MACHINE VISION SIMPLIFIED WITH DISTANCE AND RANGING SENSORS

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DEPARTMENT APPROVAL

of a senior thesis submitted by

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STATEMENT OF CANDIDATE

I, Ryan Barnes declare that this report, submitted as part of the requirement for the award of Bachelor of Engineering in the Department of Mechatronic Engineering, Macquarie University, is entirely my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualification or assessment in any other course or academic institution.

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ABSTRACT

Machine vision in industry is dominated by 2D Cameras. These camera systems are very effective for object tracking, but are labour and skill intensive to implement and require powerful standalone controllers to process the images. 3D and 2D ranging distance sensors provide three dimensional data which could easily be utilised to perform the same tasks, without the issues of ambient light changes which cripple a 2D cameras ability to function. Currently Distance and ranging sensors are marginalised to quality control applications in the machine vision field, focusing on product fill completeness and profile consistency checking. These distance-based-sensors have the potential to perform tasks currently done by 2d cameras in industrial vision application, but in a fundamentally different way. The sensors provide an enhanced way of looking at a scene which would be very useful in applications that require identification of shapes and object tracking. Implemented correctly, the ranging and distance sensors should provide better and more flexible performance. The ability for these sensors to detect the actual size and distance of these objects eliminates the need for estimating size and position, which currently requires an experienced programmer to teach the system what it is incapable of learning itself. Furthermore, if programmed correctly a distance-sensor-based tracking system could be made far easier to implement than traditional cameras and therefore cheaper on labour and more accessible to less experienced users and companies. This thesis project will

quantitatively compare the accuracy of multiple industrial distance and ranging sensors on a range of commercial consumer goods. It will also develop a program to automate the tests and feature a quick setup program to explore the viability of end user self-installation.

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Chapter 1

Introduction

1.1 Motivation

This thesis project is funded by Paksmart Machinery. They are a cartoning machine manufacturer based in Australia and all the machinery is built in Sydney. Paksmart plans to increase its product range through the inclusion of a robotic loader, which will allow for bagged products to be further automated as part of their Cartoning machine line. The Vision system being developed through this project will be the eyes for the robotic loader for the Paksmart cartoner PC40 ***Figure 1.1***, which is a horizontal load, carton erector, loader and gluer.

Figure 1.1: *Paksmart Cartoner Pc40*

Machine vision in industry is currently dominated by 2D cameras. These systems work effectively but require an experienced and well trained individual to install and tweak each camera system. Even though the camera systems get cheaper every year, the cost to install the camera system will often far exceed the cost of the unit itself. In certain areas of machine vision, distance and ranging sensors have to potential to break free of these costly setup factors. For this thesis the focus will be on object tracking on a fixed conveyor. This task is important for pick and place applications where a robotic arm is required to pick up and translate randomly placed objects. This application is commonly done with 2D cameras but has lots of potential for 3D distance and ranging sensors. The area where a 3D sensor could excel is in setup and learning. By utilising a 3D distance sensor's awareness of 3D space, a programmer could develop a user interface with a high enough level of automation for an end user to set up and maintain the system. This will result in a huge saving in skilled labour, potentially making a more expensive sensor the cheaper option overall. The company funding this research, Paksmart Machinery, has looked into machine vision for many different applications to further improve their packaging machinery and supporting equipment. Until recently these machine vision requirements have all been addressed with 2D Camera systems, but due to cost the further automation by vision systems has not been adopted by Paksmart's customers. 3D cameras and Laser Distance Sensors provide another avenue to achieve machine vision with higher capability for semi-automated setup for an end user or quicker install and setup for a technician.

1.2 Project Overview

This thesis project aims to research and develop a distance-sensor based object identification and tracking system. The thesis will be broken down into 3 Stages; Stage 1; Sensor research, testing and comparison, Stage 2; Program a setup interface that displays the potential for end user self-instillation of a vision system, And Stage 3; Implementation of the vision system with a robotic arm. Stage 1 involves researching and acquiring possible sensors, then putting them through a test suite which will automate the test procedure. The sensors will be industrial distance sensors and will perform object Identification and tracking on a conveyor and compare their effectiveness on a wide range of typical products that Paksmart Machinerys PC40(Paksmart Cartoner) has and will be used for. Stage 2 is to develop an automated setup program that is designed to reduce install time. This is expected to be achieved by utilising distance sensors 3D. The program developed will be paired with an intuitive program interface in future work. In theory and end user should be able to set up the sensor on their own. By reducing the labour requirement to setup and maintain a vision system the cost to the customer can be dramatically reduced. Stage 3 which is a stretch goal, will involve integrating the sensor with an Omron Robotic arm. This will be a show piece for Paksmart's exhibit at the 2017 Auspack Packaging Show in Sydney. This was not met in the time constraints of the thesis.

1.3 Objectives

From stage one, there should be sufficient data collected to catalogue sensors and their effectiveness at detecting each variant of Paksmart target products. This data should show the accuracy, reliability and other important data for each targeted product so that the appropriate sensor can be chosen for any future application.

1.3.1 Research Objectives

From stage one, there should be sufficient data collected to catalogue sensors and their effectiveness at detecting each variant of Paksmart target products. This data should show the accuracy, reliability and other important data for each targeted product so that the appropriate sensor can be chosen for any future application.

1.3.2 Technical Objectives

Stage one should result in an object tracking and sizing program, that is capable of interfacing with 2D and 3D distance based sensors. Stage two should result in a proof of concept for an easy to setup vision system. It should aim to automate steps required in setup and give feedback to a user to ensure they install it to the same standard as an experienced technician.

Chapter 2

Literature Review

2.1 Background: Paksmart Machinery

Paksmart Machinery deals with many niche products, many of which are incompatible with a standardised mechanical collating and loading design due to their inconsistencies. Products like bags of flour or crackers have a highly variable form and often require a tight fit into their cartons. This is often been too difficult to automate and have previously been hand loaded into the PC40 cartoner.

Figure 2.1: *Example products at Paksmart machinery*

As stated in *Systems Approach to Computer-Integrated Design and Manufacturing*, from the customers point of view, a company has to respond to smaller and smaller market niches quickly with standardised products that will be built in lower and lower volume (pg. 6, Singh). Paksmart machinery has often had to turn to customised methods of product loading and collating to meet a clients request. This is a costly procedure which can often go over budget. Thus Paksmart has decided to turn to robotics in an attempt to make a single solution to cater to all predicted problems. This project focuses on machine vision as Paksmart's product range for cartoning applications is vast and exhibits problematic materials for optical based sensors and it is not expected that one sensor will be the best fit for all applications.

2.1.1 Pushing For More More Flexible Automation

The Industrial Robot has been a crucial resource to the ever expanding Manufacturing industry since the 1960s, and since 1989 the demand has been on the rise, as seen in Figure 3.

Figure 2.2: *Shipments of industrial robots in North America in millions of US dollars*

The cost of these robotic systems has dropped while the cost of labour has continued to increase. This is highlighted In ***Figure 2.2*** from *Introduction to Robotics*, though theses stats are 16 years old during the 5 years I have worked for Paksmart, I have observed an increase in the number of multipurpose robots at trade shows and in use by customers.

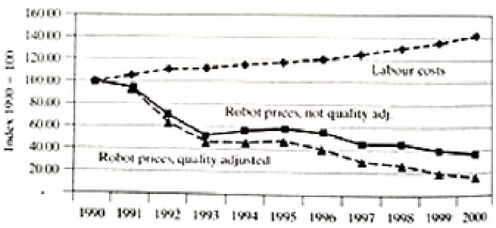


Figure 2.3: *Cost of Industrial Robots compared to human labour costs (John J. Craig, Chapter 1)*

Though the scope of this project is to develop a gantry style robot, the trends shown in this textbook ***Figure 2.3*** are very applicable, as the actuators, sensors and control systems have all dropped in price and also have improved in effectiveness to facilitate these trends.

2.2 Sensor Research

2.2.1 SICK Sensors

The local SICK representative recommended some sensors and after further research more were chosen

DX50-2

Optical 1D distance sensor

Measuring range	10 m on Black targets and up to 30 m on White targets
Sample Rate	3,000/s
Repeatability	0.5 mm to 5 mm
Measurement Technique	Reliable, patented HDDM™ time-of-flight technology
RRP	$500

Figure 2.4: *SICK DX50-2 - Specifications*

UM18

Ultrasonic 1D distance sensor

Measuring range	Four ranges up to 1,300 mm
Sample Rate	6/s
Repeatability	0.5 mm to 5 mm
Measurement Technique	Ultrasonic
RRP	$480-$520

Figure 2.5: *SICK UM18 - Specifications*

LMS400 - Short Range

This sensor is a 2D laser scanner; It has a good distance accuracy and a very high angular resolution so width measurements should be highly accurate. This Sensor takes 2D slice and will be paired with an Encoded conveyor to build a 3D image

Measuring range	0.7 m -3 m
Scan Rate	180 Hz -500 Hz
Aperture angle	70°
Angular Resolution	0.1° ... 1.0°, configurable
Repeatability	Systematic error ± 4 mm Statistical error 3 mm
Measurement Technique	Light frequency modulation
Light source	Visible red light (650 nm)
Laser class	2, in standby mode laser class 1
RRP	~$8000

Figure 2.6: *SICK LMS400 - Specifications*

Measuring range	141 mm ... 541 mm
Scan Rate	2,000Hz
Field of Veiw	141 mmx90 mm to 541 mm x 330mm
Repeatability	40 µm ... 280 µm
Measurement Technique	Triangulation
Light source	Visible Red light (660 nm)
Laser class	Laser class 2M
RRP	$10,000

Figure 2.7: *SICK TRISPECTOR1000 - Specifications*

TRISPECTOR1000 / TRISPECTOR1030

The SICK TriSpector is usually used for object identification as it has a very high resolution and frame rate. Same as the LMS400 This Sensor takes 2D slice and when paired with an encoded conveyor, builds a 3D image. Out of the sensors researched it is the most accurate and produces the highest resolution 3D models. Possible issues could arise due to the quantity of data and a separate dedicated processor may be required. It is expected that this sensor will be far too accurate than what is needed but there is no sensor offered by SICK that bridges the gap between this sensor and the LMS400.

2.2.2 Leuze Sensors

LPS36

The LPS from Leuze is an alternate triangulation line profile sensor to the SICK TriSpector100, the LPS36 has a lower price point and overall lower specs, but on paper it still has higher accuracy than required.

Measuring range	150 ... 600 mm
Scan Rate	100Hz
Field of View	200 ... 800 mm
Repeatability	0.5 % of distance measured
Measurement Technique	Triangulation
Light source	Visible red light
Laser class	laser class 2M
RRP	$6,000

Figure 2.8: *Leuze LPS36 - Specifications*

2.2.3 IFM Sensors

O3D302

The O3D302 3D camera from IFM is an emerging technology that is just reaching the industrial market, Sick is also has a time of flight camera but it has not been released in Australia yet. This style of sensor is by far the cheapest. What makes this sensor so interesting is it's ability to take full 3D image at once which could makes programing for it more like a dealing with a traditional 2D camera, just with distance rather than colour. This should make it easier to implement existing image processing techniques to the data outputted by this sensor.

Measuring range	300mm...8000mm
Scan Rate	25Hz max
Field of View	60° x 45° (horizontal x vertical)
Repeatability	± 7mm
Measurement Technique	PMD 3D ToF (Time of Flight)
Light source	Infrared LED (850 nm)
RRP	$2,000

Figure 2.9: *IFM O3D302 - Specifications*

2.3 Implementation of Sensors

2.3.1 1D Distance Sensors

The distance sensors Dx50-2 and UM18 would provide the most cost effect solution under ideal conditions.

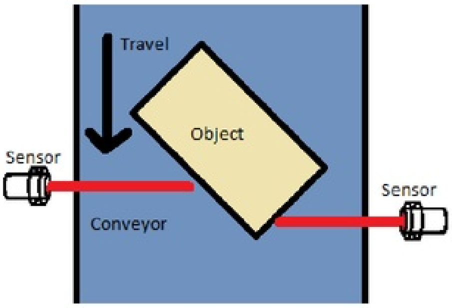


Figure 2.10: *birds eye view of detecting product with 2 offset 1D distance sensors*

These 1D sensors would be paired to detect the outer edge of each side of one object. This method should be the lowest cost but severely lacks in features - it cannot detect height without the introduction of further sensors, it is not capable of dealing with multiple objects at once and also requires an encoder to be fitted on the conveyor. Even though this system should be the least process intensive, it will not be investigated further due to its lack of compatibility with the other sensors.

2.3.2 2D Distance Sensors

2D distance sensors will be set up so that they cross the width of the conveyor taking 2D slices which will be paired with the conveyors encoder value. These slices are then compiled into a 3D image which will be treated like a 3D camera image.

2.3.3 3D Distance Sensors

These sensors will be mounted pointing vertically down perpendicular to the conveyor. This sensor does not need to be paired with an encoder, but in future implementations it may improve reliability as it will enable multiple samples to be converged to gain a higher density of data.

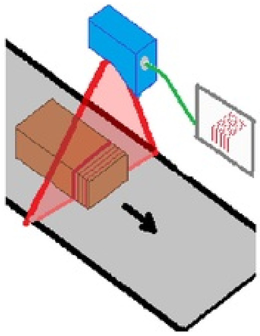


Figure 2.11: *2D Distance sensor on a conveyor with encoder feedback to space 2D profiles, forming 3D point cloud data.*

2.4 Sensor Physics

2.4.1 3D Tof Cameras

Time of Flight (TOF) cameras utilise a very common, low cost CMOS pixel array to do its measurements, but still boast thousands of distance measurements in a 3d space with reasonable distance accuracy (10mm) and reasonable frame rates. It is in essence a camera which sends back distance instead of colour. A time of flight camera works by illuminating a scene with a pulsed light source and observing the reflected light. The pulsed light is in the near-infrared range (850nm) invisible to the human eyes. The CMOS sensor reads both reflected light from the scene as well as the ambient light and distinguishes the two sources

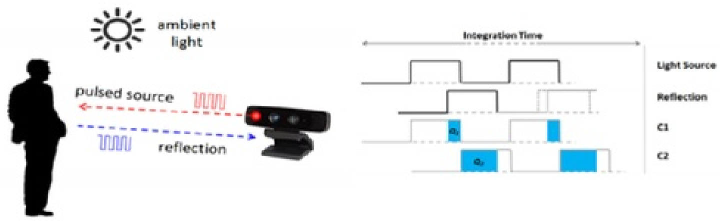


Figure 2.12: *Operation of a Tof sensor and Tof phase shift measurements ([V] Larry Li)*

As explained by Larry Li: The light source illuminates for a brief period (t), and the reflected energy is sampled at every pixel, in parallel, using two out-of-phase windows, C1 and C2, with the same t. Electrical charges accumulated during these samples, Q1 and Q2, are measured and used to compute distance using the formula (figure: 13) ([V] Larry Li)

$$d = \frac{1}{2} c \, \Delta t \left(\frac{Q_2}{Q_1 + Q_2} \right).$$

Figure 2.13: *Distance formula for Tof calculations ([V] Larry Li)*

Due to the nature of the 3D TOF cameras' sensing method, the conclusion can be drawn that reflective surfaces should be detectable. On the other hand clear surfaces will be detectable by this method, but how well is down to the sensitivity of the device and its internal program and filters. Once again this is not an issue for our application.

2.4.2 Triangulation

Triangulation for distance measuring is a fairly simple concept, yet is capable of producing highly accurate distance measurements in a small field of view. A laser is emitted from the sensor onto the measured objects surface to produce a visible dot. The dot produced on the objects surface is then detected by a camera sensor. The sensor can compute its distance based on the dots position on the pixel array.

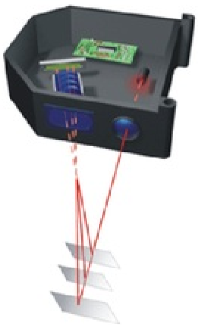


Figure 2.14: *Triangulation Distance Sensor*

This detection technique is capable of .1mm accuracy in the Leuze LPS36H and even higher accuracy is boasted by SICKS Inspector series of sensors. These sensors are capable of making measurements in 2D by moving the laser with mirrors. The industrial triangulation sensors have highly specialised camera like chips. These chips are capable of making the distance measurements without having to output the image. This technique allows these sensors to reach sample rates of 50,000 distance measurements a second. The high sample rate paired with a moving laser allows for full 2D line profiles to be generated at 100 Hz to 1000 Hz.

2.4.3 Laser Scanners

The LMS400 from SICK has a unique distance sensing technique patented by SICK. This sensor began development in the barcode sensor department of SICK where reading a barcodes at varying distanced proved difficult. The engineers faced the issue of needing to detect the distance the barcode was from the scanner in order to focus the optics to ensure a useable read from each barcode. After analysing the reads from barcodes at different distances a frequency shift in returning light was observed, resulting in the returning laser having a lower frequency the further it traveled. This distance measuring technique is very fast, allowing a barcode scanner to focus on a barcode in under 10ms. Eventually the research department responsible for distance and ranging sensors caught wind of the new barcode scanner breakthrough, they removed the unnecessary barcode reading gear and renamed it the LMS400. In essence the LMS400 is a barcode scanner without a barcode reader.

Figure 2.15: *SICK LMS400 Ranging Sensor(Left) - SICK CLV62x / CLV620 Bar-code scanner (Right)*

Chapter 3

Project Methodology

3.1 Measurable aspects

The PC40 cartoning machine is an End Load cartoner, this makes classifying axis of the box confusing due to the standard box measurements are labeled with a Top load machine in mind. As shown in ***Figure 3.1*** Carton sizing standards follow; W for opening width, L for opening Length and H for insertion height.

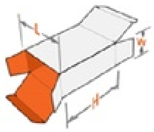


Figure 3.1: *Carton Dimensioning Standards*

The way a product must be orientated and sized to successfully be inserted into a carton is so that the products Height(Y axis) fits the opening Width, the products width(x axis) is the cartons opening Length and the products length(z Axis) is the cartons insertion Height.

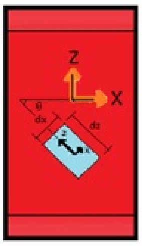


Figure 3.2: *Product measurement standards for automated*

To follow this standard the measurements of the products will be dx(distance x axis) carton width, dz (distance z axis) product length and angular offset which is the angle at which the product is measured to in testing. This is illustrated in ***Figure 3.2***.

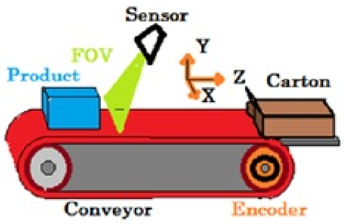


Figure 3.3: *XYZ reference for conveyor and carton. Sensor positioning*

Raw data will be generated by a 3D sensor or a 2D sensor with an encoder (***Figure 3.3***). These 2 formats of data will be converted to a 3D point cloud. From the 3D point cloud the program will run the same for each sensor to produce the real time results. This will be replicated for multiple different products and with each sensor tested. The test products will span a section of Paksmart targeted market and will feature variables that are predicted to strain the sensor performance.

3.2 Setting Accuracy Baseline

This is a difficult aspect to quantify as different products will have differing requirements. Paksmart is looking into this system to automate bag in box loading which requires relatively high tolerance in mechanical design due to the dynamic nature of bags. The only measurement that is consistent is the volume of the bags so the width and length of the bag will change when manipulated. These bags tend to be 50mm-200mm wide and 50mm to 300mm in length so it can be expected to have variances of 10-30mm in these dimensions. This variance will be catered too in the pick and place design, but what this means for the vision system is pin point accuracy will not be utilised effectively for this type of application. Any detected object with less than 10mm of variance in size and position would be optimal, but up to 20mm is acceptable. Even though the sensors tested are capable of much higher resolutions(up to 0.1mm) the packaging material of the bags tested are not optimal for optical detection, so it is possible that even the highest accuracy sensors will not meet the minimum specification for object detection.

3.3 Quantifying Effectiveness

The effectiveness of these sensors essentially comes down to how much reliable, repeatable information can be gathered about each object from each sensor. The main focus is on the ability to find the edge of the products to locate them and detect the orientation and size of the object. This functionality will directly competes with the function of the camera systems in a pick and place scenario. Further effectiveness of the sensor is to detect the height of the object and therefor detect volume or irregularity in shapes. This is a common problem, which can result in the robotic arm damaging product, itself or supporting equipment. It is possible for the sensors to meet the first requirement and not the secondary height detection. Null and inaccurate distance measurements still indicate the presence of an object. The testing code does allow for this method of detection to an extent by identifying a control surface (the conveyor bed) and treating all values outside of this range as objects. This method suffers from shadowing and other height related pitfalls which are present in 2D camera detection techniques, so it should not prove as accurate but still should prove effective. Due to time constraints the implementation of the null data is only effective on the 3D O3D302 sensor not the 2D sensors.

3.4 Automating Sensor Setup

Ease of setup is a key element in establishing distance sensors as an alternative for future machine vision applications. Utilising the 3D awareness of the distance sensors allows for the detection of working planes and background. In the testing application written for this thesis, a plane is detected from the centre of the sensors field of view. Once this plane is detected the sensors data is zeroed about this plane and the plane becomes the X and Z axis(Conveyor Width and Conveyor Travel). This setup application is functionally meant to remove bias in the results resulting from setting up a sensor slightly skewed of perpendicular. The setup application used in testing also provides a proof of concept of automated setup, upon which a user friendly GUI/wizard could be developed to enable anyone to set up the sensor in a real world application.

3.4.1 Real Time Data Analysis

Real time data analysis is a requirement of the final system in order for the robot to detect the products as well as an important testing tool, as it will allow for more tests to be done in less time. This is due to fact that the more expensive sensors may only be tested in the manufacturer's test facility during a predetermined time period. Therefore real time data analysis will be performed and logged for each test suite and will be the predominant form of sensor testing. The real time testing will identify the outer profile of the products from above(X,Z plane), and determine the rectangular size of the product dx(opening length) and dx (insertion height)***Figure 3.2***.

3.4.2 Outline Detection

For this method an outline of each object will be constructed from the outer most pixels that define each object. This sub program will:

1. Test each grid square till it finds one above the conveyor's height.

2. Once a starting pixel is found, the program searches clockwise around the pixel till it finds another pixel with a value above the bed height.

3. Repeat the previous step till the starting pixel is found again.

4. Once an outline is finished, the pixels that are enclosed are removed so that the object is not found again. This allows for multiple objects to be detected at once.

3.4.3 Object Orientation by Detection of Axis of Symmetry

Generating the axis of symmetry could be achieved by:

1. Finding the centroid of the outline shape
2. Intermittently calculate the distance of outlining points to the centroid.
3. Group common distance points and find the bisecting angle between each.
4. The most grouped bisecting angles should be the 2 axis of symmetry

This process is visualised in ***Figure 3.4***, in the first image(left) the common colour lines represent the line to equal distance points from the centroid. In the 2nd image the coloured lines represent the bisectors of the same coloured lines

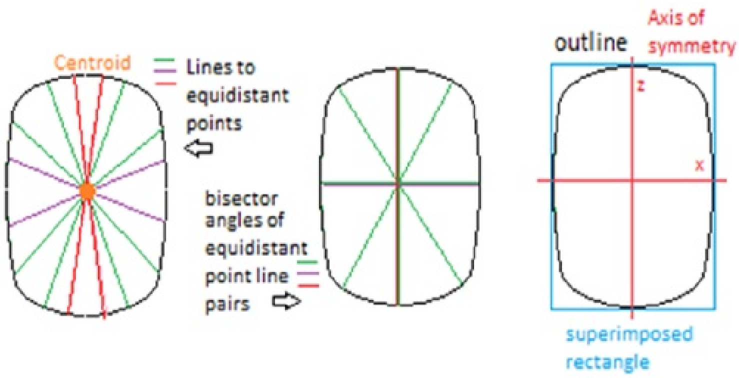


Figure 3.4: *Outline of bag of flour. Steps to superimpose rectangle to find width x and length z*

Note ***Figure 3.4***: The green set of line had 2 hits for the vertical and horizontal bisectors and only 1 hit for each of the diagonals. In a ideal case(the shape being perfectly symmetrical about the 2 axis) only a set of 8 equidistant points(shown by the green lines) is required to find the lines of symmetry. But in real world cases a larger sample will show trends in less symmetrical shapes, which can be interpreted as the most symmetrical axis.

3.4.4 Object Orientation by Brute force

The Following method rotates the object and fits it into a fixed orientation box. The angle of rotation that results in the smallest width box should indicate the best orientation for the product to fit in a carton. By incremental rotating the outline of the object by some degree increment, the program can see every possible orientation the object could be changed too. The program measures the X and Z axis max and min values after each rotation, to get the width and height at that angle. It can be assumed that the test that showed the minimum difference between the Max min values for the X axis has the product in the best orientation to fit in a carton. This method is currently used instead of the previous method Object Orientation by detection of Axis of Symmetry. This method is slower but is more reliable at this time.

3.5 Hardware Requirements

3.5.1 Conveyor

The testing conveyor is required to maintain a constant speed and will be a belt conveyor. Flatness of the conveyor is crucial. The Conveyor beds nominal travel speed was calculated to be 69.6mm/s

3.5.2 Sensors

The Sensors to be tested are the O3D302 from IFM, the LPS36H from Leuze and the LMS400 from SICK. All 3 sensors were lent to Paksmart for periods of 2 to 3 weeks. Details of these sensors are in the Literature review.

3.6 Test-Bed Design and Construction

3.6.1 Mechanical Design

The test bed as provided by Paksmart consists of a belt conveyor with aluminium extrude for mounting the various sensors. Each sensor tested came with some variation of a bar round bar friction mount. So a section of round bar was used to mount the sensors allowing for quick adjustments, the structure was secure to maintain stability to ensure consistent measuring environment. The sensors were levelled before the tests began. This was done using the test program which could detect the sensors angle. Small errors in setup were accounted for by the program, which detected the angle and translated the incoming data to correct it, and ensure optimal performance from each sensor.

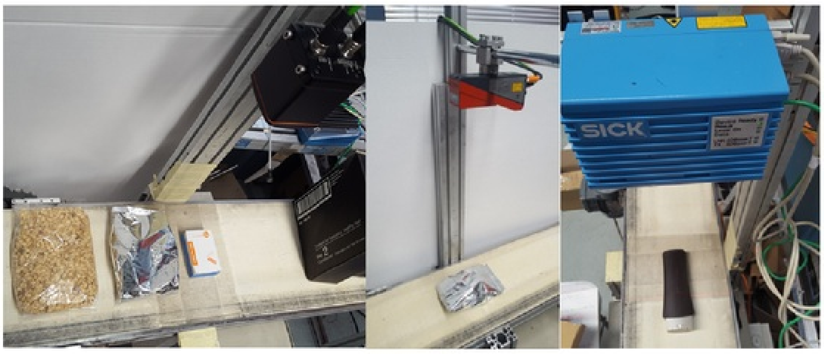


Figure 3.5: *O3D302, LPS36H and LMS400 (Left to Right)Mounted on test conveyor*

Mounting Setup issues LPS36H

Unfortunately Leuze only had the "H" High resolution variant of the LPS36 so its field of view is significantly smaller and its max window width is 140 mm which is almost half the conveyor width. This means that this sensor is not applicable. But its results for each test will be easily relatable to the standard model especially for reliability testing. Based on the resolution differences the accuracy can be approximated.

3.6.2 Computer Workstation

For writing the program and running the program a laptop running Windows 10 was used. It has an i5 quad core processor and proved sufficient to run the program and perform measurements in real time.

3.7 From Sensor to Results

This section brings together the materials and methods covered thus far.

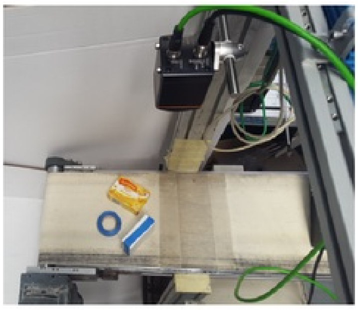


Figure 3.6: *O3D302 Capturing scene*

In figure ***Figure 3.6***, it shows the 3D camera set up on the test bench with three objects consisting of two varying size boxes and a role of tape, the 3D camera has all 3 objects in its field of view.

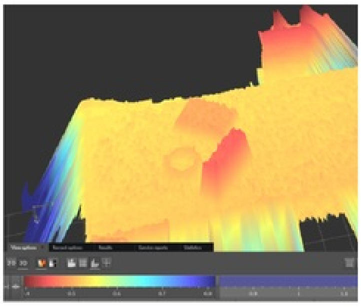


Figure 3.7: *O3D302s outputted image in 3D*

Figure 3.7 shows what the sensor sees, distance is portrayed by a colour spectrum as defined under the 3D view. The conveyor appears as a flat plane mainly yellow and the 3 objects(w boxes and tape) are the areas rising from the plane ranging from orange to red on top. There is also data around the conveyor which is blue as it is the floor. This form of data is what each sensors outputs will be converted too befor the testing program interprets it.

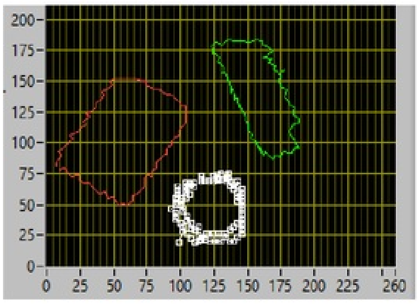


Figure 3.8: *Program Outlines objects*

In ***Figure 3.8*** three outlines which have resemblance to the three objects are graphed; these outlines are derived from the grouping of pixels that rose above the conveyor bed plane.

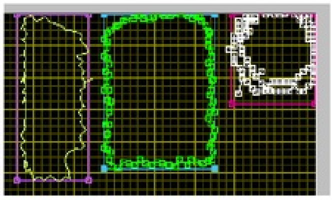


Figure 3.9: *Program Identifies size and position*

In ***Figure 3.9*** : the objects have been located, sized and rotated to fit in the purple blue and pink boxes, to visually show that the program has indeed measured the size of the objects and knows the orientation and location. This is now for show, but was used for debugging as it uses the test results to form the visual representation.

3.8 System Programming and Data Acquisition

3.8.1 Labview Coding

LabVIEW is a graphical function-block style programming language designed by National Instruments. LabVIEW is a programming language that I am quite experienced with and most comfortable using. The programming language has plenty of tools built in which makes programming quicker and easier. Most importantly the program could be run from a laptop so no extra processing unit was required, unlocking all the computing power of quad core processor and allowing utilisation of the on-board Ethernet port used to interface with each sensor. Also I already have developed programs to interface with SICK branded LIDARS, so it was already established that LABVIEW pared with a PC would allow for connection to industrial sensor over Ethernet.

3.8.2 Sensor Communications

O3D302 Coms

The O3D302 data string structure was simple to find and is customisable through the sensor's supporting software. The sensor works via a TCP/IP so the data comes in a consistent structured fashion making it easy to handle.

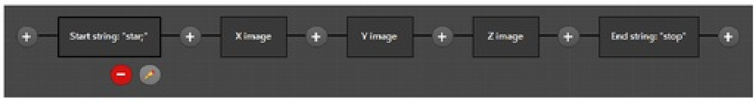


Figure 3.10: *O3D302 TCP/IP Output string user configured structure*

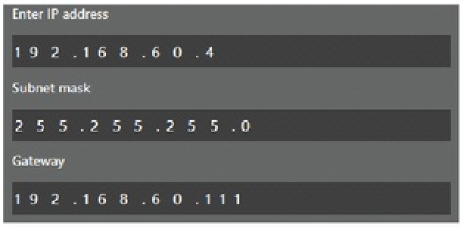


Figure 3.11: *O3D302 TCP/IP Addresses*

The data is outputted upon connection to the TCP/IP port and no data needs to be sent to the sensor As shown in ***Figure 3.10***, The data output was configured to output a star; string containing the information for the sensors status and the following Chunks size and quantity the chunks consisted of X values, Y values and Z values and ended by and end string stop. The X,Y and Z values were outputted for each pixel of the 3D camera, so to read each point of data you have to collate the x,y,z for that pixels measurement. The sensor itself detects a distance then forms the X,Y,Z location of that point in space with a polar to cartesian conversion. This does save some overhead for the vision program, and if the sensor is set perfectly perpendicular to the plane it is searching for objects on, there is no need to perform taxing spatial transformations.

LPS36H Coms

The LSP36H uses a UDP communications protocol for its Ethernet connection. This protocol lacks the packet loss detection and timing of TCP/IP but exhibits lower latency and faster data transmission speed. The coding required to retrieve the data string from the sensor was similar to the TCP/IP implementation on the 03D302.

This sensor required "establishing coms" to start outputting data over the UDP and exhibited a large header for the sending and receiving. The 2D Data was also broken up into 2 Packets (X,Y).

UDP Coms	
Sensor IP	192.168.60.3
PC IPv4	192.168.60.111
Remote Port	9008
Local Port	5634

Table 3.1: LPS36H Coms

The Flowchart in ***Figure 3.12*** was developed as a programming aid from reading the LPS36Hs data sheet. The flowchart represents the basic programming steps to read the sensor and translate the string to a usable array of data. Due to the use of the faster UDP coms, it could not be assumed that chunks would appear in order, this was accounted for by dumping chunks that were not expected and restarting the read process. This was the main difference of this code from the TCP/IP coms of the other 2 sensors tested but the other two codes followed very similar flows with less stops and checks.

Figure 3.12: *LPS36H coms flowchart*

LMS400 Coms

This sensor proved quite time consuming to interface. It used a TCP/IP interface but required stop/start instructions to begin data transmission and had a very in depth telegram structure which had to be utilised since only the distance measurements were outputted in the data chunks. This meant that the program was required to fetch the start, angular increment and end locations of each scan to convert the distance data into Cartesian coordinates.

TCP/IP Coms	
Sensor IP	192.168.0.69
PC IPv4	192.168.0.1
Remote Port	1024

Table 3.2: LMS400 Coms

Bed Leveling

The bed levelling code uses a 3D point cloud image and levels a plane about the centre of the sensors FOV. The purpose of this is to eliminate any bias imposed on the sensor by poor sensor mounting and setup. The bed levelling data then is used to level the sensor on a software level by translating and rotating the data to make the conveyor a level surface at height 0. The bed levelling tool takes the rows and columns of a 3D image and detects the average slope along each. The method is iterative to a user specific pixel range (default 50x50). Each iteration takes a single row and tests the angle based of a line of best fit, this is repeated for the number of columns and the mean of the results is taken. This process is then repeated down the columns and iterated based on the number of rows in range. The results are then used to rotate the plane flat where relative plane distance is calculated by averaging the height (Yaxis Values). These results are then saved and used after each scan to translate the new scan data to maintain a reference plane on the conveyor.

2D to 3D Data

In this Vi slices of 2D sensor data are concatenated to form a 3D image. These slices are positioned based on an encoder input which quantifies the z axis (conveyor flow).

Firstly an empty 2D array for each axis is formed with a predefined size based on the first 2D scan from the sensor and the users chosen z axis limit. Each iteration of the code adds the new scan to the front of the array and moves existing the slices down the array till they reach the end and are popped off the end. As shown in shown in ***Figure 3.13*** each iteration also takes an encoder input which added to each of the existing slice's z axis (conveyor travel) value. This code creates a 3D image to emulate the 3D camera allowing the following SubVis to be compatible with all 3 sensors.

2D Array (Zaxis)

New Scan(N)	N-1	N-2	N-3	N-4	N-5	N-6(overflc
Z1	Z1+enc(n)	Z1+enc(n)	Z1+enc(n)	Z1+enc(n)	Z1+enc(n)	Z1+enc(n)
Z2	Z2+enc(n)	Z2+enc(n)	Z2+enc(n)	Z2+enc(n)	Z2+enc(n)	Z2+enc(n)
Z3	Z3+enc(n)	Z3+enc(n)	Z3+enc(n)	Z3+enc(n)	Z3+enc(n)	Z3+enc(n)
Z4	Z4+enc(n)	Z4+enc(n)	Z4+enc(n)	Z4+enc(n)	Z4+enc(n)	Z4+enc(n)
Z5	Z5+enc(n)	Z5+enc(n)	Z5+enc(n)	Z5+enc(n)	Z5+enc(n)	Z5+enc(n)
Z6	Z6+enc(n)	Z6+enc(n)	Z6+enc(n)	Z6+enc(n)	Z6+enc(n)	Z6+enc(n)
Z7	Z7+enc(n)	Z7+enc(n)	Z7+enc(n)	Z7+enc(n)	Z7+enc(n)	Z7+enc(n)
Z8	Z8+enc(n)	Z8+enc(n)	Z8+enc(n)	Z8+enc(n)	Z8+enc(n)	Z8+enc(n)
Z9	Z9+enc(n)	Z9+enc(n)	Z9+enc(n)	Z9+enc(n)	Z9+enc(n)	Z9+enc(n)
Z10	Z10+enc(n	Z10+enc(n	Z10+enc(n	Z10+enc(n	Z10+enc(n)	Z10+enc(n)
Zn	Zn+enc(n)	Zn+enc(n)	Zn+enc(n)	Zn+enc(n)	Zn+enc(n)	Zn+enc(n)

Figure 3.13: *Array of Z-axis data points, 2D scans have the encoder increment added to each z data point to maintain each 2D slices position in 3D space*

Outline Objects

This Vi finds the objects and separates them. The outputted data consists of the points that make up the object as well as the 2D outline which will be used to calculate the size and position of the object.

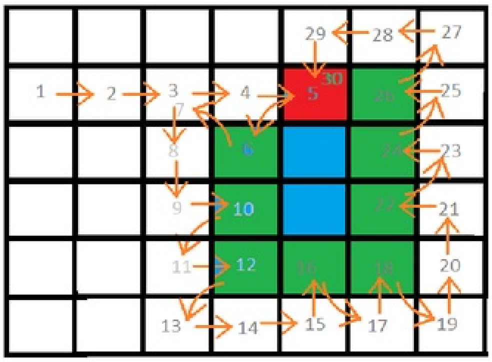


Figure 3.14: *Sensor pixel grid; White cells are the reference plane, Coloured cells belong to an object(height values outside the bounds of the reference plane). Blue cells are inner points, Green cells are outline points and the Red cell is the start/Finish point. The numbers represent an iteration of the code and the number is placed in the cell in that iteration.*

As illustrated in ***Figure 3.14***;The outlining Vi tests for points along the rows until it finds its first point of an object (red cell, iteration 5). The next point it tests is determined by looking at the previously tested point "4" and moving to the next cell in an anticlockwise direction around the last found outline point "5", It searches around the point in the anticlockwise direction until it finds another outline point and repeats the process searching in an anticlockwise direction around the new found point. This is repeated till the starting cell is found again (Red). Once the outer points are found the points are sorted and used to collect the remaining data points that belong to the object (Blue cells). These points are removed from the main image to stop the program from finding the same object more than once. The object is now saved in a separate array of its own. Further filters can now be applied to the smaller array to help removing anomalies like shadowing. If no further refining is selected, the object's outline is outputted for size and orientation detection and the object's point array is outputted for height and shape recognition.

Standard Divination Filter

This filter was made to simply remove majority of the shadowing effect that was experienced with the 03D302 sensor. The filter takes the standard deviation of the object's values and filters out any points that fall outside of 3 times the standard deviation. This is effective for detecting flat topped objects and excluding shadowing from them. The advantage of this filter was that it also works for more rounded objects which do not suffer from shadowing to the same degree and showed no detrimental effect having the filter active even if not needed. This solution was very simple to implement and served its purpose. A more elegant filtering technique would possibly need to be developed as if the O3D302 is chosen.

Object Orientation and Sizing

The orientation and sizing of the objects was performed using the outlines outputted by the outline code. The program found the centroid of the object, then rotated the object around that centroid testing its height(Y axis result) and width(X axis result) till a minimum width was found. This resulted in the orientation of the object to be calculated and the minimum sized box that would fit the object. The results of this test were the angle that the object had to be rotated and the width and height of the box at that rotation. The location of the box was also outputted and defined as the location at which the centroid was detected. The Height and null data was calculated using all the data points that made up each object. The mean value and standard deviation of the height was calculated, excluding the null and error values. This gave an indication of the sensors ability to consistently detect the objects height and rough shape.

Program Front Panel

The front panel provided the tools to conduct the testing. Pixel outline shows the pixels that formed the outlines, contrastingly the Sized objects graph showed the pixel outlines translated to their spatial positions. Identified and transposed Objects graph showed the program was working correctly by isolating the object and repositioning them in a neat row and confining them in boxes. These graphs were derived from the tables Object outline stats, Object Detected Stats and Centeroids. These tables contain the test results.

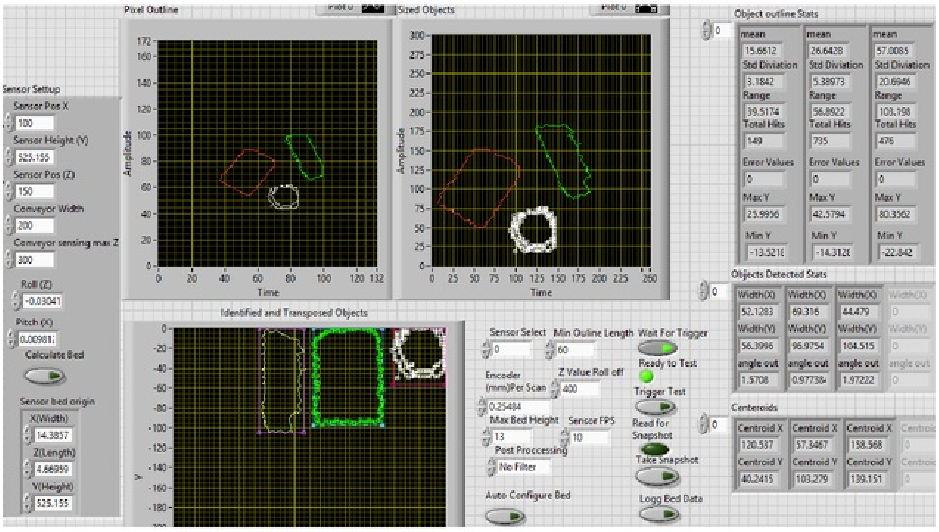


Figure 3.15: *Front Panel of testing program*

The button auto Configure bed was all that was required to set the sensors up between tests. Once the button was pressed the bed configuration program used the next sensor input to calculate the Sensor Setup parameters; sensor Height, Roll(Z) and pitch(X) which were responsible for locating the position of the Conveyor. This feature highlights the capability of these sensors to provide the required data to automate setup.

Chapter 4

Results and Analysis

4.1 Sensor Comparison

4.1.1 Observations

O3D302 Shadowing The biggest issue with the 03D302 is shadowing. This occurs when a pixel partially reads the box and the conveyor resulting in a distance between the two. As shown in figure below, it will result in the box forming a sloped side thus increasing the size of the box.

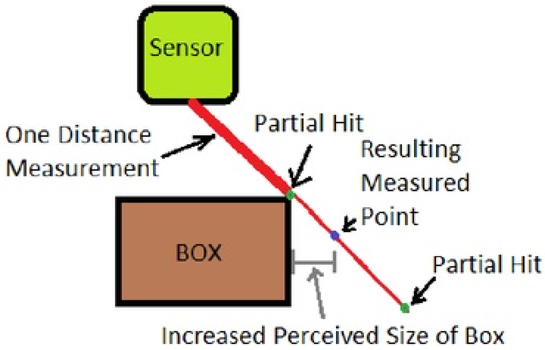


Figure 4.1: *03D302 Shadowing example diagram*

On a raw scan it manifests as a soft edge to each object in an image but as shown in the figure above, this can have a significant impact. Due to the increased perceived size of box labeled in ***Figure 4.1***, this was combated buy taking the standard deviation of the height measurements of the box and filtering out points that fell outside of 3 times the standard deviation, this filter was quick and simple to implement. A triangulation filter was in development to detect points that were shadowed, by comparing it to neighboring points and testing if they formed a shadow. This filter had varying success and was left for future work due to time constraints.

4.1.2 Sensor direct comparison: White Cardboard Box

In this section each sensor is put head to head on an analogue object. The analogue object is a white cardboard box. It was chosen due to its ease to detect (the white appearance is easy to disperse light off while not being reflective). The shape is also simple and easily measured. The dimensions of the box used for testing are: Width:64mm, Length:96mm,Height:30.5mm.

Figure 4.2: ***White cardboard box sizing***

In ***Figure 4.3*** the outline profile of a single sample is shown for each sensor. The outlines are of objects with a heading of 90 degrees, this gives a consistent and distinguished x and z Axis which reflects the x and z axis of the conveyor. The importance of this is that for the 2D scanners(LPS36H and LMS400) the rows across the x axis are a single scan and the z axis is dependent on encoder input. The 03D302 being the 3D camera has a very consistent spacing and also exhibits the largest spacing between data points which also appear to have more randomness to them. The LPS36H has the highest resolution in the X axis and a reasonable z axis. The LMS is only slightly better than the 03D302 on the x axis, but far surpasses the LPS36H on the Z with its 180 scans per second.

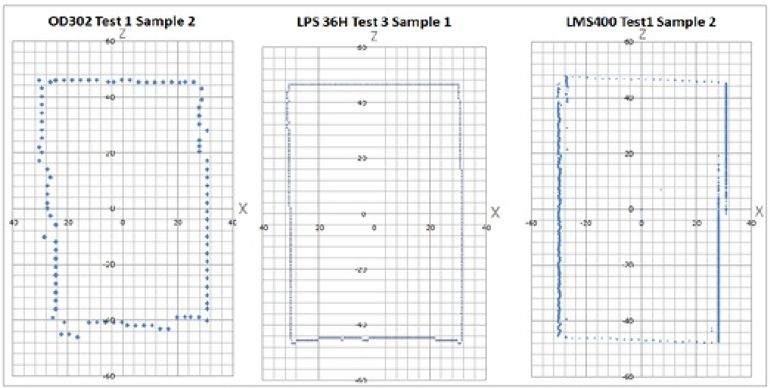


Figure 4.3: ***White cardboard box outline profiles***

The LMS400 Test1 sample 2 clearly shows its X resolution as a point of weakness. It has no problem finding the box and returning the distance to the box, but the angular resolution of 0.125 degrees results in obvious stepping on the slightly angled edge. The higher X resolution of the LPS36H gives an obvious advantage in these outline profiles with less aliasing visible. Another feature highlighted in these outline profiles is shadowing produced only by the O3D302. In the O3D302 Test 1 Sample 2 this is still evident even though the standard deviation filter was active. This is apparent along the bottom of the outline scan there is a trend for the data to form diagonal lines along the edge rather than a clean straight line. This feature was only observed on edges where the side face of the box was not visible to the camera and its effects increase the great the angle from perpendicular of the camera to the object.

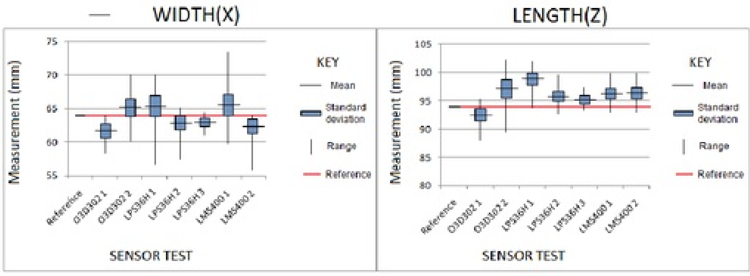


Figure 4.4: ***White Box Width(X) and Length(Z) test results***

The results of the Width and Length measurements in ***Figure 4.5***, were successful across the board. With each sensor maintaining accuracy of under 10mm. O3D302 2 and LMS400 1 tests were with the Standard deviation filter active. O3D302 2 and LMS400 1 were with no filter. The Filter caused both sensors to undersize the object but did make the results more consistent. The LPS36H showed consistent improvement through tests 1 to 3 as the exposer was reduced from 655us in test 1 to 261, in test 2 and 97us in test 3. The LPS36H test 3 was the clear winner

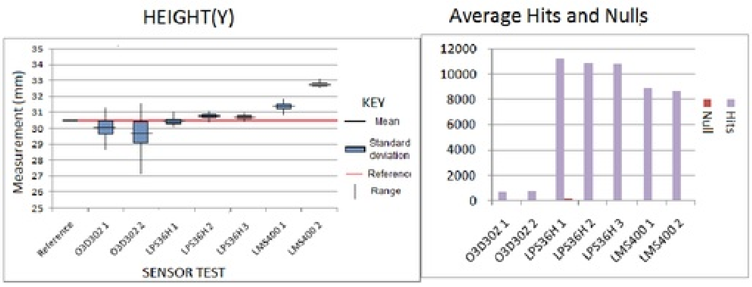


Figure 4.5: ***White Box Height(Y) and Average hits vs Null test results***

The height values were fairly consistent for each sensor with the LPS36H being the clear winner with 0.8mm of deviation and being well with in error of the height value. Both the O3D and LMS400 displayed repeatable results with a standard deviation of under 5mm.

The error values for this product were minimal as the surface was easy for the light based sensors to pick up. The LMS36H did encounter a fair amount of error values but they would be due to occlusion, these errors were not significant as it only affected 1% of the values.

4.1.3 Bag in Box Samples

Included in the document is three common bag materials, being translucent, transparent and opaque packaging.

Figure 4.6: *(left)Bag Opaque Bag 180 mm x 280 mm, (middle)Bag Clear 145 mm x 215 mm, (Right) Bag Foil 120 mm x 208 mm*

Test Specific Methodology

These products being quite large in comparison to the test conveyor were orientated on the conveyor straight, so angle did not deviate resulting in a constant heading angle of each sample equalling 90 degrees (based on the programs angular classification of objects). This has biased the results of the width to be dependent on the x axis of the measured data and the length of the object to favour the z axis accuracy.

Opaque Bag

Opaque Bag is a cereal product with a slightly opaque packaging, It should test the ability of a sensor to detect an object which will allow some light to pass through.

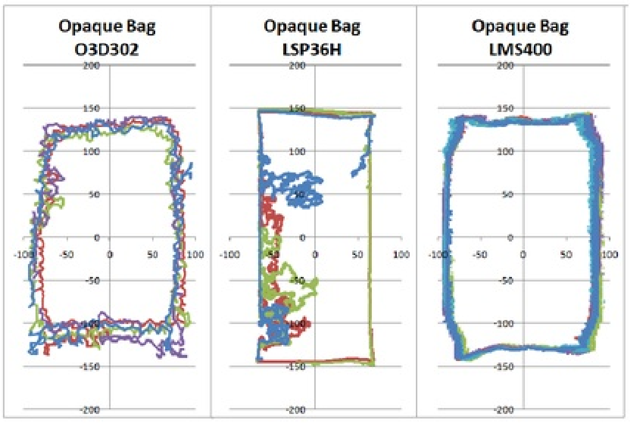


Figure 4.7: *Opaque Bag Outline profiles overlapped, Note: The LPS36H scan is thinner due to the bag being larger than the Field of view of the sensor.*

From the outline profiles, it is clear that the 03D302 has the least consistent edge but the LPS36H shows some issues highlighted by the outline trailing into the object. The LMS400 is the clear winner from this set of data. It is interesting that the three distinct sensor technologies would behave so differently in this test.

Despite the concerning outline consistency of the 03D302's scans of the opaque bag it performed well. In ***Figure 4.8*** the width measurements fell within a tight grouping with its extremes reaching the outsides of the reference size range. This result was found across the board. The LPS36H's field of view was too small to scan the entire bag so its width measurements are not completely valid, they do have an extremely tight grouping so this is evidence that the product was definitely detectable. However the LPS36H's 2nd round of tests (exposure 655us) resulted in a length measurement oversized by 12mm, but maintained a higher consistency between measurements; This is an odd outcome and was not seen in any other results. The LPS36H also experienced the highest percentage of null/error values with this product as seen in the figure above. This is also evident in ***Figure 4.7*** by the outline trailing into the bounds of the object. These null points never impacted the results of the test program, but they may cause issues in future programs. The LMS400 had the lowest standard deviation of the results that fell within the reference bounds, it also trended to the higher end of the bounds unlike the 03D302, this may indicate that it is better at detecting the falling edge of the opaque bag. The height data indicates a difference in measured surfaces between the 03D302 and the LMS400. The LMS400 measured 10mm higher than the O3D302 on average. It can be seen in figure(picture of Bag) the surface of the bag is higher than the cereal inside, so if the

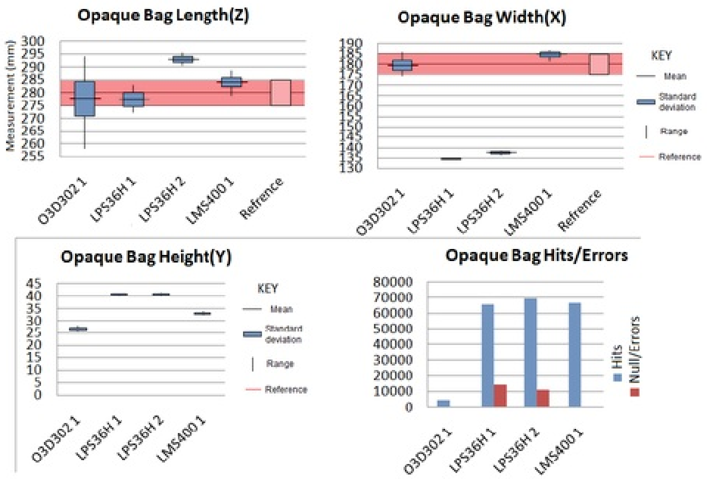


Figure 4.8: *Opaque Bag Test results (LPS36H 1 - Exposure set to 261us and LPS36H2 - Exposure Set to 655us)*

LMS400 sensed the Bag and the O3D302 measured the cereal underneath this would explain the difference in height data. Unfortunately due to the LPS36H not scanning the entire object(only the centre section) the comparison cannot be made to it too.

Clear Bag

The Clear Bag is another cereal product and has an almost perfectly see through film. This should allow the sensors to see through the bag, making it hard to detect the tabs at the end.

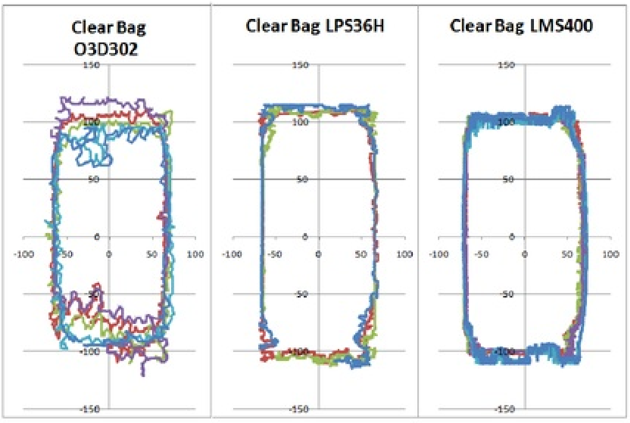


Figure 4.9: *Clear bag outline profiles*

The outlines for the clear bag are similar to that of the opaque. Key difference is the O3D302 has more consistent sides but the top and bottom ends of the bag are even more erratic in appearance. This is not unexpected as the end tabs of the bag are clear. The LPS36H and LMS400 also appear to have difficulty with the ends of this bag, but they do return enough hits on the end tab to detect it adequately. From visual inspection the LMS400 once again looks the most consistent of the outline profiles.

Once again, the clear bag was wider than the field of view of the LPS36H, so the width measurements should be dismissed. The LPS36H had negligible error values thrown, but this does not appear to have a great impact on the overall results. The standard distribution of the length is slightly higher (2.5mm for opaque to 5.7mm for clear) in the 251us test(test 1). This change could be caused by the clear tabs at the end of the product being harder for the LPS36H to detect following the trend seen in the outlines ***Figure 4.9***. The LMS400 showed excellent performance in width detection with a standard deviation of 3.1 mm, but did show limitations with 5.5mm deviation and 15mm range in the length measurement, were the sensor has the highest resolution. This indicates difficulty detecting object that are clear. The O3D302 underperformed in this test its range of measurements was very high at 30mm in the width and 50 mm in the Length. however its standard deviation was only just outside the reference tolerance. even though the sensor outputted good data it was let down by outliers. This may not be problematic if the applications conveyor speed allows for multiple scans to happen and outliers to be excluded. The height data ***Figure 4.10*** is consistent for all the sensors once again and the same trend between the LMS400 1 and O3D302 is seen, though to a lesser extent. This could be attributed to the LMS400's difficulty detecting the clear film.

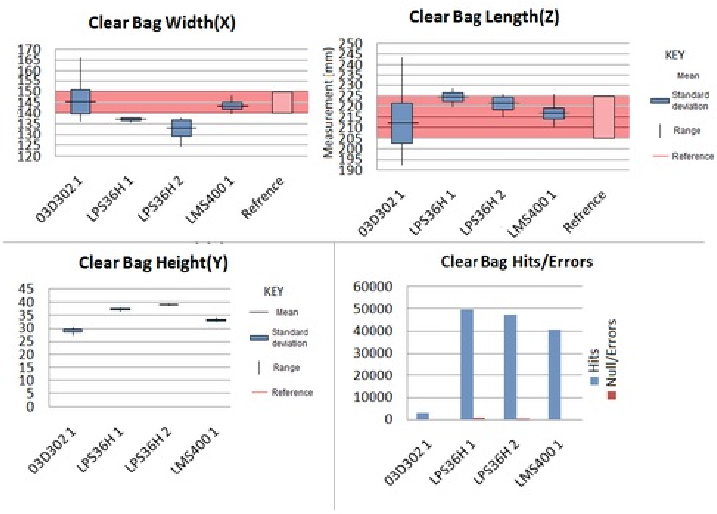


Figure 4.10: *Clear bag test results (LPS36H 1 - Exposure set to 261us and LPS36H2 - Exposure Set to 655us)s*

Foil Bag

This product proved too problematic for the LMS400 and LPS36H both outputting too many null values to form a measurement. The O3D302 did not perform well as shown in figure 40. The data is erratic, however by including negative measurements as well, the 03D302 was able to retrieve usable data.

	Width(X)	Length(Z)	Height(Y)	Standard Deviation of Hits	Range of Hits	Hits	Nulls
Average	150.6	226.6	-9.9	64.5	403.0	2708.1	221
Standard Deviation	12.3	5.2 9.8					
Range	34.6	16.0	30.3				

Table 4.1: Foil Bag Test results

The size of the foil bags was measured at 120 mm x208 mm The 03D302 measured the bag at 150.5 mm x226 mm . This is the least accurate results of the products that returned data, but it does show it is possible to detect a reflective object. The standard deviation and range is a bit large and wouldn't be considered acceptable but it is surprising that it was able to get results this consistent when the height data has a range of 400mm and a standard deviation of 64mm on a 30mm high object. With further development to the code to account for the negative values and estimate their position based on a set product height, it is definitely possible to identify a problematic product like this and make the appropriate assumptions to detect it.

4.1.4 Shampoo Bottles

The next test grouping is outside the scope of the bag in box robotic loader. These products have been included in the research in preparation for a new application for the 3D vision system in development by Paksmart. The application for the new project requires the same sensing technology but for a conveyor transfer and collating application for an existing PC40.

Figure 4.11: *Shampoo Pink, Shampoo Clear and Shampoo Black reference sizing*

The Pink shampoo is glossy and highly reflective. The Black shampoo bottle is also glossy, but due to the black colour it is especially difficult to disperse light off of. The clear bottle is clear and contains a Green transparent gel. The objects are 84-86mm x 220-221mm

Test Specific Methodology

This product being 220mm long were orientated on the conveyor meaning measured heading angle of each sample was close to 90+-10 degrees (based on the programs angular classification of objects ***Figure 3.2***). This has biased the results of the width to be dependent on the x axis of the measured data and the length of the object to favour the z axis accuracy.

Shampoo Pink

This is the least Challenging of the three shampoo bottles, its reflective but does have a bright colour to it which is easy to disperse light off.

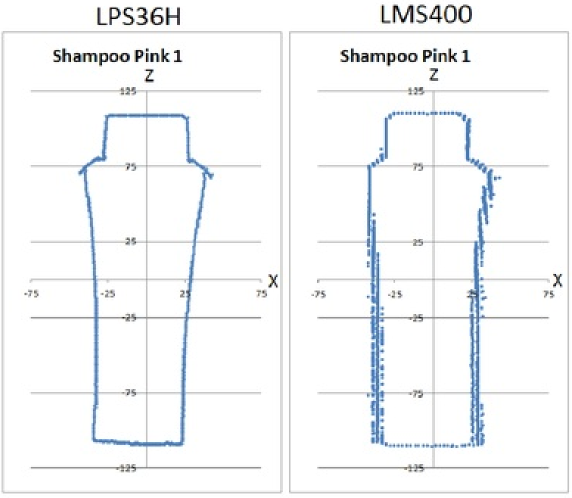


Figure 4.12: *Shampoo pink outline profiles (O3D302 outlines not included due to it not adequately identifying the bottles)*

The outlines look consistent, but the LPS36H does appear to be having trouble reading the edge of the bottle. This is evident in the overhanging feature to the very left and right of the outline.

Both laser based 2D sensors performed very well on the Pink shampoo bottles and the results are consistent. The results from the LPS36H were repeatable to 2mm on width measurements and surprisingly outperformed the LMS400 on the Z axis even with its less than one third resolution in that axis. In the graphed X and Z measurements, the Z axis results trended above the reference line while the X axis varied above and below between tests. This is not unexpected as the orientation of the objects were fairly consistent in the rounds of testing keeping the measured orientation tight around 90 degrees. This has resulted in the width(X axis) measurements more greatly being affected by the reflective surface at very obtuse angles causing the light to reflect and measure the conveyor rather than the bottle. This actually results in localised negative height measurements(results falling below the Conveyor reference plane) due to the extra distance the light had to travel, or null points both shrinking the size of the object. This was a major issue with the 03D302 and resulted in it being very inconsistent and breaking objects into 2 specifically around the cap.

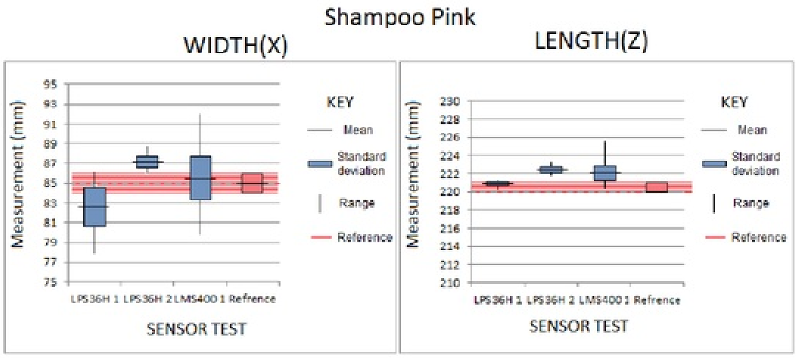


Figure 4.13: *Shampoo Pink Width and Length Results (LPS36H: 1 -¿ exposure = 255us and LPS36H: 2 -¿ exposure = 651us)*

Shampoo Clear

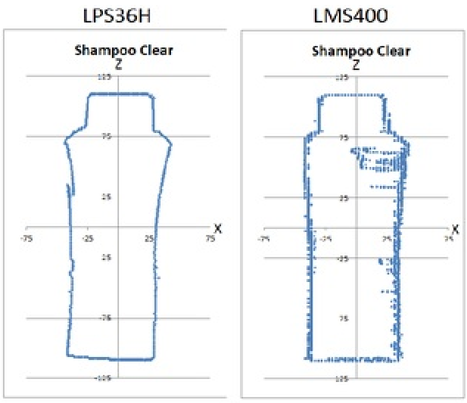


Figure 4.14: *Shampoo Pink Width and Length Results (LPS36H: 1 -¿ exposure = 255us and LPS36H: 2 -¿ exposure = 651us)*

The error values can be seen manifesting in the outline profile of the LMS400 ***Figure 4.14***. These occur around air pockets in the bottle. Interestingly the distance measurements did not read the surface of the bottle or the conveyor bed behind the bottle but somewhere towards the middle in both the LPS36H and the LMS400. As for the LPS36H this could be due to refraction through the liquid causing the triangulation of the dot hitting the conveyor bed to read as being closer than it is. This unexpected result is consistent enough to provide distance measurements usable for object detection.

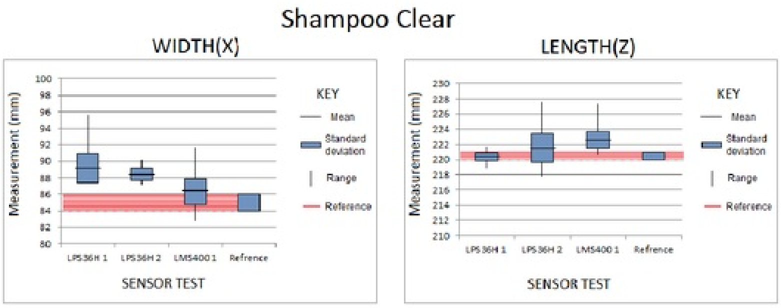


Figure 4.15: *Shampoo Clear Width and Length Results (LPS36H: 1 -¿ exposure = 255us and LPS36H: 2 -¿ exposure = 651us)*

The length measuremnts of the Clear Shampoo dont vary greatly from the Pink shampoo results. In comparrison the clear and pink length measurements show simular trends of oversizing the obects length by 0-3mm, the standard diviation for the LMS400 is doubled to 2mm in the clear results, which indicates some issues with the material. The results of the LPS36H test 1 at 261us exposure showed a tight and accurate length reading while it suffered consistency on the width. The exposure was changed to 655us for test 2 which greatly improved the width measurements at the cost of the length. The LPS36H was also set to 97us but this change cause a high percentage of null values resulting in no objects being detected.

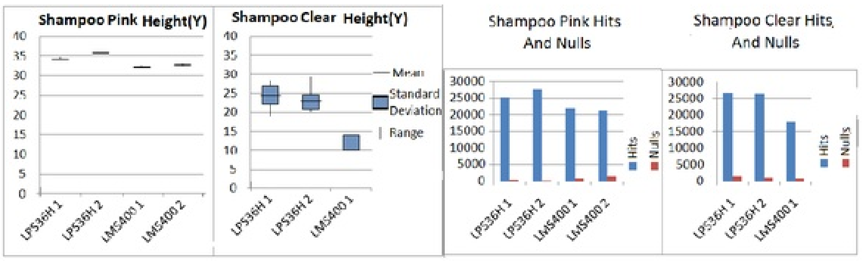


Figure 4.16: *Shampoo height and hit Results Shampoo Clear and Pink)*

The results of the Shampoo Clear were very surprising. An increase in error values was observed ***Figure 4.16*** yet not as high as expected. The LPS36H went from very low 1.4% errors on the Pink shampoo to 5.2% which still provides more than enough data.

Shampoo Black

Shampoo Black was predicted to be the most difficult of the shampoo range. Its combination of shiny finish and black plastic. Makes it reflect or absorb all the light. The Black

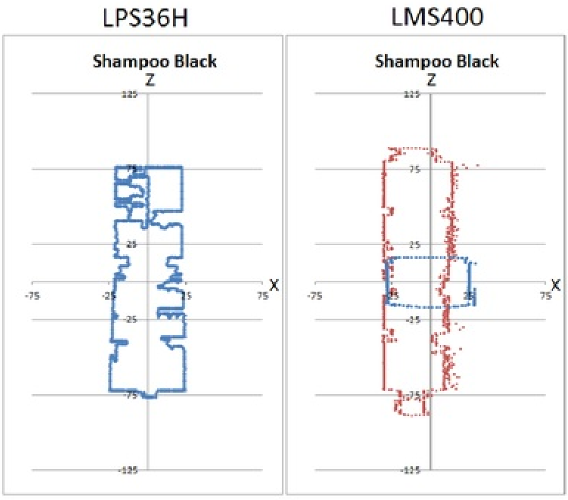


Figure 4.17: *Shampoo Black outline profiles (note overlapping sections of the bottle comprising of cap and label of bottle due to difficulty measuring black glossy plastic)*

shiny bottle of the 3rd Shampoo sample has proven to be much harder to detect than even the clear bottle. The Black bottle did not produce results that were reflective of the overall size and shape of the object. The results often split the bottle into 2 features- the label and the bottles cap. This can be clearly seen by the outline profile shown in ***Figure 4.17*** LMS400 Shampoo Black, the red outline is mostly label with some points returning of the black surface, giving the inconsistent edge. The blue grouping of points is the cap of the bottle. The testing program isnt capable of grouping these objects but further development could provide usable positioning by repeating the two scannable areas.

Shampoo Comparison

The 03D302 could not provide usable data under the test conditions and has been ruled out for this application. The LMS400 and LPS36H both performed well on the Pink bottle and the clear bottle. The LPS36H provided the best results for the Pink bottle and the LMS400 provided the best results for the clear bottle.

4.2 Result Discussion

The O3D302 was definitely the worst performer of the group with its relatively low resolution and 8mm distance accuracy this was expected. Unfortunately it also had the most trouble detecting shiny, clear and opaque objects. The LMS400 and LPS36H were hard to distinguish with the LPS36H's X resolution giving higher accuracy, but only when the conditions were right. The LMS400 was the most robust in its ability to detect the bagged products with little concern for the opacity. So its hard to look past the LMS400 for a standardised solution until cost is factored in. The O3D302 even though it was easily the worst performer in every test bar one it still has the advantage of being a third of the cost of the LPS36H and a quarter of the price of the LMS400. With further development a program could allow for accurate detection and positioning of the black shampoo as well as the foil bag with all sensors. This could be made possibly by handling null data differently. A theoretical solution would be interpreting null or error data as a read of a predetermined height, this would prove effective as null data is only caused by an object being present.

Chapter 5

Time-line

1. SENSOR ANALYSIS

This Will be the main research component of the Thesis, and will decide the sensor needed or sensors to choose for certain products.

1.1. RESEARCH POSSIBLE SENSORS

1.1.1. ONLINE RESEARCH - 08/04/16 - 06/05/16

Initial online research was conducted with the literature review and has continued as the project has progressed

1.1.2. MEETING WITH SICK - 18/05/16

After brief email correspondence the local SICK Rep came to Paksmart to meet me and discuss the

1.1.3. MEETING WITH IFM - 18/05/16

I was contacted via email by IFM in regards to a new product and they are coming next month to show me it.

1.1.4. FURTHER ONLINE RESEARCH BASED ON MEETINGS - 18/05/16 - 01/07/16

1.2. TESTING SENSORS

From my correspondence with The Sensor Companies I've got offers to test sensors at Paksmart and at IFM and SICK's Premises in Melbourne.

1.2.1. SICK

1.2.1.1. ORGANISE IN HOUSE TESTING - 27/06/16 - 27/07/16

1.2.1.2. PERFORM IN HOUSE TESTING - 27/06/16 - 01/07/16

1.2.1.3. ORGANISE TESTING AT SICK HQ - 19/05/16 - 01/07/16

1.2.1.4. DO TESTING AT SICK TEST FACILITY IN MELBOURNE - 26/06/16 - 15/09/16

1.2.2. IFM

1.2.2.1. ORGANISE IN-HOUSE TESTING - 27/06/16 - 27/07/16

1.2.2.2. PERFORM IN HOUSE TESTING - 27/06/16 - 01/07/16

1.2.2.3. VISIT IFM IN MELBOURNE - 26/06/16 - 15/09/16

1.3. CHOOSE SENSOR

1.3.1. COLLATE DATA FROM TESTS AND COMPLETE SENSOR REVIEWS - 18/07/16 - 19/09/16

From the Tests that have been performed on the Sensors, a document should be created to compare and contrast the Sensors and their performance for the application.

1.3.2. PURCHASE SENSOR(S) - 23/09/16 - 23/09/16

Purchase the most appropriate sensor based on the Senor review reports.

2. PROGRAMMING - 19/05/16 - 05/12/16

2.1. SENSOR TEST SUITE - 19/05/16 - 24/06/16

Create a Point cloud display of data points to visualise data shown by a sensor and if possible detect shapes and measure sizes to calculate accuracy

2.2. SENSOR IMPLEMENTATION - 20/09/16 - 17/10/16

Gants Chart in appendix A

Chapter 6

Conclusions and Future work

The research in the thesis has shown where each sensor strives and since not one sensor proved most effective in all scenarios, the sensor chosen may come down to the best suited for Paksmarts first real world implementation. The LPS36H wouldnt be chosen due to its very small field of view but the non-high resolution model the LPS36 would be a good choice as its x resolution is still very high, and would provide the best accuracy in most applications. For applications where your dealing with the more difficult to detect clear bags, the LMS400 would be the obvious choice, as its reliability allowed it to maintain the highest consistency in object sizing.

The fact that the O3D302 was the worst performer does still not rule it out. With its very low price point and open source programing capabilities, this sensor itself is capable of running the program on-board if the program is ported to C++. This capability will have to be explored in future work as it would prove to be the most cost effective solution. It is currently being used for completeness application in a Paksmart PC40.

As discussed in the results conclusion, there is further work to be done in order to expand the capability of the 3D sensor object tracking. Just because it has now been proven that this sensor will not detect some of the products put forward by Paksmart machinery it doesn't actually mean that the system will not work for these objects. By writing an amendment to the code, allowing it to handle the null data as a detected object of a set height, the objects size and location can be estimated and it could be just as accurate as a detectable object. The only downside to this is that it adds another step to the set up procedure, requiring the user to set the height of the objects that cause null data.

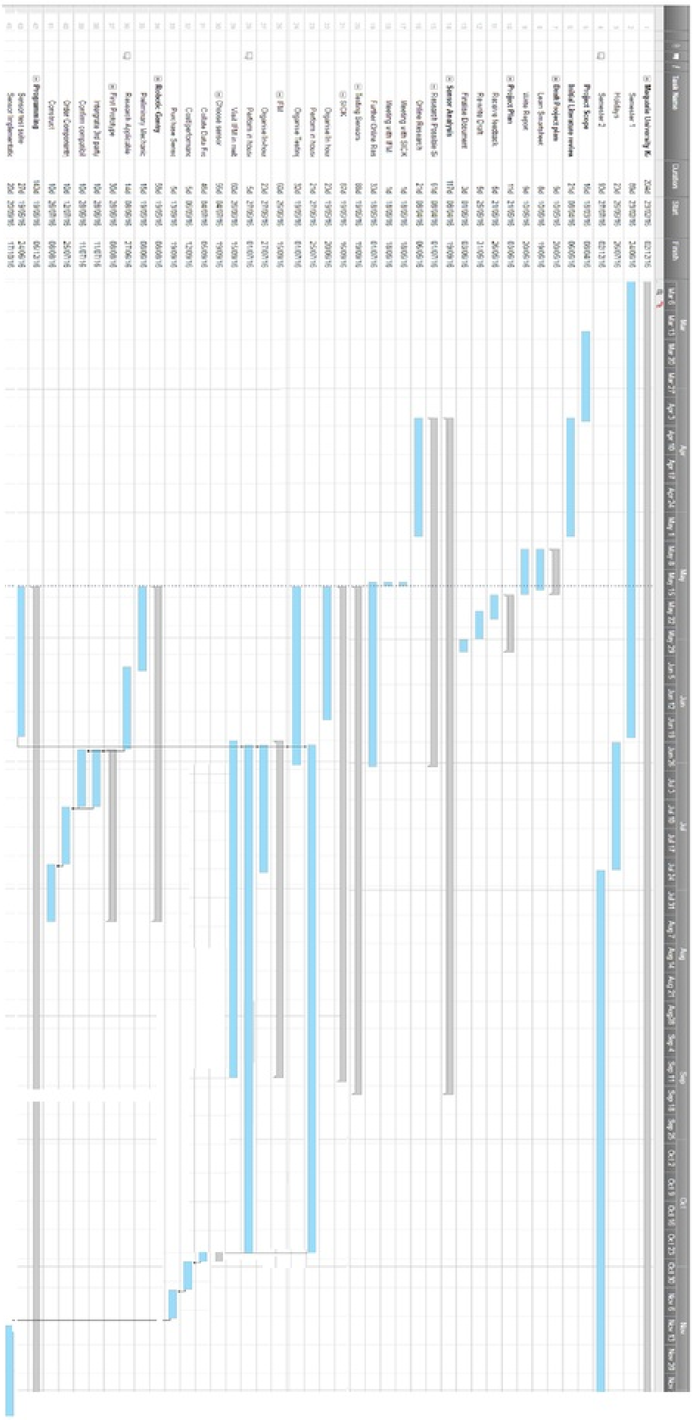
The user friendly setup wizard for the tracking program is also going to unfortunately fall under future work. However the implementation of the auto bed setup was a success. The only issue is lacks the step by step nature you would find in a setup wizard. The Program only contains some of the elements, those of which were useful to the test procedure and are accessed via the front panel of the program and indeed did speed up the setup proccess.

So in conclusion all 3 sensors were found to be viable for machine vision applications, but each one proved itself in different situations brought on by the sensor test suite. The distance and ranging machine vision system has much more capability than the current program can show and the tests results really do show what can be achieved with very simple programming techniques. Distance sensor are definitely where the industry is headed and they will be capable of bringing machine vision tracking applications to the masses.

Appendix A

name of appendix A

A.1 Gants Chart



Appendix B

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