calibrated measuring analysis techniques will standardise different manufacturing plants and individuals' interpretations of these specifications.

Mikael organised a knowledge sharing meeting with the other OPEX Engineers from James Hardie around the world. It was in this meeting that the Reno site shared that they have been working with a company called, "Intrinsic," to develop such a system. "Intrinsic," have their own servers and data bases that any company can pay to use in conjunction with local online hardware. It was also learned that the Research and Development team in Rosehill have been working with a company called, "SICK," which is local PLC based system.

The two systems use slightly different technologies, which this research report will go into further detail, but they both inevitably want to achieve the same result; detect dimensional obscurities and surface condition defects. To ensure that given timelines are met, this research report will begin with a cross examination of the effectiveness of both systems being able to detect surface defects. If time permits, further trials investigating the effectiveness of dimensional checks will be conducted.

This research proposal will contrast and compare the, "Intrinsic," & "SICK," vision systems, analysing their suitability for use on the James Hardie, Carole Park Green Sheet Lines short term and long term, against a set list or requirements and specifications, and ultimately determine which system the company should invest in.

1.4 Research Aims and Objectives

The overall goal of this research is to understand the, "Intrinsic," & "SICK," online automated quality management systems and decide which system, if either, will be most suitable for James Hardie, Carole Park. Specific research objectives are outlined as follows.

- Undertake a literature review of previous research into QMS, specifically systems that are online automated for the detection of surface defects.

- Engage with the quality team to understand what tolerances and product specifications the automated online QMS needs to achieve to be successful.
- Engage with the manufacturing and production team to understand what speeds the system is required to run at and what the response times of the system need to be to be successful
- Construct a list of criteria to compare the success of both automated online QMS's, Raw performance, scalability, global consistency.
- Develop a decision matrix to weight and score each criterion of both automated online QMS's.
- Develop a methodology that will effectively test these systems against one another to a specific criterion.
- Review and analyse the installation location, i.e.; Size, framework, lighting, humidity, dust, etc.
- Install a trial version of both systems in similar locations and conduct field tests, focusing on surface defects.
- Analyse data and collate into results tables to find overall averages of system effectiveness.
- Select the most suitable and capable system and justify reasoning

If time and resources permit;

- Run similar trials with the focus being on dimensional checks
- Review and refine design making recommendations for future installations.

1.5 Conclusions

This dissertation aims to analyse existing QMS's used in different applications in engineering manufacturing facilities. A literature review of previous dissertations and existing systems used in industry, will provide a substantial platform for further research to be undertaken. A review of all methods of automated online surface defect analysis will give reason as to what system is the most appropriate for the James Hardie application. It will step through the research objectives ensuring that every goal is met throughout the process. Any failure to reach such goal will be examined analysed and reviewed so that so that recommendations and proposed improvements can be given.

CHAPTER 2 – LITERATURE REVIEW

2.1Introduction

Machine vision systems being used in quality control systems have existed within industry since the industrial revolution. Many different industries can benefit from the implementation of an online QMS. Once the quality control parameters are set, it is simply a matter of choosing what sensing devices will best capture and transmit the required information. External parameters such as the surrounding environment and communication or response speeds times will also affect the decision-making process (Weckenmann et al., 2015, pp. 1-28).

2.2 Surface Defect Detection Methods

Without an online automated surface defect detection system in place, online quality checks are currently undertaken by human operators. The speed, efficiency, and level of reliability of these human operators are limited and dependant on the individual's ability to capture information with their eyesight, process this information and make a decision. It is also reliant on the individual's interpretation of this information, i.e.; what one operator deems to be a surface defect, may be passed by another as acceptable. Through the use of some sensor-based vision system, the interpretive human error can be eliminated.

2.2.1 Optical

Camera based vision systems can detect surface defects at a much higher rate than the human eye, allowing manufacturing facilities to run at higher speeds while maintaining their quality specifications (Malamas, E.N., et al, pp.171-188). (Tejas, R., et al, pp. 455-484) identifies the two types of sensors used within cameras as; charge coupled devices (CCD) or complementary metal oxide semiconductor devices (CMOS). Each camera type has their own benefits, but in short (Tejas, R., et al, pp. 455-484) explains that CCD cameras are more appropriate for high quality, high focus, high resolution image capture, and CMOS cameras are more appropriate for high-speed image capture and information retrieval processes.

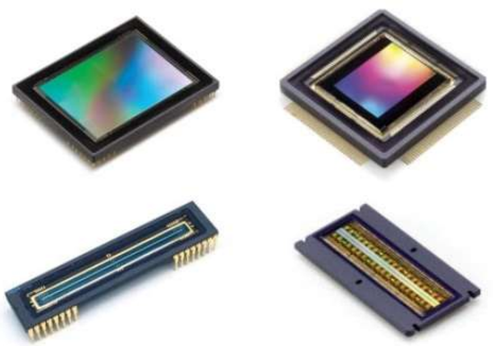

Figure 1: Teledyne DALSA CCD (left) and CMOS (right) image sensors (Anon, 2018)

In “Manufacturing Systems Modelling and Analysis,” (Curry & Feldman, 2010, pp. 109 - 123) stress that if a product is not moving through its manufacturing process, the production line is stagnant, and stopping further product from being made. As such, a camera-based vision system for a manufacturing facility, will need to be able to capture images of moving objects. To assist with camera selection, the rate of speed at which these objects need to be moving, coupled with the number of images required to be taken of that object, will determine the minimum frame rate that the camera needs to be. (Keyence Corporation of America, 2022) write that the most important feature in determining camera selection is the resolution. This parameter is determined by the size of the object wanting to be captured, versus the minimum tolerance of the size of the defect to be captured. For an object of size, (a*b)mm, with a minimum tolerance of, (t)mm, the resolution can be calculated as;

Eq. (1). $Resolution = (a / t) \times (b / t)$

Once these parameters are known a suitable camera for the image capturing process can be selected. How this image is then interpreted into some useful information will depend on the software used to analyse it.

Typically, when a camera is supplied as an online vision system, it will be partnered with a vendor supplied software, that will have a “tool” package containing layers of algorithms to interpret images and produce information. The rate at which this software can interpret this information, make decisions, and produce an output is also extremely important. In a local based plc system, this processing speed is heavily dictated by the processing capabilities of the local hardware (Cognex, 2018). In a cloud-based system, not only is the local hardware a factor, but also the bandwidth i.e.; the upload and download speed of the internet available to the image capturing system.

(Chamorro et al., 2022, pp 38-50) investigated a QMS to monitor the health of a conveyor belt using machine vision. One of the greatest limitations to (Chamorro et al., 2022, pp 38-50) proposed system is that their cloud base range was only 4km. (Chamorro et al., 2022, pp 38-50) discussed methods to reduce bandwidth thereby also reducing total storage required. These extra processes need to be considered when determining the speed of image processing. The camera may suit the criteria, but the processing speed of the vendor-based software may provide some limitations. Local server systems and cloud-based server systems will be discussed in more detail later in this report.

Camera image capture relies heavily on light (Cognex, 2018). While there are lots of other factors to consider, the type of light and the amount of light that an object wanting to be captured is subject to, plays a major role in camera selection. (Batchelor, 2012, pp. 801-870) discusses the effects of volume and the type of light, claiming that both factors affect how the processing system is able to refine an image and produce some useful information. (Batchelor, 2012, pp. 801-870) confirm that a poorly lit image may not allow a processing system to define certain extremities or specific details of an object. Similarly, an extremely well lit object may be too bright for a processing system to refine and define particular points of interest on the image captured. Choosing the amount of light and the light source type, needs to be strongly considered prior to camera selection, but also during the trial phase of an install. A light source of alternating current will have a changing wavelength, as opposed to a dc light source that will produce a constant wave (Batchelor, 2012, pp. 801-870). AC light sources may introduce a flicker effect during image capture resulting in light and dark moments in time. This may be an issue pending the cameras frame rate and method of capture. Alternatively, as discussed by (Schnee & Futterlieb 2011), laser beams can also be used to produce a consistent light source or datum plane for a camera to capture images against. Laser type and selection will be discussed later in this report.

2.2.2 Ultrasonic

(Essig, et al, 2021, pp.32-43) use Ultrasonic or Ultrasound testing, whereby very high frequency sound waves are used to gather information about the internal properties and thickness of a product. (Essig, et al, 2021, pp.32-43) make use of an ultrasonic processer connected to a transducer that converted an electrical signal sent by the processor unit, into sound waves. The transducer uses piezoelectric material that when supplied with electrical current, vibrate and produce sound waves. (Langenberg, et al 2012) note there are two main methods for ultrasound testing. The first being the, "Pulse echo," method, which uses one transducer to transmit sound waves.

(Langenberg, et al 2012) explain that the waves return after colliding with some interface (air) the transducer will then receive these sound waves and display them on a monitor. If these were to be displayed on an ultrasonic processing screen, there will be two wave peaks. The first being the sound waves produced by the transducer and the second being the soundwaves received by the transducer. (Langenberg, et al 2012) go on to explain further that the thickness of the material can be determined by the distance between to the peaks. If there was some lump on a product these two peaks would be further apart, if the there was some deficit on the product these two peaks would be closer together. If there is a smaller peak within these two larger peaks, it means that some of the waves have hit some other unexpected interface, perhaps debris, meaning that there is some defect within the product. Again, (Langenberg, et al 2012) state that this wave peak can be measured from the initial peak to give an exact distance measurement of where the surface defect is. (Langenberg, et al 2012) mention that this process can be automated through software and a straight digital output returned to the user, identifying the materials thickness, if any defects were present and the exact location of these defects.

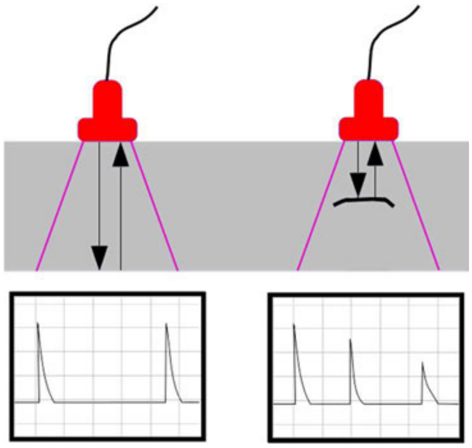

Figure 2: Principle of Ultrasonic Testing (Werner Solen, 2022)

The “Through transmission,” method, (Langenberg, et al 2012) explains, uses two transducers, one each side of the material. One transducer acts as the transmitter for the sound waves while the opposing works as the receiver. The same principals apply for information collection as the pulse echo method. According to (Langenberg, et al 2012), ultrasonic testing is typically used for the testing of metals, plastics composites, and ceramics and in industries such as; Aerospace, Automotive, Electronics & Battery, Metals & Casting, Oil and Gas, Power Generation and Railroad. There was no evidence found that ultrasonic testing is as effective and reliable for tests conducted on raw materials or cellulose based organic products.

Ultrasonic NDT field testing units can be quite small and dynamic, where a portable control pad with some monitor interface is coupled with one or two transducers (Blitz & Simpson, 1995, pp. 111). This allows operators to carry this portable unit around to particular sites and carry out thickness and defect detection on typically pipes and structures comprised of metal, plastic, or ceramic material, located in various locations of an engineering facility. (Blitz & Simpson, 1995, pp. 111) identify that this portable feature is fantastic on providing accurate measurements on specific thickness in localised areas on pipework or structure. Setting up multiple transducers along pipework, with some common transmitter, communicating the information provided by the transducers back to some home base, can also provide users with an interface displaying continual thickness and internal integrity defects (Blitz & Simpson, 1995, pp. 111). Allowing digital displays to raise alarms when thickness fall below a certain a tolerance due to general wear from the internal friction of the matter travelling through the pipe (Blitz & Simpson, 1995, pp. 111).

2.2.3 Mechanical

The simplest form of measuring an objects mass of dimensions is through the method of direct measurement, whereby some calibrated tool is held against a manufactured object, and a direct reading is retrieved by the measuring device. (Mitutoyo, 2022b) highlight these mechanical devices which are commonly used in engineering facilities. According to (Mitutoyo, 2022b), these instruments may come in the form of micrometres, callipers, dial indicators, and scales. Most of these Mechanical measuring devices require the object to be static, and for a human to apply a physical clamp or hold the measuring device against the surface of object.

Specifically, for surface defect detection, (Mitutoyo, 2022b) recommend a dial gauge attached to some roller or guide, encompassing the length of width of a desired objects surface, can determine whether some change in height is within range of a required specification. (Mitutoyo, 2022b) explains that a dial gauge works via a pin, in contact with a surface, connected to a series of gears, that when pressed, will move a dial on a physical gauge. This gauge can be set to ‘0’ at some datum point, with each rotation of the dial gauge representing some unit of distance measurement. i.e.; one turn on the gauge may be equivalent to 1mm, with each increment on the dials face being the equivalent of 0.01mm.

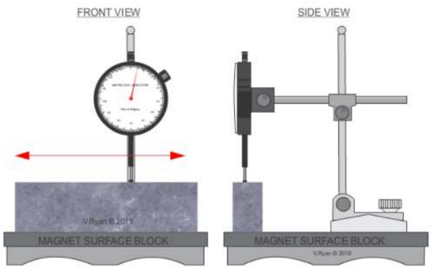

Figure 3: Engineers Dial Indicator Set Up (Ryan 2019)

Once calibrated this dial gauge can be read as it’s passed over the surface of a material to determine the overall flatness of a surface. According to (Mitutoyo, 2022b) as the dial gauge passes over a raised face, or lump, the read out will positively increase by the exact change in height on the product. Similarly, as the height of the object decreases from its datum point, replicating a dent, the dial gauge will read negatively. As they are internally geared, (Mitutoyo, 2022b) note that some slipping or movement in the pin height needs to be controlled by a solid rigid mounting base. When conducting a google search of dial indicators that where available online, it was found that the digitalised products are battery powered and require regular calibration.

2.2.4 Radiometric

Radiometry calculates the difference in a radiation beam sent by a source against the amount detected after the beam has either passed through an object or been reflected off of it. Radiometric measuring can use a solid state laser light source to emit a radiation beam into an object (Schnee & Futterlieb 2011). This beam, depending on the object type, can then be reflected off the object or pass through the object into a CMOS detector. When reflected, the measurement of distance from the beams light source to the object is calculated via the laser triangulation principle (Swojak et al 2021, pp. 109 - 190). Alternatively, the beam can pass through the object with some detector on the opposing side and some calculations can then be done a by a processor to determine the change in density of the beam, which can be used to determine the change in density or change in thickness of an object (Swojak et al 2021, pp. 109 - 190).

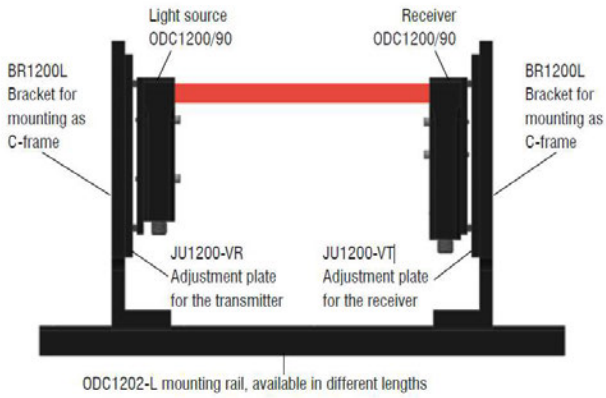

Figure 4: optoCONTROL recommended installation set up (Micro-epsilon 2022a)

(Hecht 2018, pp. 8 - 10) notes that when selecting the correct laser to use for a certain application, considerations such as; beam size, shape, type, and wavelength are extremely important. According to (Hecht 2018, pp. 8 - 10), laser beams come in three different shapes;

- Circular
- Elliptical
- Rectangular

The shape of a laser beam is dependent on the surface of the selected product that is being scanned. This shape may be obsolete pending the scanning range of the laser assembly, and the width of the projected beam. If the object can comfortably fit within the extremities of this beam then the beam shape is not critical (Hecht 2018, pp. 8 - 10). The shape of the beam may be more critical when undertaking precision measurement of extremely small objects, whose shape may be placed into one of the three shape categories; circular, elliptical, rectangular. In such case, the shape of the beam should be selected to best match the subject areas general shape (Hecht 2018, pp. 8 - 10).

(Dickey, 2018, pp. 210 - 217) discusses various methods of beam shaping, but his findings can be separated into two broad methods of beam distribution; Gaussian and Flat Top. (Dickey, 2018, pp.

210 - 217) explains that the Gaussian method distributes irradiance in a way that the irradiance will decrease the further the beam travels from its source. Flat top distribution, which may also be referred to as a Top Hat beam, will provide a constant irradiance over some given area. (Dickey 2018, pp. 210 - 217) explains that there are multiple methods to change a gaussian beam to a flat top beam, but essentially achieve the same result.

(Hecht, 2018, pp. 8 -10) notes that these beam shapes range in size, pending the strength of the gamma ray sent by the light source, and the distance of the object from the beam. This an extremely important limitation to consider when choosing a laser. The environment or proposed installation location may not permit a light source or a detector to be some distance from the product.

According to (Hecht 2018, [[. 8 - 10) there are two types of lasers to choose from; continuous or pulsed. Pulsed lasers are able to emit an ultrafast pulsed laser beam, as opposed to a continuous wave laser, which by name, emits a continuous laser beam until told to stop (Hecht, 2018, pp. 8 - 10). Choosing which type of laser will depend on the application that the laser is going to be installed into. If one continuous light source is required to capture continual information, then a continuous beam would be required. If intermittent points of reference or data are to be captured than a puled light source would be preferable (Hecht, 2018, pp. 8 - 10). Another consideration discussed by (Hecht, 2018, pp. 8 – 10) with regards to laser type, is the amount of radiation that the object or product being scanned can be subject too.

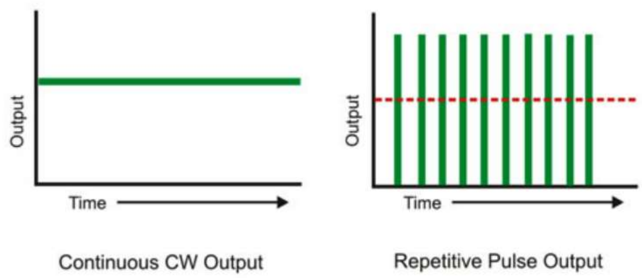

Figure 5: Continuous Wave vs Pulsed Wave Laser Beams (Ilic 2006)

(Ilic 2006, pp. 458-466) highlight that some products are negatively affected by gamma ray beams and having a continuous wave as opposed to a pulsed one would increase the exposure that the object would have to the radiation source. (Ilic 2006, pp. 458-466) reiterate this, identifying that overexposure has the potential to compromise the integrity of some materials due to the amount of energy that the material is subject to by the laser. Alternatively, (Dunlap 2019, pp.1 - 16) explains that this level of exposure can be reduced or regulated by changing the wavelength of the laser.

(Dunlap, 2019, pp.1 - 16) goes on to explain that a laser with a large wavelength results in a less focused and lower energy laser beam. Conversely, a laser with a very short wavelength results in a more focused and higher energy laser beam. As the energy emitted by the laser increases, so does the excitement of the photons within the subject matter, resulting in an increase in heat (Dunlap 2019, pp.1 - 16). According to (Dunlap 2019, pp.1 - 16), the visible spectrum of lasers is between wavelengths of 400nm to 700nm, with all wavelengths outside of this, not visible to the human eye. Within this visible spectrum, a change in wavelength will also result in a change in laser beam colour. The colours seen in the visible spectrum with relation to their wavelength can be seen in the table below;

Figure 6: Visible Light Region of the Electromagnetic Spectrum (National Aeronautics and Space Administration, 2010)

2.2.5 Software

As discussed earlier in section 2.2.1 Optical, there are two types of processing systems to be considered when purchasing an online vision system; a local privately owned server or a cloud based subscription server. Local PLC based system software is typically bought and then owned by the user. All of the information captured is secure and owned by the user. As new versions of the installed software become available it is up to purchaser to make the decision to upgrade or not. And all of the collected images or data is kept private for the user to analyse, interpret, or archive as they wish.

A cloud based system is a subscription based service, where a fee is paid to use a particular server. The server will receive the information captured by the vision system cameras and sensors and produce some useful information 'offsite,' to where the process is taking place. The algorithms and data collected are owned by the business providing the service. Any upgrades, adjustments, maintenance, and troubleshooting assistance is dictated by the provider. There are many examples of this subscription vs ownership model, outside of online vision systems but as (Li et al 2020, pp.688-704) discuss, the principles and associated risks are the same.

In (Li et al 2020, pp.688-704), they acknowledge that subscription based business models have become more popular and more relevant in today's age with the expansion and availability of the global internet. (Li et al 2020, pp.688-704) note that a major factor when considering which model to invest in is the length of the planned investment, as initial costs of the ownership model are much higher than the intermittent payments of the subscription model. When investing in a subscription model, the user absolves themselves of virtually all of the risks associated with ownership. Furthermore, all upgrades to the system, day to day running and management of the service, maintenance and troubleshooting required, and insurances and liabilities for the service or product, is the responsibility of the provider (Li et al 2020, pp.688-704). This is contrary to the ownership model where all of these costs are added to the initial upfront price to purchase the model. This cost is not just financial but also worth time and effort, that could be used to provide the users business with some other asset. These running costs also require infrastructure to be implemented to support the product. In the subscription model, the user just needs to ensure that some financial fee is paid, and that service will continue (Li et al 2020, pp.688-704).

(Li et al 2020, pp.688-704) identify the major risk associated with a subscription service is trusting the business that provides the service. If the business is to have a change or failure in any form, it is out of the subscriber's control to manage that issue. If an employee was to leave the busines, there was a change in management, the business suffered a significant financial stress or suffered a major technical malfunctions, the service could become unreliable or disappear altogether (Li et al 2020, pp.688-704). The information and knowledge gathered by that provider over the time of providing the service, would be owned by the provider. The user would not have access to this information, or the processes that provided that product and then be at risk of losing some critical component to their own business (Li et al 2020, pp.688-704).

2.3 Available Products

In today's market, there are many businesses that specialise in machine vision systems. Various businesses offer an extremely wide range of individual components for vision based engineering solutions. These businesses may have certain suppliers that they regularly engage, or they may produce all of the individual parts themselves. These companies have provided their customers with engineering to solutions to their processing problems and could potentially do the same for James Hardie.

2.3.1 Cognex (Optical)

Cognex use a GigE vision interface that boasts a small bodied camera with Global Shutter resolution options from as little as 1.3 MP to 31 MP of resolution (Cognex, 2022). As the resolution increases the frame rate decreases and the power consumption increases.

AREA SCAN

Model Number	Body Type	Reso-lution	Frame Rate	Sensor Type	Sensor	Sensor Size	Power Consumption	Lens Mount	Color / Mono
ROLLING SHUTTER									
CAM-CIC-5MR/5000R	A	5MP	14 fps	CMOS	Aptina MT9P031	1/2.5"	2.5 W / 2.2 W	C	C, M
CAM-CIC-10MR	A	10MP	10 fps	CMOS	Aptina MT9J003	1/2.3"	3.3 W / 3.5 W	C	C, M
CAM-CIC-12MR	A	12MP	8 fps	CMOS	Sony IMX226	1/1.7"	2.5 W / 2.9 W	C	C,M
GLOBAL SHUTTER									
CAM-CIC-1300	A	1.3MP	60 fps	CMOS	e2v EV76C560	1/1.8"	2.4 W / 2.0 W	C	C, M
CAM-CIC-2000-60	A	2MP	60 fps	CMOS	e2v EV76C570	1/1.8"	2.1 W / 2.5 W	C	M
CAM-CIC-4000	A	4MP	25 fps	CMOS	CMOSIS CMV4000	1"	3.4 W / 2.9 W	C	C, M
CAM-CIC-5000-20	A	5MP	24 fps	CMOS	Sony IMX264	2/3"	2.4 W / 2.8 W	C	C,M
CAM-CIC-3100	G	31MP	3.82 fps	CMOS	Sony IMX342	APS-C	5.4W / 6.7 W	F	C,M

Figure 7: Cognex GigE vision Camera (Cognex 2022)

Models	CIC-5000R/ CIC-5MR	CIC-10MR	CIC-12MR
Shutter	Rolling		
Pixel Bit Depth	12 bits		10 or 12 bits
Synchronization	hardware trigger; free-run; Ethernet connection		software trigger, hardware trigger, free-run
Exposure Control	programmable via the camera API; hardware trigger	programmable via the camera API	
Digital I/O	1 input, 1 output		1 input, 1 output, 1 general purpose
Power Requirements	PoE or 12 VDC	PoE or 12–24 VCD	
Form Factor (L x W x H)	Body Type A: 42 mm x 29 mm x 29 mm		
Housing Temperature	up to 50 °C		
Weight	90g		
Compliance	CE, RoHS, GenICam, GigE Vision, IP30, UL, FCC, IEEE 802.3af (PoE)		

Figure 8: Cognex GigE Vision Data technical data (Cognex 2022)

Cognex have developed VisionPro Deep Learning Software compatible with Microsoft systems, that has Defect detection and segmentation, material classification, assembly verification and part location, character reading (Cognex, 2022). VisionPro Deep Learning tools require sample images to be uploaded into its data base prior to use. It then requires the user to go through four steps; locate, analyse, classify, read, in order to train the software by example (Cognex, 2022). This process can then be continually refined, uploading more sample images, once the system processes are validated and the correct pass fail decisions are being made, the system can be deployed into its final application.

Also, part of the Software is the ViDi EL Tools has a library of pre-trained algorithms that can use the Locate, analyse, classify, and read steps, to decipher when a part has some abnormality than a regular part (Cognex, 2022). The Software systems must be used in conjunction with the Cognex Industrial cameras. They supply a hardware and software system but don't offer any sought of storage options, whether they be local, or cloud based. Their industry renowned areas are in solid ferrous and plastic materials; Semiconductors, Consumer Electronics, Medical, Pharmaceutical, Automotive, specialising in label and barcode reading, mechanical and electronic part inspection, some medical tooling surface defect recognition.

2.3.2 SICK (Optical))

SICK's business background is vehicle detection or collision avoidance systems in the mining, metals, and processing industries. They are an industry leader in high frequency technology sensor intelligence. Their scope of industry solutions is not limited to vison systems, but also high spec industrial sensors. Their products have been proven to be effective and reliable in difficult environments, where it is typically very difficult to have a reliable and trustworthy sensor.

SICK has a 3D machine vision camera called the Ruler3000, primarily designed for high speed quality inspections of linear measurement through 3D line scanning (SICK, 2022). This global shutter camera has a working distance up to 1.445m and a field view of 1.2m x 0.345m (SICK, 2022). Requiring a 24V power supply, and less than 12W of power consumption, it has an impressive frame rate of 7,000 3D profiles per second (SICK, 2022). The SICK vision system has the ability to be coupled with an encoder interface for optimal performance and improved measuring accuracy (SICK, 2022).

Figure 9: SICK Ruler3000 camera (SICK 2022)

Intrinsic are a vision analytics company who have been working with the James Hardie site in Reno. The Intrinsic system claims to be able to immediately detect surface defects on fibre cement board through a product of the business called, "Heijunka vision analytics (Intrinsics Inc. 2020)." This system is a proven system in fibre cement roofing manufacturing facilities, and by rights should be directly transferable into the James Hardie plant in Carole Park. Intrinsic claim that the Heijunka Vision system can also detect dimensions, smoothness, straightness, and colour (Intrinsics Inc. 2020).

An installation document that was provided by Intrinsic cannot be shared in this dissertation due to IP restrictions, but the following information was gained from that document. The Intrinsic system uses two overhead ASIX P3248 4K cameras to scan the boards as the pass along the conveyor belt. Their starter package comes with (2) cameras, a controller (using a Mac Mini), and a portable monitor, ready for installation. Their system uses a video stream to a cloud based server that contains all of their companies' algorithms for defect detection. The system does not come with any lighting, but they do suggest mounting (2) strong DC LED flood lights below the cameras but above the product.

2.3.4 Controle Mesure Systemes (Ultrasonic)

Controle Mesure Systemes, are a French based business, specialising in Ultrasonic Non Destructive Testing (NDT) (CMS 2016). This company was the only company found while conducting the literature review, that offers a, “production line,” method of Ultrasonic NDT on products along a conveyor belt style system (CMS 2016). They have not branched out into fibre cement product, nor was there any other research available during the conducting of this thesis that there has been any proof that Ultrasonic NDTs are effective or efficient for raw materials, such as cellulose fibre cement (CMS 2016). Furthermore, when an Ultrasonic NDT is implemented on a production line, they require their own local and quite large and robust radio wave transmitting and receiving system where radio waves are formed and captured over a much larger surface area (CMS 2016). Although this is hypothetically possible to be a solution to surface defect detection on the green sheet boards at James Hardie, it is also going to be a very expensive exercise and also quite a large installation process. There is no way for a system to be, “added in,” to the existing lines without major structural changes to the sheet machines, as the infrastructure does not currently exist. As such, this system will not be considered as a possible alternate option to the SICK or Intrinsic systems.

2.3.5 Mitutoyo (Mechanical)

Mitutoyo have a digital dial indicator that claims to be accurate up to 0.001mm (Mitutoyo 2022). This indicator would need to be built into some greater design, with custom attachments to the pin to be able to be used on the James Hardie Green sheets. The scale of the extra work and modifications required to make this option a plausible option is too great for the purpose of this thesis. As such this option will not be considered.

Figure 10: Mitutoyo ABSOLUTE Series 543 Dial Indicator (Mitutoyo 2022)

2.3.6 Micro-epsilon (Radiometric)

Micro-epsilon offers a wide range of sensor based quality systems. The use of sensors and laser technology they can achieve high precision measurements in a wide range of applications. For surface deflection, deformation and waviness in saw blades, Micro-epsilon have developed one system that is comprised of three optical micrometres (Micro-Epsilon, 2022a). There is one micrometre positioned at each end of the blade and the third in the middle. The micrometres on the outer make a straight line, with the deviation in mm determined by the middle unit. The accuracy of these units goes up to 0.02mm tolerance, with the span of the laser going up to 40mm (Micro-Epsilon, 2022a.)

	Measuring ranges	Measurement mode	Page
optoCONTROL 1200			
Compact, fast and space-saving 90° version; integrated controller	Measuring range up to 30 mm		4 - 5
optoCONTROL 2500			
High accuracy and stability / resolution 1 µm; target-sensor gap up to 700 mm (optional 1850 mm)	Measuring range up to 34 mm		6 - 7
optoCONTROL 2520			
Compact design with integrated controller; target-sensor gap up to 2000 mm / resolution 1µm	Measuring range up to 46 mm		8 - 9
optoCONTROL 2600			
Maximum accuracy and stability; target-sensor gap up to 400 mm; telecentric lenses / resolution 0.1 µm	Measuring range up to 40 mm		10 - 11

Figure 11: optoCONTROL measuring ranges (Left) and blade inspection set up (Right) (Micro-epsilon 2022)

Micro-epsilon also offers an optoNCDT sensor, used for precision measurement (Micro-Epsilon, 2022b). These sensors shoot a laser that returns to the unit, measuring ranges from 2-1000mm (Micro-Epsilon, 2022b). These lasers provide pinpoint measurements with accuracy up to 1mm. Micro-epsilon also offer multiple 3D scanners that can monitor the surface quality and conduct uniformity checks.

The scanCONTROL products also use the GigE vision standards similar to Cognex (Micro-Epsilon, 2022c). With a wide range of different scanners, products, or areas, can be measured from 25 x 15 mm up to 200 x 300 mm (Micro-Epsilon, 2022c). These sensors can be set upside by side to cover a larger area. At the maximum area spread of 200 x 300 mm the scanner has to be a minimum of 450mm from the product (Micro-Epsilon, 2022c). This limits the installation options of the scanner, places the product in range of being struck from a jam up. Micro-epsilon state that these scanners can be used on transparent of organise surfaces but would suggest the use of their blue light range for this application.

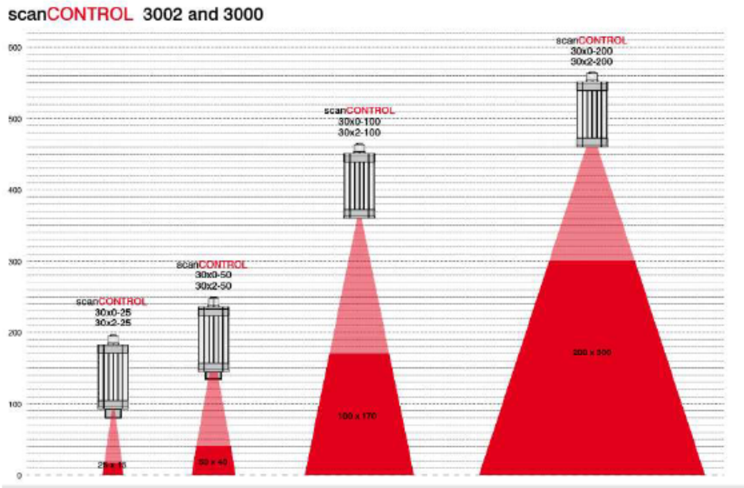

Figure 12: scanCONTROL field of view range (Micro-epsilon 2022c)

2.4Conclusion

Based off the collected information from this literature, the following table was made to identify which method/s of surface defect detection, are most appropriate for the James Hardie site;

	Optical	Ultrasonic	Mechanical	Radiometric
Accuracy	✓	✓	✓	✓
Proven effectiveness in wet environments	✓	X	X	X
Proven effectiveness in dusty environments	✓	X	X	✓
Proven effectiveness on Fibre Cement Products	✓	X	X	X
Compact design	✓	X	X	✓
Low Cost	✓	X	✓	✓
High Speed & Volume Processing	✓	X	X	✓

Table 1: Surface Defect Detection Check sheet

This literature review has proved that a Radiometric surface defect detection system, such as the service provided by Micro-epsilon are one plausible solution to the problem, and would benefit James Hardie in Raw performance, scalability, and to achieve global consistency. One issue with using these scanners is the surrounding environment at James Hardie. On the line where these scanners will be installed, the area can experience some human interaction, vibration, dust, steam, and moisture. These environmental factors may bring about some unwanted noise in the scanned images causing false alarms and false readings. The issue of dust has previously been rectified by placing a positively displaced air source in front of the laser lens. The issue of vibration has been rectified with rigid framework. While the issue of human interaction has been rectified by some form of guarding. If these lasers were to be used, some consideration into the removal or containment of the moisture present in the area would need to be considered. Pending the results of the trials for SICK and Intrinsic systems, the Micro Epsilon 3D scanners may be considered thereafter this dissertation.

SICK's background in mining and metals is equally as important as the quality of their technology. The typical environments that their equipment has had to work in and be reliable and trustworthy, is reassuring, as the system installed at James Hardie Carole Park, will experience similar impacts. The Ruler3000's long working distance and large field of view means the camera or cameras, can be mounted up high and away from the product. This is important in the James Hardie environment as jam ups can occur daily on the line. If a build-up of product was to occur and pass through the location of the cameras, significant if not catastrophic damage to the cameras could occur.

After discussions with SICK and Intrinsic, both businesses believe that their systems can achieve the design criteria. Through the use of a camera based system, coupled with some artificial lighting, the systems will aim to measure surface defects, and perhaps after some further development, linear dimensions. Trial systems from both SICK and Intrinsic now need to be installed in similar locations on the green sheet production lines, to begin analysis of the effectiveness of these systems.

CHAPTER 3 – RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

The following methodology design will aim to critically analyse the performance and raw results of the SICK & Intrinsic machine vision systems to identify surface defects on green sheet products produced at James Hardie Carole Park. Secondly, the design will bring focus on system scalability, assessing each systems sustainability, maintainability of the systems. Thirdly, their ability to achieve global consistency, that is to replicate performance and results in similar environments in other James Hardie plants around the world. This will be achieved by;

1. Identifying and understanding the set specifications by James Hardie for surface defects
2. Engaging with SICK and Intrinsic to develop a suitable machine vision trial system
3. Purchase, installation, and calibration of those systems
4. Initial Trials
5. Review Raw results of captured data
6. Refine system to achieve better results
7. Review Results of data captured
8. Review performance and scalability of the designs based on findings
9. Review implementation of the systems on a global scale based on findings

3.2 James Hardie specifications

While initial trials will be focusing on surface defect detection, some performance specifications for the dimensional checks should also be noted during initial discussions with both SICK and Intrinsic. This thesis will focus on surface defects however the underlying goal is for both systems to achieve both tasks of surface defects analysis and linear measurement analysis. Considering this, multiple departments within the James Hardie team will need to be engaged with prior to engaging with the SICK an Intrinsic teams.

One of these departments is the quality department, headed by a Quality manager and supported by a laboratory team. Through discussions with the Quality department, the following specifications for what dictates a “failed product,” can be found;

Parameter	**James Hardie Requirement**
Surface Defect Detection Size	?
Outer Dimension Accuracy	+/- ?
Thickness Measurement Accuracy	+/- ?
Number of Thickness measurement points	?

Table 2: James Hardie Carole Park Quality Specifications

While the system needs to display the raw performance of being able to detect a surface defect to these above specifications it needs to be able to do this without compromising the production speeds of the machine. The Production team will need to be engaged to understand the speed in linear metres that the boards will be travelling at as they pass through the camera's field of vision. Further to this, it needs to be understood how much time the machine vision system will have from the moment a green sheet board is identified as defective, to the moment that some output to an actuator scrapping the sheet is required. Once this is known I response time can be dictated and added to the required specifications table.

The maximum dimensions of the boards required to be seen also needs to be understood. James Hardie manufactures many different products with varying board sizes. Understanding what the largest board size will dictate the maximum viewing range required by the machine vision system. The minimum viewing range has already been dictated by the tolerance specifications. These requirements can be added to the required specifications table;

Parameter	**James Hardie Requirement**
Surface Defect detection Size	?
Outer Dimension Accuracy	+/- ?
Thickness Measurement Accuracy	+/- ?
Number of Thickness Measurement Points	?
Response Time	?
Maximum Board Size	L = ? W = ?

Table 3: James Hardie Carole Park Quality & Performance Specifications

Once this information is finalised, SICK and Intrinsic Engineering teams will be consulted put together their offer and trials system proposals. This will result in both parties putting forward a quote for either the loan or purchase of their equipment for a period of time. Within this offer, both parties should also identify what support they will be offering over the installation and trial process. On receipt of these quotes, we will review, refine, and once satisfied with the terms and conditions, the trial packages will be purchased.

3.3 Installation of Equipment

Assuming the Hardware supply has been outlined in the supplied quotes, some framework and mounting designs can begin. When considering the installation of the hardware on the green sheet production line at James Hardie, the external environment and the functionality of that line need to be considered. Therefore, the framework that they are mounted on, need to be able to straddle the conveyor width while having minimal to no movement through the framework and into the camera housing. Some vertical adjustment may also be preferred in order to find the optimal distance from the product during the initial set up.

Any extra movement from shuddering or other processes on the line will result in waviness or deformation to the final image. Having these cameras for both SICK and INTRINSIC, set up in a way where movement is negated, but still within range to the product, is extremely important. The design of the frame for the camera mounts should also be done in a way, where it can be dismantled and removed from the line. If the trial is not successful or causes functionality issues to the day to day running of the line, we will need to be able remove the framework, so that normal operation can occur. If the framework was to be fixed and something was to go wrong, or was not correct, this could result in downtime for the machine, which is not acceptable.

All trial installations and maintenance need to be conducted while the machine has a scheduled outage or while some other part of the feeding system has a scheduled outage. This will be achievable as fortnightly the machines have their scheduled, “Down Days,” where the production team take the opportunity to clean the machines and maintenance undertake major repairs. In this time there will be opportunities to install, and trial fit the framework, temporarily run the machine, and make adjustments as required. This will ensure that the framework is going to be suitable on the line.

Both systems will need some power source to run their PLC’s and support their hardware. The decided trial location of installation of these systems needs to be inspected prior to hardware arrival to ensure that the correct power sources are available. If not some consultation with the electrical department will be required to provide an adequate power source. While the SICK system will be local, and for the purpose of initial trials not requiring an Internet connection, it can be assumed that post trials iterations of this design would gain benefit from some remote access. This may be to download data, undergo maintenance, review system processes, or witness live time running.

The intrinsic system, being a cloud based service system will require Internet for its initial trials. While a wireless connection is available throughout the James Hardie site, for optimal bandwidth speeds a dedicated Ethernet cable would be desired. On review of the Intrinsic offer, it must be understood what this Ethernet connection requirement is and if it is available at the trial location. If not some consultation with the IT and Electrical department to provide disconnection must be had.

On arrival of the hardware to site, some consultancy with the suppliers will need to be undertaken to ensure that the initial set up has been done correctly, to give both systems the best opportunity to succeed.

3.4 Calibration of equipment

Both SICK an Intrinsic are camera based machine vision systems and as such the camera will need to be calibrated prior to use. This is undertaken by using some precision machined part with known measurements, placed in the optical viewing field of the camera. The camera is then the camera is then calibrated through some manual user input identifying what extremities all points of interests are 2 calibrate the required measurements. There are many different image processing techniques that can be used to achieve this task for surface defects and linear dimensions. A full understanding of the calibration process cannot be achieved until it is understood what system is being supplied by SICK and Intrinsic. It can be assumed though that this process will be required and sometime needs to be allowed for it to be undertaken and troubleshooting to occur.

3.5 Initial Trials

The first iteration of trials for both SICK and Intrinsic systems will not be connected to any formal output. The focus of initial trials will be to get both systems to work to achieve their basic function of identifying a surface defect on a board. Assuming both systems will have some display monitor at the location of the trial set up where a user interface is available, time will need to be spent at the monitor witnessing the effectiveness of the system. With the conveyors running at full speed, it needs to be seen that the green sheet boards containing surface defects as identified by the operator are also identified as green sheet boards containing surface defects by the machine vision systems.

There will be three different types of surface defects aiming to be captured by the systems;

1. Lumps
2. Dents
3. Debris

With approval from the production team during the initial trials some purposely damage sheets may need to be sacrificed in order to inspect the machine vision systems capabilities of surface defect attention this could include the spiking of a board to create a lump or dent or placing a piece of green sheet board on top of another board to create debris.

Once the system is up and running and it has satisfied its immediate requirement of identifying surface defected boards the system will then be left to run for some period of time. This length of time will need to be decided upon through consultation with the suppliers of the systems. This period of time will dictate the range of possible data spread to analyse the effectiveness of the machine vision systems. During period, daily checks need to occur to ensure that these systems are still operating as per their initial function. If for any reason the systems have begun to skew in effectiveness, a reset in calibration may be required. This will only be able to occur during a machine outage and may prolong the trial process period.

Trouble shooting time for software and hardware issues need to be allowed for during the trial phase process. SICK have a local engineering consultancy team in Australia and are readily available during normal working hours Monday to Friday. Their response times will be a lot faster than that of Intrinsic who are based in Bolton, Massachusetts, who may take up to 2-3 days to respond to emails requesting information. Phone calling window times during the trial period will need to be scheduled with the Intrinsic support team to allow for fast turnaround response times. For reference, Brisbane QLD, Australia is 14 hours ahead of Bolton, MA, USA.

3.6 Assess scalability

After trials have been proven successful an assessment of the cost and timeline for installation across the entire site acara pot can be made. Negating the time for troubleshooting and initial errors of during the machine visions trial period, Will give an accurate time frame to the installation time required to fabricate instal calibrate and initialise the same system across the other sheet machines at Carroll park.

A product list needs to be made, based off of the hardware required for the first effective set up. From this list some accurate costs can be identified. The list will need to include the fabrication of the framework and any other infrastructure required for the installation of the machine vision systems. Time spent and billed by the SICK and Intrinsic teams during the installation team needs to be tallied and included in this table. This table should outline the overall cost and time required to be invested by James Hardie in order to replicate these systems across multiple sheet machines. As the exact number of sheet machines is not allowed to be disclosed due to IP reasons, an estimate on cost per Australian sheet machine will be given;

Description	**QTY**	**Approx. Cost per EA**	**Total**
Hardware Supply	?	?	?

Hardware Installation	?	?	?
Framework Fabrication	?	?	?
Framework installation	?	?	?
Contractor Engineering assistance for set up	?	?	?
James Hardie Engineering assistance for set up	?	?	?
Ongoing annual cost for running of system	?	?	?
Estimate of machine down time (if any) caused during set up phase	?	?	?
Power Source Installation (if required)	?	?	?
Internet Router/Source Installation (if required)	?	?	?
Total Power consumption of the system	?	?	?

Table 4: Cost per Australian Install

Another factor to consider when identifying the scalability of these machine vision systems is their capacity to handle a higher volume of product throughput than what is currently expected at the James Hardie site. This answer will be theoretical only. It will be dictated by the hardware's capacity to capture the same amount of information as speed increases, and the processing systems ability to process the images and produce outputs at higher rates. If this is not achievable some assessment needs to be made as to what would be required and the associated time and cost that would be needed for the machine vision systems to achieve some percentage of speed increase.

3.7 Materials Table

Resource type	Description	QTY	Cost
DATA	request data sheets of Intrinsic hardware	1.0	$ -
DATA	request data sheets of SICK hardware	1.0	$ -
QUOTE	Quote from Intrinsic to supply hardware, assist with set up, and run trial	1.0	Unknown
QUOTE	Quote from SICK to supply hardware, assist with set up, and run trial	1.0	Unknown
SOFTWARE, HARDWARE, SHIPPING	James Hardie, request approval for purchase of equip, trial system Intrinsic	1.0	Unknown
SOFTWARE, HARDWARE, SHIPPING	James Hardie, request approval for purchase of equip, trial system SICK	1.0	Unknown
APPROVAL	James Hardie, request approval of use of the line for trials, machine down time? Can be done during scheduled outages so no cost to business	1.0	$ -
MATERIALS	Steel work for frame fabrication Intrinsic	1.0	$ 1,000 00
MATERIALS	Steel work for frame fabrication SICK	1.0	$ 1,000 00
LABOUR	Fabrication of Framework Intrinsic	8.0	$ 880 00
LABOUR	Fabrication of Framework SICK	8.0	$ 880 00
LABOUR	Installation of Framework Intrinsic	4.0	$ 440 00
LABOUR	Installation of Framework SICK	4.0	$ 440 00
LABOUR	Installation of Hardware Intrinsic	8.0	$ 880 00
LABOUR	Installation of Hardware SICK	8.0	$ 880 00
LABOUR	Extra labour assistance for electrical assistance SICK – 10hrs @ $110 cost to the business	10hrs	$ 1,000 00
LABOUR	Extra labour assistance for electrical assistance Intrinsic – 10hrs @ $110 cost to the business		
TOOLING	Basic Hand tools, basic measuring equipment (rules, verniers) some power tools (grinders, drills, welder, saw) zero cost, personal use	1.0	$ -
PPE	supplied free of charge by James Hardie, cost to the business is negligent	1.0	$ -

Table 5: Resource / Materials List

3.8 Planned Timeline

TASK	START	END
INTRODUCTION		
Engage with quality team for product & project specifications	2/03/2022	7/03/2022
Research and understand the need for the project	7/03/2022	14/03/2022
Define the research objectives and finalise conclusion	14/03/2022	17/03/2022

Submit draft of introduction	17/03/2022	21/03/2022
LITERATURE REVIEW		
Begin to read previous dissertations in similar fields	3/21/22	3/28/22
Collect most relative dissertations and discuss similarities	3/28/22	4/1/22
Products and reports of products in automated quality control	4/1/22	4/3/22
Submit draft of Literature Review	4/3/22	4/4/22
METHODOLOGY		
Asses proposed areas of installation and review pros and cons	4/4/22	4/7/22
Identify base line data and method of collection	4/7/22	4/15/22
Identify areas of interest for performance analysis	4/15/22	4/20/22
Review existing engineering business decision making methods	4/20/22	4/25/22
Submit draft Methodology	4/25/22	4/26/22
Collect base line data	7/22/22	7/29/22
Install SICK system onto the line	7/22/22	7/29/22
Install INTRINSIC system onto the line	7/29/22	8/5/22
Conduct a functionality test of all equipment	8/8/22	8/10/22
Schedule and conduct trial runs of both systems	8/10/22	8/13/22
Analyse results and reference against base line data	8/13/22	8/15/22
Submit second draft Methodology	8/14/22	8/15/22
PROGRESS REPORT		
Review Feedback from all submitted drafts and rectify	4/26/22	5/13/22
Draft layout and formatting of Dissertation	5/13/22	5/25/22

Submit Progress report	5/24/22	5/25/22
Review Feedback from progress report, make changes, resubmit	6/27/22	7/22/22
RESULTS & DISCUSSION		
Gather all results and put through decision matrices	8/15/22	8/17/22
Compare results of decision matrices and discuss	8/17/22	8/21/22
Submit Draft Results & Discussion	8/21/22	8/22/22
CONCLUSIONS		
Draw conclusions from methodology and results & discussion	8/22/22	9/5/22
Submit Draft	9/5/22	9/7/22
FINAL DISSERTATION		
Review Layout and Formatting of final dissertation	9/7/22	9/14/22
Review Feedback from draft submission and rectify	9/14/22	10/8/22
Submit Final Dissertation	10/8/22	10/13/22

4.0 Introduction

After identifying the required design criteria for a complete analytic assessment of both the SICK and Intrinsic machine vision systems, the following results were found through the methods discussed. These results will dictate the final decision on which system James Hardie should invest in long term across their global business.

4.1 James Hardie Specifications

After discussions with the quality and production teams at James Hardie, Carole Park, the below specifications were agreed upon as set requirements for the machine vision systems.

Parameter	**James Hardie Requirement**
Surface Defect detection Size	Diameter = ~3mm Length = ~8mm
Outer Dimension Accuracy	+/- 1mm
Thickness Measurement Accuracy	+/- 0.1mm
Number of Thickness Measurement Points	Every 100mm across the width of the board
Response Time	1 second for reject signal
Maximum Board Size	L = 9m W = 1.35m

Table 6: Final James Hardie Carole Park Quality & Performance Specifications

One point of interest to note from these discussions was that surface defect detection size is not currently collected by the operator on the green sheet lines. These surface defect parameters are not used until the board has gone into the finishing line. Identifying these surface defects at this early stage of the process should result in a higher scrap rate of green sheet boards, but not an overall increase of scrapped product on the James Hardie Carole Park site.

The dimensional accuracy of plus +/- 1mm is 1mm less than the current specifications for finished product. However, the quality team wanted to ensure that the accuracy of the machine vision system was greater than the finishing tolerances. This would allow earlier detection of out of shape product and better accuracy on more critical products that may be produced in the future.

Response time was calculated by measuring the distance from the trial location to the next scrap door on the line and dividing this number by the speed of the conveyors. A taco was used to measure the speed of the fastest running product at James Hardie Carole Park, as larger products in size and thickness run slower through the machine. This speed was found to be approximately 0.8m/s.

Eq(2) *Time = Distance / speed*

Time = 1.500 m / 0.8 m/s

Time = 1.875s

These calculations needed to be confirmed by a real time check. As such a time of one second was determined by standing on the sheet machine line and using a stopwatch too measure the actual time that the green sheet board took to travel from the trial location through to the next scrap door. The stopwatch was started when the last part of the sheet moved past the trial installation area and was stopped when the first part of the sheet passed over the front lip of the scrap door. Trials were done on multiple products, running at maximum conveyor belt speeds. Times were taken as below.

Test No.	Product	Time
1	1	2.4s
2	1	2.4s
3	1	2.3s
4	2	1.9s
5	2	1.9s
6	2	1.8s
7	1	2.2s
8	1	2.3s
9	1	2.2s
10	3	1.9s
11	3	1.7s
12	3	1.8s
13	4	2.5s
14	4	2.4s
15	4	2.5s

Table 7: James Hardie Response Time to scrap sheet

Allowing for some time for an output to actuate, it was agreed upon through consultation with the engineering team that a response time of one second would be applicable for the purpose of these trials. Although the green sheet boards are cut into smaller shapes, the overall size of the entire green sheet product moving down the line was found to be 8.4 metres in length and up to 1.35 metres wide. After the green sheet product comes off the size roller it is cut by guillotines and high-pressure water jets. This overall size has compensated for the gap left between the cut boards. It is the overall dimensions from the product off the size roller passing through the trial area to the last edge of that product passing through the trial area, no matter the size or number of cuts made to the board. As there are different products cut in different ways, the following images were supplied to both SICK & Intrinsic, to help further understand the areas of interest for different products.

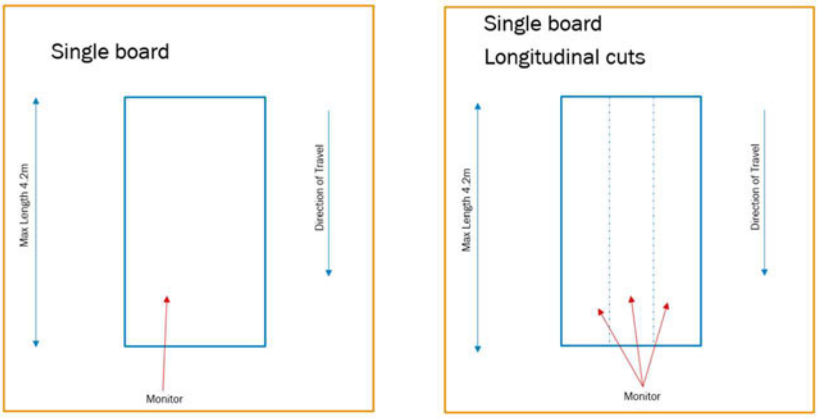

Figure 13: Field of View Product 1

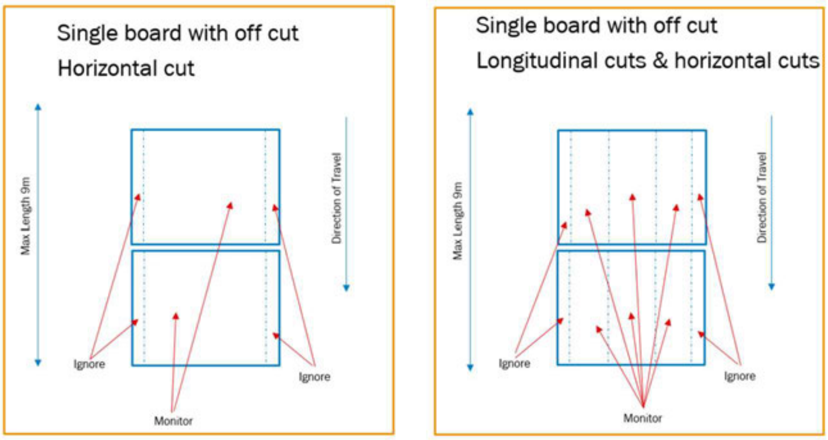

Figure 14: Field of View Product 2

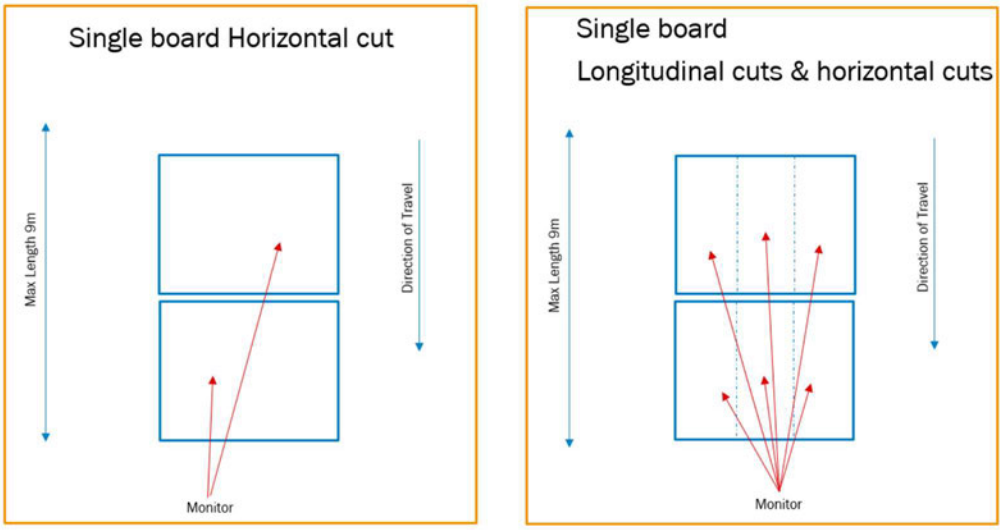

Figure 15: Field of View Product 3

4.2 SICK Offer

SICK's initial offer put forward was for a Modular Quality Control System (MQCS). SICK claim that the componentry offered within this system would be able to read codes, counting or comparing with reference values, as well as checking shapes and volumes with 3D camera system. This system consisted of;

- (3) x CMOS Ranger3 Cameras, to be mounted over the conveyor belt in some way
- (3) x Lasers, to be mounted over the conveyor belt in some way
- (1) x Trigger Sensor, to be mounted in ahead of the laser line
- (1) x Encoder, used to reference the speed of the conveyor
- (1) x Industrial PC, mounted in a cabinet with 24VDC power supply and IO module
- (1) x HMI, for operator interface

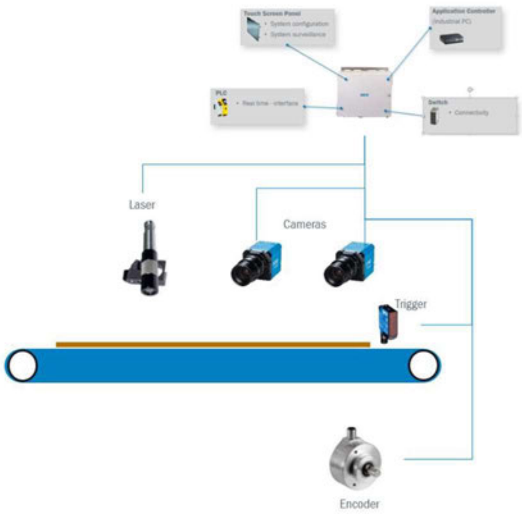

Figure 16: SICK offer reference drawing

Once the board passes the trigger laser, the system will begin image capture, via the (3) x 3D cameras. These cameras would capture images using the plane of light supplied by the overhead lasers. As the board passes through the laser plane the camera will be able to take a collection of profile images where each profile will show the height of the object along its width in the direction of This information can then be used to analyse and detect any deviations in height on the board.

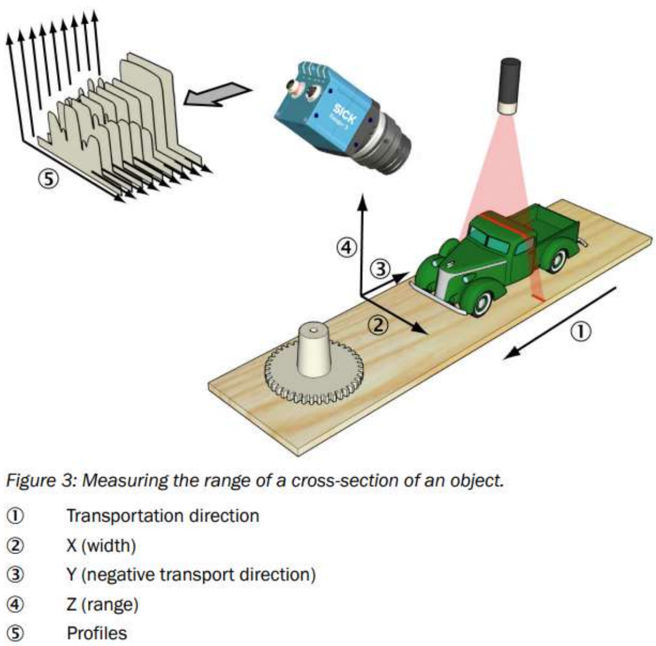

Figure 17: Ranger3 Camera, Measuring with a 3D Camera (SICK, 2022a)

Part of SICK's offer was to supply and install the hardware on site and collect data from the system for approximately (2) weeks. During this period of time, they would perform an analysis of the data, conducted through a data logger, which is part of the PLC system. SICK's offer would be invoiced after a site acceptance test of the system was conducted and both James Hardie and SICK were satisfied that the system was meeting the specifications as stated by James Hardie. SICK's offer also included Measurement and Surface Defect Algorithm development, which they would they carry out offsite. James Hardie would assist with installation and trials, while running cables and fabricating and installing framework for the hardware to be mounted on.

4.3 Intrinsic offer

The Intrinsics business head office is based in South America and as such correspondents for the purchase of a trial system has been significantly delayed compared to the communications regarding the installation of the seek system. At the time of writing this dissertation, there have only been emails backwards and forth and a few online meetings discussing proposal systems, but no formal offer has yet been accepted of a trial system from Intrinsic.

So far, it is understood that the Intrinsic offer will include the use of multiple 4K Dome cameras with some box lights dedicated to providing the total light required for the capture of the image. The control system is driven by a Mac mini, built into a control box that mounts next to the installation location. One keynote of Intrinsics proposed system is that all algorithms and decision-making of the lump, dent and debris identification will be carried out offsite by the Intrinsics external servers in North America. As such it is extremely important that the system is provided with a good Wi-Fi connection or alternatively an Ethernet cable which is preferred by Intrinsics. Intrinsics have identified that due to the processing servers being so far away from the site here in Carole Park, there will be some delay in response time during our trial periods. This delay may be able to be reduced further down the track with dedicated servers being installed in the Australian network however that will not be the case during these trials. Intrinsics also note that as their system is run by their business, they will also own all of the information and data collected by the system. In the same way they will also own all of the ongoing maintenance and system upgrades required to continue and improve system performance.

Once the system is set up Intrinsics claim that the mapping of the system will take 30 minutes. They identify that the camera mounting, and lighting is the most difficult part but also the most important. Discussions have been had with current engineering fabrication vendors but without the formal offer from Intrinsics and the purchase of the system, no framework designs have been made.

4.4 Installation of SICK system

SICK provided an initial set up image showing the positions of the camera, conveyor belt and the lasers all relative to each other. This image was used to design the base framework for the mounting of the componentry.

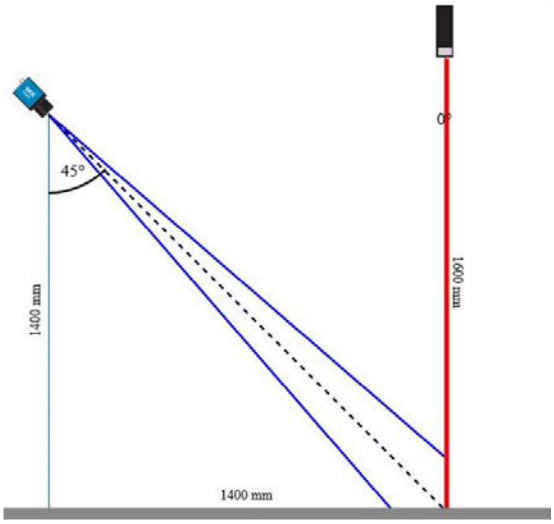

Figure 18: SICK laser and camera position requirements

After inspection of the Ranger3 product data sheet, as offered by SICK, the camera dimensions were found to be 77 x 55 x 55 mm (L x W x H) and weighing 330g. Mounting can be selected to come with the cameras that have slotted holes for some adjustment when mounting.

Figure 19: Ranger3 Mounting Bracket (SICK, 2022a)

As such 80 x 40 aluminium strut was selected as the material for the frame these cameras and lasers. Aluminium was chosen and it is less prone to rust and surface corrosion in wet environments. It is also very cheap and lightweight. This is important as it is undesirable to introduce some unwanted vertical load onto the conveyor. The following images show the first iteration of the framework design (actual images of the installed frame have been omitted due to IP Protection reasons).

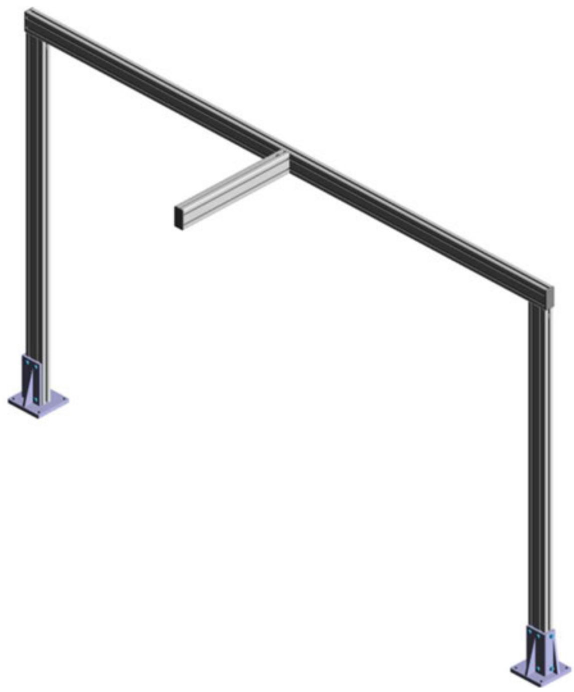

Figure 20: Base Frame design Isometric

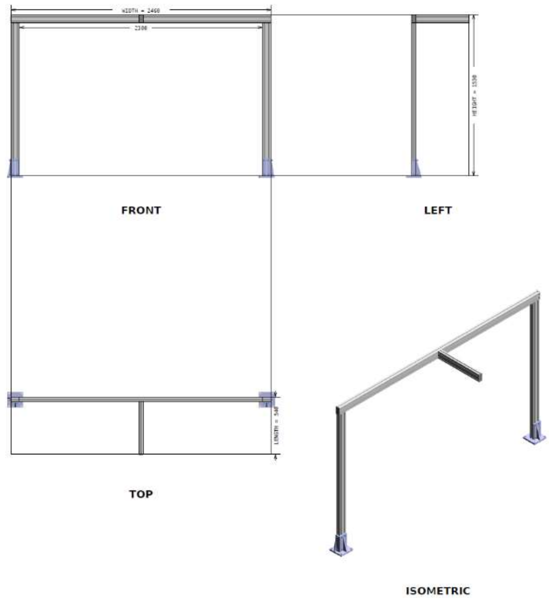

Figure 21: Base Frame design 3rd Angle Projection

Other pieces of aluminium strut were bolted to the framework to allow for the trigger laser and the field of view lasers to mounted further away from the vertical datum

point of the cameras. Once the framework was mounted onto the conveyor entering the sheet machines stacker, a laser level was used to project a line across the width of the conveyor belt from the vertical datum of the cameras centre lens position. Distances were then taken from the straight edge to the laser lines produced across the width of the conveyor by the field of view lasers. The mounting position of the lasers were then adjusted to ensure that their projections were orthogonal to the vertical datum of the cameras. The PLC was then set up on a desk adjacent to the conveyor of the sheet machine.

The encoder was then mounted to the drive roller of the conveyor where the boards were being measured. Cabling was then run top and from the cameras and encoder to each together, to the power supply and to the PLC. A diagram of general setup for Ranger3 camera with the encoder can be seen below;

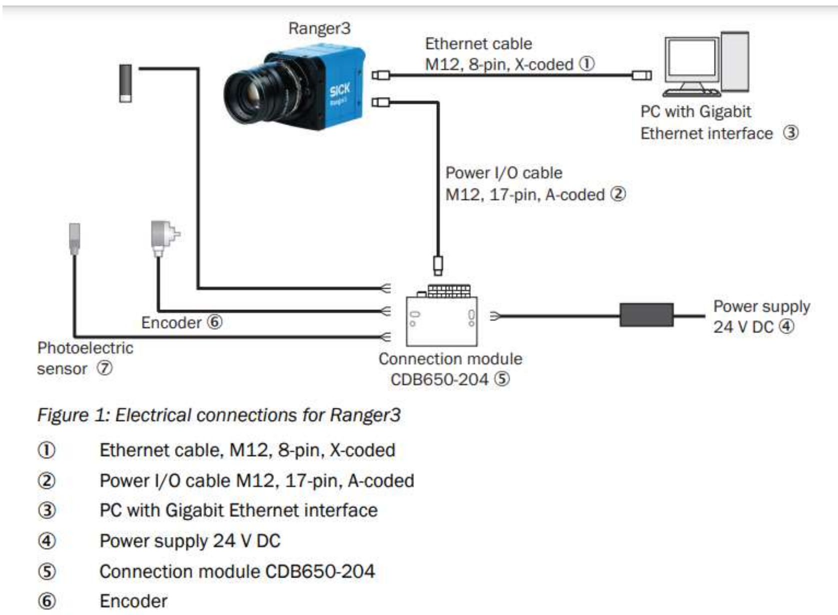

Figure 22: Electrical Connections for Ranger 3 (SICK, 2022a)

A SICK technician was then called out to site to assist with the calibration process of the Modular Quality Control System. Two test pieces were used for this process, the first being a toothed test piece, supplied by SICK, that uses the laser light intensity to determine changes in height. The technician placed these test pieces in different positions and angles on the conveyor, and then past it through the field of vision of the machine, stepping through the pre-installed calibration process as programmed into the PLC. The second test piece was a poly cell board, also supplied and owned by SICK, with some other known dimensions that the tech used to further calibrate the cameras.

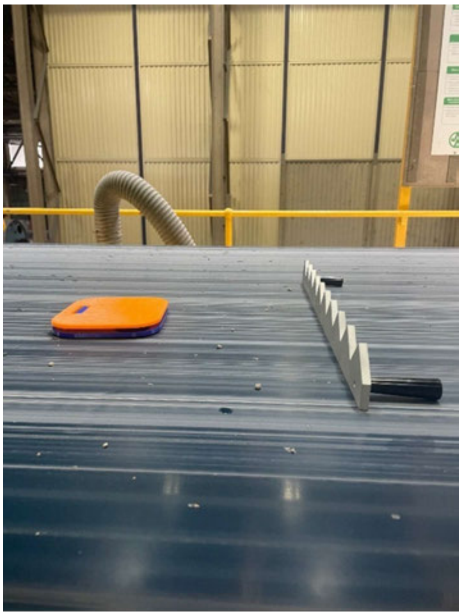

Figure 23: Test Pieces Image 1

Figure 24: Test Pieces Image 2

4.5 SICK system trial

After the calibration process was complete, the agreed upon timeframe of two weeks began, where intermitent pilot runs were conducted. The data was collected via the data logger built into the PLC. Scheduled times of when these pilot runs were conducted were agreed upon. During this time I would stand with the operator on the sheet machine line, manually inspecting each board as it passed through the trial system. Results identified by the operators on the line, were then compared aginsr the results identifed and logged by SICK system. These initial results were focused on producing some raw data, to prove that the system was seeing greensheet boards, captruing these images correctly, and identifying surface defects with no set tolerances. This trial was succesful the supplied system could produce these images. An example of some imgaes showing a surface defects on a board during this first trial is below;

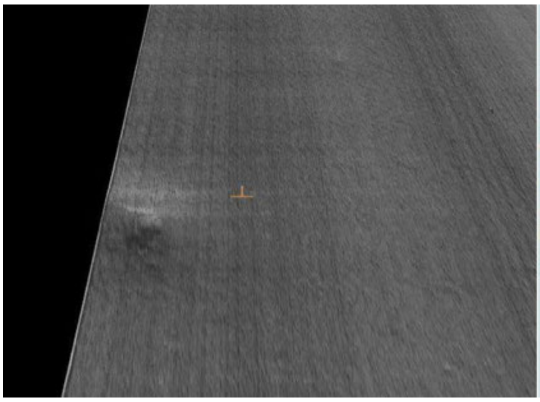

Figure 25: SICK vision system trial lump image 1

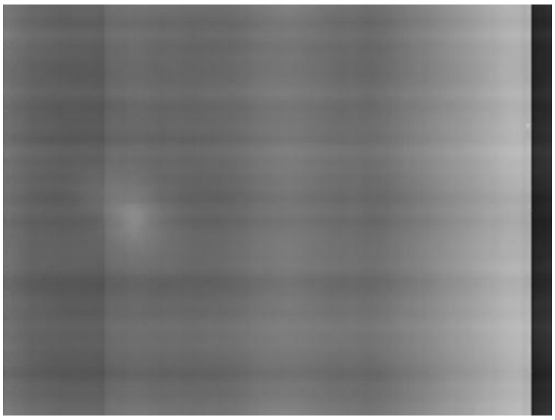

Figure 26: SICK vision system trial lump image 2

These intial trials did not output any sort of visual or audible alarm as the system had not yet proved to be reliable. Intiaiting some alarm on the line could trigger panic for the operator on the line.

After this two week period had been agreed to be succesful, SICK then used remote access to fine tune the system, going through a typical PDCA (Plan Do Check Act) cycle. SICK modified their algorithms by adjusting the size of their field of view, the refresh rates of the system and the frame rates of the cameras. After these adjustments were made, another two week trial period occurred, where similarily to the initial where scheduled pilot runs were conducted while I was present on the line. During these trial runs, approximately 100 boards would be looked at. The data captured by the SICK system was collated the SICK engineering team, and then cross referenecd against the data recorded by the line operator and myself. These checks looked at both the length and width checks conducted by the operator of every tenth board, along with the number of boards that passed through the system that were identified to have a surface defect, what surface defect that was and if it matched the defect type recorded by the SICK system. Some of the boards were intentionally spiked during this process to replicate lumps, dents and debris.

4.6 Trial Data Findings

Initial findings were that the SICK supplied system could detect a surface deviation of +/- 2mm within the required 3mm diameter. Dimesnional accuracy was achievied with tolerances of +/- 2.4mm for the board length, +/- 0.65mm for the board width and +/- 0.1mm for the thickness. As shown in Table 8 below the one second time requirement for responsiveness of the system was achieved with a mean response time averaging down to .9 seconds. The initial response time was much larger however after processes were refined in terms of Reducing the field of view to be captured and the frame rate capture of the cameras the response time came hello the one second requirement.

<u>**Parameter**</u>	<u>**James Hardie Requirement**</u>	<u>**SICK Trial Results**</u>
Surface Defect detection Size	Diameter = ~3mm Length = ~8mm	Diameter = 3mm Length = 3mm Deviation = +/- 2mm
Outer Dimension Accuracy (L, W)	Length = +/- 1mm Width = +/- 1 mm	Length = +/- 2.4mm Width = +/- 0.65 mm
Thickness Measurement Accuracy	+/- 0.1mm	+/- 0.1mm
Number of Thickness Measurement Points	Every 100mm across the width of the board	✓
Response Time	1 second for reject signal	Mean time = 0.9s
Maximum Board Size (L, W)	Length = 9m Width = 1.35m	✓

Table 8: SICK trial results against James Hardie Specifications

The below graph shows the data captured after a period of machine down time due to unscheduled maintenance. When the machine was starting up at 3:00 PM it is shown that over a one hour window, thirty alarms were triggered. Identifying thirty boards that had surface defects out of specification. After cross referencing this data with the data from the operators it was found that all of these reject counts where not captured in this time and no boards were scrapped. This validates this research and the system proving that the system would have prevented not only the thirty boards on startup but also the thirty-four boards up until 10:00 PM when the trial was ended. All of which were not identified as scrap boards by the operators.

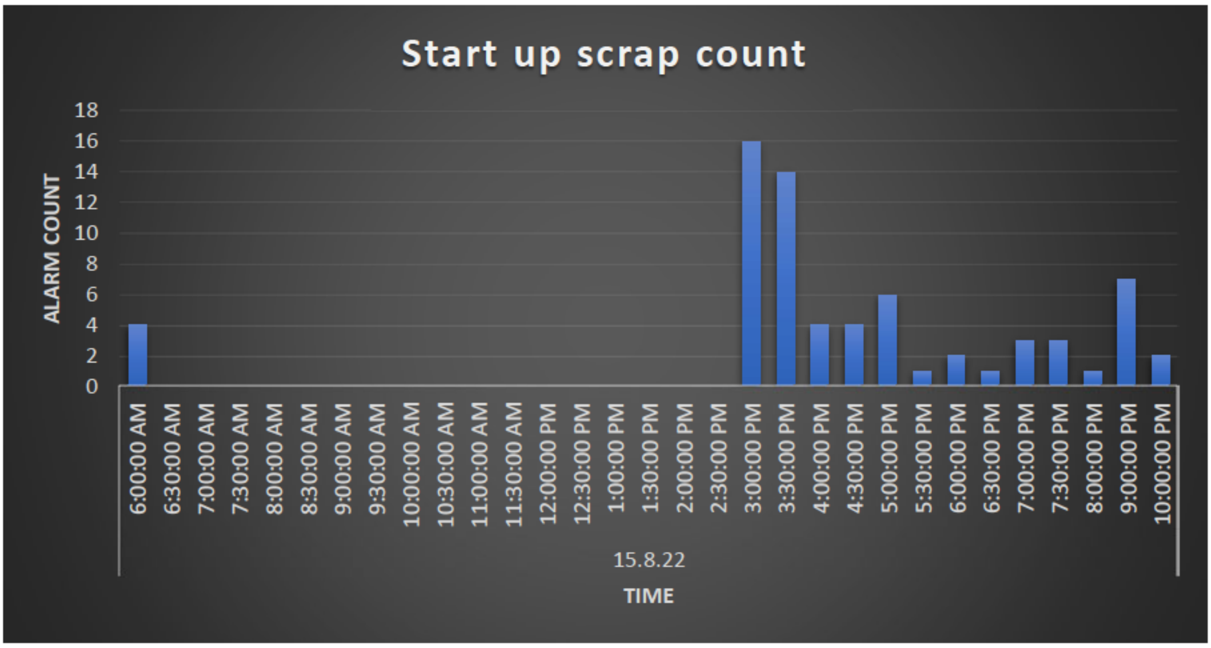

Figure 27: Bar Graph of "Start-up Scrap Count"

4.7 Waviness

Some of the images captured by the system were showing signs a waviness effect in parts of the image. On review of the installation area, this effect was suspected to be caused by the movement within the stacker. The stacker has a large gantry crane system that pics sheets up and moves the,m from one conveyor to the next. It was through the operatoiun of this lateral movement, that would cause the firaemwork of the stacker to shake. As the camera and laser framework was mounted to the conveyor framework of the stack,er this morvement was translated int othe moutning frmaework of the cameras and lasers. To rectify this a more rigid and robust frame was designed and manufcatrued. The mounting poisition of the frame was also moved out of the stacker area, further up the process to the line, to the next avaiable conveyor frame.

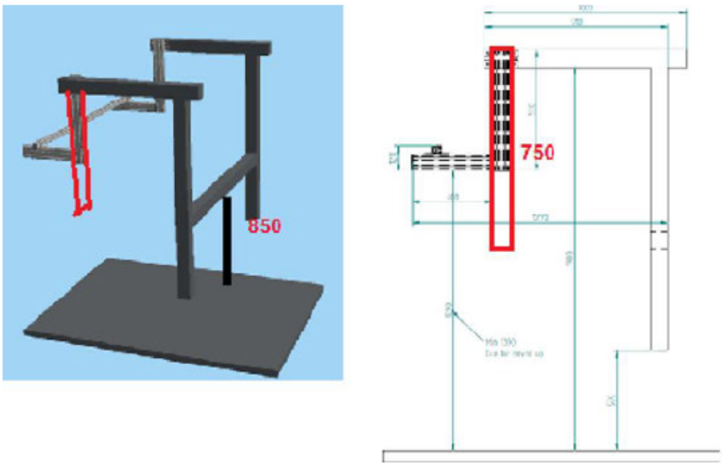

Figure 28: Ranger Base Frame Design 2, Isometric and Side View

This wavines in the images, was also thought to be caused by the up/down movement in the belt while running. There was some slack evident in the conveyor belt that caused it to wobble up and down. This was more noticeable when the conveyor was running without product, with a total distance of approixximately 30mm being witnessed while standing side on to the conveyor. It was assumed that all of the belt wobble does not dissapear once a product is placed on it.

Increasing both the speed of the stacker operatoikn and the speed of the conveyor belts, which is inevitably James Hardies goal, will only further increase these movements. Further designs need to sonider ways of eliminating this movement in order to capture clearer images.

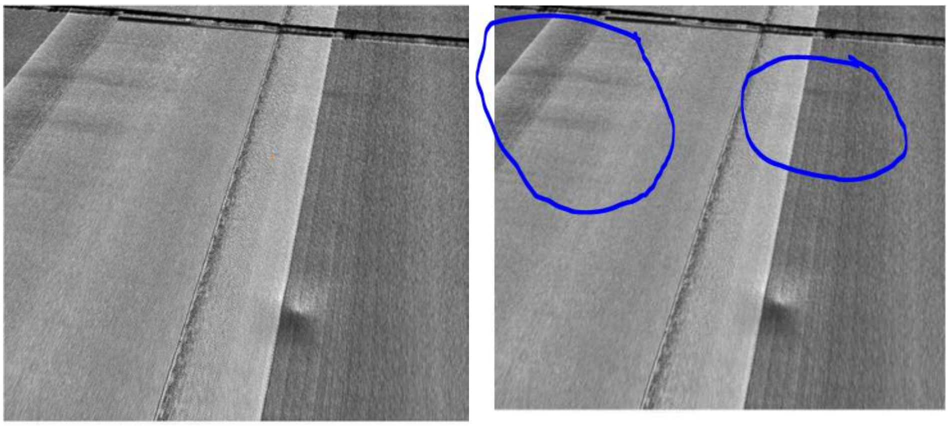

Figure 29: Waviness in image

4.8 Field of view

It was found that the field of view required to be captured did not require (3) x Ranger3 cameras. The original resolution they thought to be required was based off of a wider field of view. SICK have advised that the images required to be colelcted could be done by two Ruler3120 cameras. They also advised that (2) lasers would be able to cover the width of the belt, as opposed to (3). Having less hardware would result in less power being consumed by system, and less information being processed by the system. This would result in higher processing speeds, as the software does not need to stitch together as many images to produce some useful overall picture. It would also mean less moving parts to the system, and in turn less chance of movement and error.

4.9 Laser and camera alignment

There was some movement during the trial process in the third laser on the far left of the camera vision set up. This misalignment was somewhat rectified by the camera calibration process but not totally eliminated. This resulted in a 0.5mm difference on the far left camera for some of the later images. Some djustments were made to the mounting brackets and to the laser post trial, however eliminating the movement that is experienced by the frame would also stop this issue from occuring.

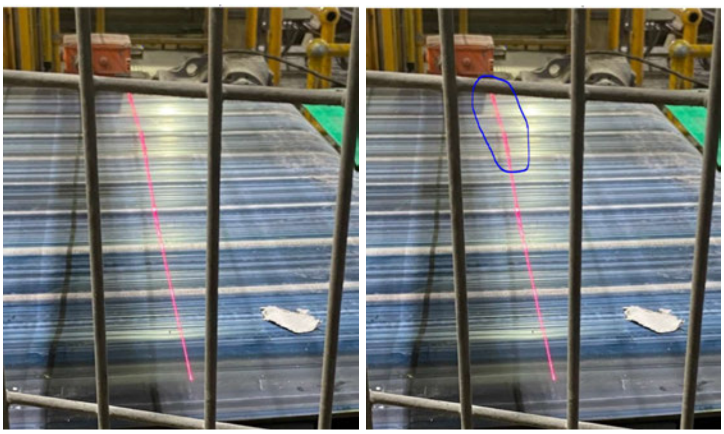

Figure 30: Laser misalignment

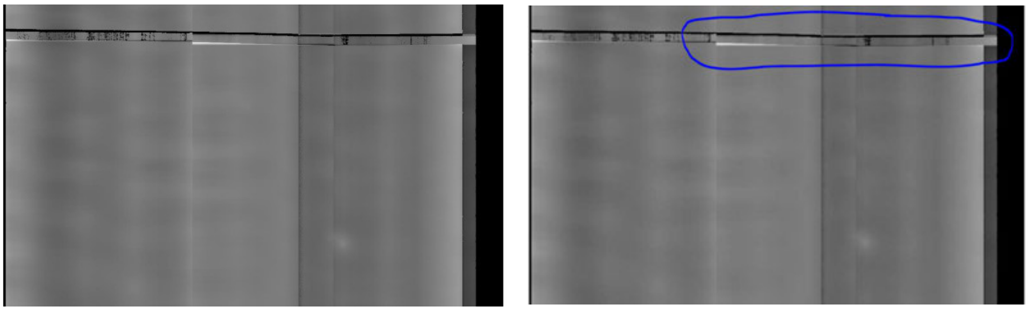

Figure 31: Misaligned Boards

4.9 Scalability

The currently installed system supplied by SICK has been purchased on a loan basis and no investment has been made yet into permanent ownership of any of the SICK components. Until a final design has been completely formalised by the Engineering team and a complete hardware purchase cost is understood, it is currently unclear on the price estimate for the cost per system.

It is too early in these trial stages to accurately assist SICK systems ability to be installed and implemented across multiple sheet machines or James Hardie sites. Furthermore, without the Intrinsics data there is nothing to compare the scalability of one system to another to. In my opinion, the SICK system, once finalised, should be very straight forward to replicate in alternate locations. The cameras are readily available to purchase along with the other hardware supplied so far. Once this installation has been complete and a final understanding of the full installation procedure is concluded, then a standard operating procedure and standard installation procedure could be developed to ensure future installations are replicated and streamlined as a direct result of these trials findings.

CHAPTER 5 - CONCLUSION

This dissertation aimed to identify, analyse, and cross check a suitable machine vision system to be implemented on the sheet machine lines at James Hardie Carole Park, to assist in the identification of lumps, dents, and debris on their fibre cement products. The trials so far have only been carried out on one system, being the SICK proposal. Until further testing has been completed on the Intrinsic system, a complete and accurate answer to this problem cannot be found. That being said, it can be concluded that the SICK system has been identified as a successful and viable option, and with continuing development, has the potential to be implemented on a global scale.

It has been proven that after some refinement the SICK system can identify surface defects on the James Hardie boards with an accuracy within the required range of the James Hardie specifications. It was also shown that the system has the potential to capture and produce good quality data for the dimensional checks as well. This capability builds an even stronger case for the SICK system, as there are clear pathways for future developments and refinement to design an effective image capturing assembly that can do both dimensional checks and surface defect detections simultaneously. The length accuracy of the trial system was out of tolerance; however, this could be improved by installing a second encoder on the idle roller of the conveying system. The local PLC would then be able to compare the speeds of the two encoders and provide more accurate feedback to identify the length of the sheet, from the point of trigger initiation to the end of the sheet passing.

The results from the SICK trial have many learnings that can be carried over onto the upcoming trials for the Intrinsic system. Most notably, the importance of the rigidity of the mounting framework for the hardware. With Intrinsics also utilising camera based technology, ensuring that this area is focused on during initial installation will prepare the system to give more accurate results with less errors. Lowering the processing requirements while maintaining the James Hardie specifications will also be considered more immediately during the Intrinsics trial. As seen on the SICK system, capturing high volumes of unnecessary data drastically slowed system response times, something that will be even more so critical with Intrinsics processing systems being cloud based.

And truly, if the Intrinsic system can produce the same results as the SICK system then the ultimate deciding question will be whether James Hardie wants a local privately owned and maintained PLC system or a subscriber based external cloud based server system. When it comes to make this decision, it will be imperative that both systems are compared against their long term and short term benefits, pitfalls, and associated costs. The future decision will need to consider what is the worst case scenario for a critical failure of each system; what part of the purchased system might fail, and what will that cost be to the business.

Without determining this final answer, this research paper has still shown that an optical based machine vision system is the most practical for the James Hardie environment. Alternate options such as radiometric testing may be practical but there is no need to visit this option with the success of the SICK trials. It has proven that the optical system has the ability to identify variances in sheet surfaces on the organic materials that James Hardie sheets are comprised of. Initial trials of Intrinsic system should begin as soon as possible while the continuing development of the SICK system is driven simultaneously, with the intention of fully understanding and analysing the two systems to determine which online machine vision system is the long term answer to quality screening the James Hardie Fibre Cement boards at Carole Park.

CONSEQUNCES & ETHICS

An early consequence that the business may experience is a percentage increase in out of spec product as more product will be checked more frequently. This will in turn increase the volume of scrapped product and some immediate profit loss for the business.

Over time, online checks will allow for faster production speeds, as manual online checks will be significantly less frequent or phased out altogether. The operators who are responsible for these online checks will no longer be required, resulting in job loss. However, an increase in volume will also boost business profits, allowing the business to grow and develop, and create more job opportunities. The operator would not need to be unemployed but moved internally into another position.

An increase in volume will mean greater waste output from the plant in terms of scrap material, wastewater, high energy consumption and increased greenhouse gas emissions. How the business manages this higher output would be critical to its overall environmental impact.

An increase in volume will mean that the operating equipment on the lines will be moving at faster speeds. This will increase the consequences of any safety incidents that may unfortunately occur on the line, as rotating, lifting, dropping, actuating, and cutting equipment will be moving at higher velocities, causing more damage to the human bodies that come into contact with them.

In terms of ethics, identifying these non-conformities prior to customer delivery will give the business a stronger validation that they are delivering their customers the promised product, and not putting themselves, the suppliers or other parties involved in a position where poor quality product could be installed into a building, with an increase chance of failure. Especially in the building industry where these products help build people's homes, workplaces, and recreational facilities.

When building the risk and decision matrix to decide which system should be chosen, it is important to not involve and personal beliefs or feelings, that are not aligned with James Hardie's. It is important to show no personal favouritism between the businesses. Any information shared with one business should be shared with the other. It should be an equal and even playing field to give each operating system an equal opportunity to perform at their highest level.

APPENDICIES

Appendix A – Project Specification

ENG4111/4112 Research Project

Project Specification

For: Adam Donnelly

Title: SICK vs Intrinsic

Major: Mechatronic Engineering

Supervisors: James Hardie: Mikael Andem /// USQ: Craig Lobsey

Enrollment: ENG4111 – EXT S1, 2022

ENG4112 – EXT S2, 2022

Project Aim:

Contrast and compare the SICK & Intrinsic vision systems, analysing their suitability for use on the James Hardie, Carole Park Sheet Machines, against a set list or requirements and specifications, and ultimately determine which system we should purchase.

Programme: Version 2, 1st August 2022

1. Engage with the quality team to understand what products the vision system will be most critical for, high volume product? High scrap products?
2. Gather the specifications that the vision system will be analyzing, what do they need to be able to, "see," and to what tolerances? And at what speed? (I.e., response time)
3. Translate this criterion into an excel spreadsheet, itemizing each product with their product specifications
4. Weight each criterion to its level of importance for sheet quality
5. Review and analyse the capacity of the current hardware and software installed on the sheet machines; Will changes need to be made? Will other equipment need to be bought?
6. Review and analyse the installation location, i.e., Size, lighting, humidity, dust, etc.
7. Contact Gocator and Omron and make them aware of the project, supplying them both with the list of relevant product specifications.
8. Review the hardware and software capabilities of the Gocator and Omron products and systems.
9. Develop a decision matrix for other factors, cost, sustainability, environment, etc.
10. Select the most suitable and capable system and justify

If time and resources permit.

11. Field Test of chosen system

12. Review and refine design making recommendations for future installations.

Appendix B - RMP

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland — Offline Version

USQ Safety Risk Management System

Note: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

Safety Risk Management Plan – Offline Version			
Assessment Title:	Intrinsic vs SICK	Assessment Date:	1/11/2022
Workplace (Division/Faculty/Section):	James Hardie, Carole Park, Brisbane, Queensland, Australia	Review Date:(5 Years Max)	1/11/2027
Context			
Description:			
What is the task/event/purchase/project/procedure?	Undertake an assesment of two online machine vision quality management systems		
Why is it being conducted?	Final year engineering thesis		
Where is it being conducted?	James Hardie, Carole Park, Brisbane, Queensland, Australia		
Course code (if applicable)	ENG4111	Chemical name (if applicable)	
What other nominal conditions?			
Personnel involved	Adam Donnelly, Mikael Andem		
Equipment	Various technical hardware, basic hand tools, computers and monitors		
Environment	James Hardie Manufacturing facilities		
Other			
Briefly explain the procedure/process	Organise a written methodolgy and follow it until completion		
Assessment Team - who is conducting the assessment?			
Assessor(s)			
Others consulted:	Craig Lobsey, Mikael Andem		

Eg 1. Enter Consequence

Eg 2. Enter Probability

Eg 3. Find Action

Probability	Consequence				
	Insignificant No Injury 0-$5K	Minor First Aid $5K-$50K	Moderate Med Treatment $50K-$100K	Major Serious Injuries $100K-$250K	Catastrophic Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L
Recommended Action Guide					
E=Extreme Risk – Task *MUST NOT* proceed					
H=High Risk – Special Procedures Required (See USQSafe)					
M=Moderate Risk – Risk Management Plan/Work Method Statement Required					
L=Low Risk – Use Routine Procedures					

This document is uncontrolled once printed and may not be the latest version. Access the online SRMS for the latest version. Safety Risk Management Plan V1.1

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	*The Risk:* What can happen if exposed to the hazard without existing controls in place?	*Consequence:* What is the harm that can be caused by the hazard without existing controls in place?	*Existing Controls:* What are the existing controls that are already in place?	*Risk Assessment:* Consequence x Probability = Risk Level			*Additional controls:* Enter additional controls if required to reduce the risk level	*Risk assessment with additional controls:*			
				Probability	Risk Level	ALARP? Yes/no		Consequence	Probability	Risk Level	ALARP? Yes/no
Example											
Working in temperatures over 35° C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Sitting in front of a computer for long periods at a time	Eye strain, muscle soreness, body aches, headaches,	Minor	Regular breaks, stretching before, during and after, good posture, ergonomic desk/chair/computer set up.	Possible	Moderate	No	N/A	Select a consequence	Select a probability	Select a Risk Level	Yes or No
Excessive typing	Carpel tunnel syndrome, hand strains and aches	Minor	Regular breaks, stretching before, during and after	Possible	Low	No	N/A	Select a consequence	Select a probability	Select a Risk Level	Yes or No
Working in a manufacturing plant	Moving Machinery and Equipment	Catastrophic	Follow site specific rules, undertake a site induction, wear the correct PPE,	Possible	Low	No	N/A	Select a consequence	Select a probability	Select a Risk Level	Yes or No
Working in an engineering workshop	Pinch Points, Slips, Trips, Use of hand and power tools, use of stationary machinery	Catastrophic	Follow workshop specific rules, wear correct PPE for the task (ie; Safety glasses, hard hat, gloves, steel cap boots, long sleeve hi-vis shirt, long pants), use the correct tool for the task, trained and compotent personell to undertake tasks	Unlikely	Moderate	No	N/A	Select a consequence	Select a probability	Select a Risk Level	Yes or No
Interstate travel to various sites	COVID	Major	Follow current COVID protocols,	Possible	Moderate	No	N/A	Select a consequence	Select a probability	Select a Risk Level	Yes or No

This document is uncontrolled once printed and may not be the latest version. Access the online SRMS for the latest version. Safety Risk Management Plan V1.1

Step 1 (cont)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
Hazards: From step 1 or more if identified	*The Risk:* What can happen if exposed to the hazard without existing controls in place?	*Consequence:* What is the harm that can be caused by the hazard without existing controls in place?	*Existing Controls:* What are the existing controls that are already in place?	*Risk Assessment:* Consequence x Probability = Risk Level			*Additional controls:* Enter additional controls if required to reduce the risk level	*Risk assessment with additional controls:*			
				Probability	Risk Level	ALARP? Yes/no		Consequence	Probability	Risk Level	ALARP? Yes/no
Example											
Working in temperatures over 35° C	Heat stress/heat stroke/exhaustion leading to serious personal injury/death	catastrophic	Regular breaks, chilled water available, loose clothing, fatigue management policy.	possible	high	No	temporary shade shelters, essential tasks only, close supervision, buddy system	catastrophic	unlikely	mod	Yes
Working with people from various cultural backgrounds	Racism, cultural insensitivty, abusive or offensive language	Moderate	Public relations, meeting preperation, HR involvement if required	Unlikely	Low	No	N/A	Select a consequence	Select a probability	Select a Risk Level	Yes or No
Installation of mechancial and electrical equipment	Electrocution, pinch points, use of hand and power tools	Catastrophic	Wear correct PPE for the task (ie; Safety glasses, hard hat, gloves, steel cap boots, long sleeve hi-vis shirt, long pants), use the correct tool for the task, trained and compotent personell to undertake task	Unlikely	High	No	N/A	Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
		Select a consequence		Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No
				Select a probability	Select a Risk Level	Yes or No		Select a consequence	Select a probability	Select a Risk Level	Yes or No

This document is uncontrolled once printed and may not be the latest version. Access the online SRMS for the latest version. Safety Risk Management Plan V1.1

Step 5 - Action Plan (for controls not already in place)			
Additional controls:	*Resources:*	*Persons responsible:*	*Proposed implementation date:*
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.
			Click here to enter a date.

Step 6 - Approval			
Drafter's name:	Adam Donnelly	Draft date:	19/05/2022
Drafter's comments:			
Approver's name:		Approver's title/position:	
Approver's comments:			
I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.			
Approver's signature:		Approval date:	Click here to enter a date.

This document is uncontrolled once printed and may not be the latest version. Access the online SRMS for the latest version. Safety Risk Management Plan V1.1

REFERENCES

Anon, 2018, Teledyne DALSA CCD (left) and CMOS (right) image sensors, AZoSensors.com, viewed 20th July 2022, <https://www.azosensors.com/article.aspx?ArticleID=1007>.

Batchelor, B.G., 2012. Machine vision handbook, Springer, London, UK, pp. 801-870.

Blitz, J., and Simpson, G., 1995, Ultrasonic methods of non-destructive testing, Volume 2, Springer Science & Business Media, pp. 111.

Chamorro, J., Vallejo, L., Maynard, C., Guevara, S., Solorio, A., J., Soto, N., Singh, V., K., Bhate, U., Kumar G.V.V., R., Garcia, J., Newell, B., 2022, Health monitoring of a conveyor belt system using machine vision and real-time sensor data. CIRP Journal of Manufacturing Science and Technology, vol. 38, pp 38-50.

CMS, 2016, Controle Mesure Systemems Non-destructive Inspection: Eddy Current & ultrasonic Equipment, viewed 8th August 2022, <http://www.cmseddyscan.com/en/news/>

Cognex, 2022, Cognex Industrial cameras, Data Sheet No. 12229, 2022.

Cognex, 2018, Introduction to Machine Vision: A guide to automating process & quality improvements, Data Sheet No. 17151, available at <https://www.cognex.com/resources/white-papers-articles/introduction-to-machine-vision-17152>.

Curry, G.L. and Feldman, R.M., 2010. Manufacturing systems modelling and analysis. Springer Science & Business Media, pp. 109-123.

Dickey, F., M., 2018, Laser beam shaping: theory and techniques, CRC press, pp. 210 – 217.

Dunlap, R., A., 2019, Lasers and Their Application to the Observation of Bose–Einstein Condensates: The basic physics of lasers, Morgan & Claypool Publishers, pp. 1 – 16.

Essig, W., Bernhardt, Y., Döring, D., Solodov, I., Gautzsch, T., Gaal, M., Hufschläger, D., Sommerhuber, R., Marhenke, T., Hasener, J. and Szewieczek, A., 2021. Air-coupled Ultrasound–Emerging NDT Method. Fachbeiträge, pp. 32 - 43.

Hecht, J., 2018, Understanding lasers: an entry-level guide, John Wiley & Sons, pp. 8 - 10.

Ilic, S., Leichliter, S., Streeter, J., Oron, A., DeTaboada, L., and Oron, U., 2006, Effects of Power Densities, Continuous and Pulse Frequencies and Number of Sessions of Low Level Laser Therapy on Intact Rat Brain, Photomedicine and Laser Surgery, vol. 24, pp. 458-466.

Intrinsics Inc. 2020. Intrinsics Expands Heijunka Vision™ Analytics into Building Materials Manufacturing, Intrinsics Inc, April 6th, viewed 10th July 2022,

<https://www.intrinsicsimaging.com/news-releases/intrinsics-expands-heijunka-vision-analytics-into-building-materials-manufacturing/>.

James Hardie, 2022, Company History, viewed 5th July 2022, <https://www.jameshardie.com.au/company-history>

Keyence Corporation of America, 2022, Beginner's Guide to Vision Systems, Vol.1 Selecting the devices required for inspection: Camera

Langenberg, K.J., Marklein, R. and Mayer, K., 2012. Ultrasonic nondestructive testing of materials: theoretical foundations. CRC Press, Boca Raton, Florida, United States.

Li, S., Luo, Q., Qiu, L. and Bandyopadhyay, S., 2020, Optimal pricing model of digital music: subscription, ownership or mixed?, Production and Operations Management, vol. 29(3), pp.688-704.

Malamas, E.N., Petrakis, E.G., Zervakis, M., Petit, L. and Legat, J.D., 2003. A survey on industrial vision systems, applications and tools. Image and vision computing, vol. 21(2), pp.171-188.

Micro-Epsilon, 2022 optoCONTROL // Optical precision micrometers, Data Sheet No. cat--optoCONTROL-ODC—en.

Micro-Epsilon, 2022 optoNCDT // Laser displacement sensors (triangulation), Data Sheet No. cat--optoNCDT—en.

Micro-Epsilon, 2022, scanCONTROL // 2D/3D Laser profile sensors, Data Sheet No. cat--scanCONTROL--en-us.

Mitutoyo 2022, ABSOLUTE Digimatic Indicator ID-S Series 543-with Simple Design, Data Sheet No. 543-782, <https://www.farnell.com/datasheets/1926630.pdf>

Mitutoyo, 2022, Quick Guide to Precision Measuring Instruments, Catalog No. E11003(3), <https://www.mitutoyo.com/webfoo/wp-content/uploads/E110033.pdf>

National Aeronautics and Space Administration, Science Mission Directorate, 2010, Visible Light Region of the Electromagnetic Spectrum, viewed 16th August 2022, <http://science.nasa.gov/ems/09_visiblelight>

Ryan, V., 2019, Engineers Dial Indicator, viewed 8th August 2022, <https://technologystudent.com/equip_flsh/indicator1.html>

Schnee, J., Futterlieb, J., 2011. Laser Line Segmentation with Dynamic Line Models. In: Real, P., Diaz-Pernil, D., Molina-Abril, H., Berciano, A., Kropatsch, W. (eds) Computer Analysis of Images and Patterns. CAIP 2011. Lecture Notes in Computer Science, vol. 6854. Springer, Berlin, Heidelberg.

SICK, 2022, Operating Instructions Ranger 3 3D Machine Vision, Data Sheet No. 8020774/1D7Q/2022-03

SICK, 2022, V3DU3-120RM21A Ruler3000, Data Sheet No. V3DU3-120RM21A 1115260.

Swojak, N., Wieczorowski, M. and Jakubowicz, M., 2021. Assessment of selected metrological properties of laser triangulation sensors. Measurement, 176, pp. 109 - 190.

Tejas, R., Macherla, P. and Shylashree, N., 2023. Image Sensor—CCD and CMOS. In Microelectronics, Communication Systems, Machine Learning and Internet of Things, pp. 455-484.

Weckenmann, A., Akkasoglu, G. and Werner, T. 2015. Quality management–history and trends. Applied Scholastic Models in Business and Industry, vol. 25(1), pp. 1-28.

Werner Solen, 2022, Non Destructive Testing – Ultrasonic Testing, viewed 15 September 2022, <https://www.wermac.org/others/ndt_ut.html>