University of Southern Queensland

Faculty of Engineering and Surveying

COST-EFFECTIVE 3D MODELLING

A dissertation submitted by

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Towards the degree of

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ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

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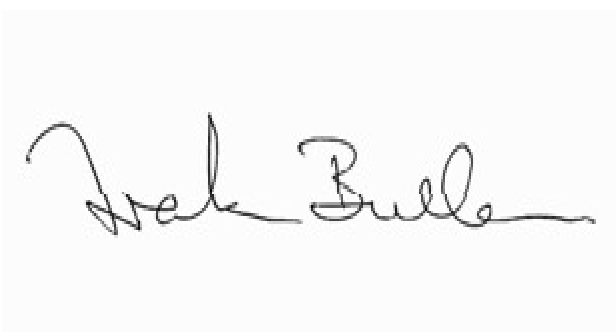

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CERTIFICATION

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.

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ABSTRACT

The use of Computer-Aided Drafting has led to the adoption of three dimensional modeling into routine drafting practice. These three dimensional models have enabled designers to build a "virtual object" which can be studied, analysed, modified and duplicated prior to costly manufacture. This cycle enables a reduction in risk for a design in terms of cost and schedule.

The construction of a three dimensional model can be a simple process. This process basically involves four steps. The steps are:

a. an important feature of the real item is selected

b. physical measurement of the feature is conducted with an instrument such as a ruler or vernier caliper,

c. this data is entered into the cad program, and

d. step (a) through (c) is repeated until the object is completely described in the application.

These four steps are quite easy to execute for simple objects. But objects with more complex shape require more features to be selected, more data to be entered and possibly more sophisticated measuring equipment.

So the problem arises: Is there a method which can take a large number of data points from a complex object and can this method be accomplished in a cost effective manner?

The aim of this project is to develop a method of generating a three dimensional model of a small object using cheap and readily available components. The

resulting data from this model should be made suitable for use by common industry software such as MATLAB or Autocad in order to demonstrate usefulness of the design in areas such as virtual prototyping, non-contact metrology and artificial vision.

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Finally, to my wife Tricia, I owe my deepest gratitude. Her support and encouragement were fundamental to completion of this project and indeed my degree studies.

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Chapter 1. Introduction

1.1. Project Background

“Regardless of all the statements and the talk about what is the oldest profession in the world, drafting is the only profession that historically can be documented.” (ADA, 2006)

Engineering drawing, also known as drafting is a method of representing ideas by the use of descriptive illustration. These illustrations communicate the method or process detail required to bring ideas for everyday objects to reality. The drafting process is ages old and is first recorded when ancient cavemen recorded their hunting practices of on the walls of their caves.

Slowly, humans evolved and with them so did methods of drawing. The Arab invasion of lower Europe in 720AD introduced the Chinese invention paper, to the western world. This had a great impact on drawing as the act was no longer a monastic endeavor conducted on animal skins and dried cane parchments. Drawing was now accessible to the masses.

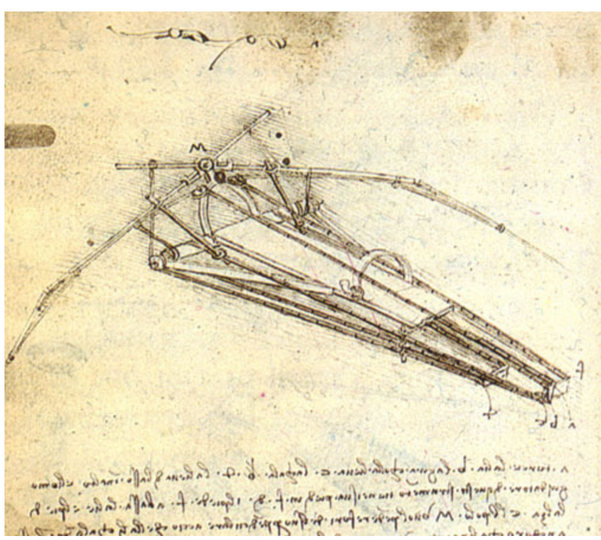

Figure 1.1 Leonardo's Flying Machine

One of society’s most recognizable drafters was engineer, scientist and inventor, Leonardo Da Vinci. He lived between 1452 and 1519 and was responsible for pictorial essays on many ingenious inventions- some which work and some which could not.

Until recently, the basic equipment required to produce Engineering Drawings was an accurate table, and the dexterous manipulation of instruments such as squares and compasses. It was only with a high degree of skill that an accurate drawing could be produced, as even the slightest misalignment of the equipment would produce large errors. This made drafting a slow and tedious process.

The drafting machine was introduced to eliminate some of the tedium of instrument handling. The use of the pantograph-like assembly gave drafters rapid and repeatable access to reference angle at any place on the page.

In recent times, computer technology has profoundly influenced the manner in which Engineering Drawings have been conducted. Computer Assisted Design (CAD) has been implemented in most aspects of design regardless of the scale. Figure 1.2 shows just how many stages of the modern design process is influenced by a CAD activity.

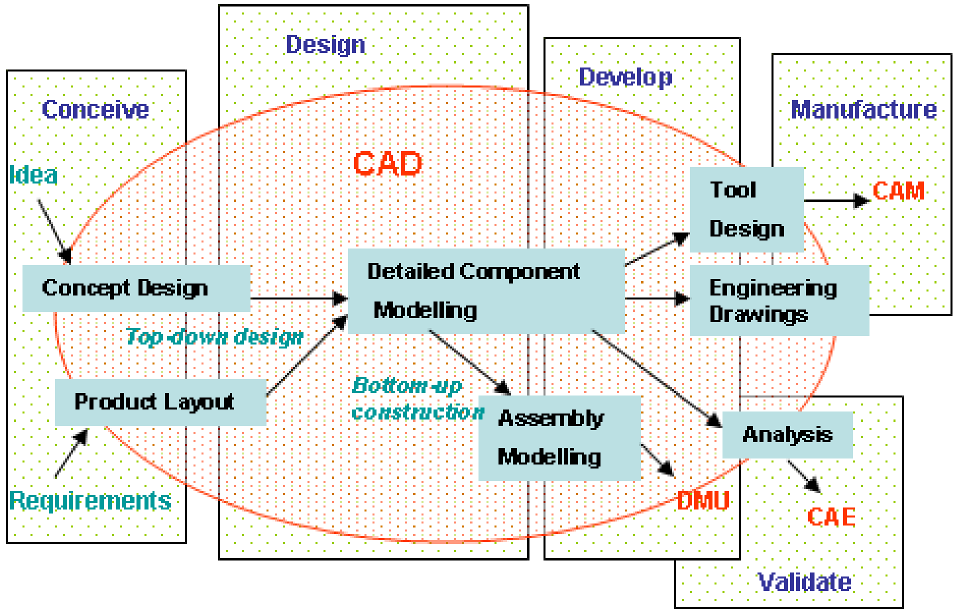

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Figure 1.2 CAD's Influence on the Design Process

The process of drawing, in an engineering context, has now evolved from a largely manual and skill-intensive activity to one highly augmented by technology. As a result, in many organisations, large offices once filled with expanses of drawing machines and draftspersons have been replaced with fewer multi-disciplined technicians and engineers operating powerful CAD stations.

1.1.1. Three Dimensional Modeling

One of the trends that has emerged as CAD programs became more powerful, was the adoption of three dimensional modeling into routine drafting practice. These three dimensional models have enabled designers to build a "virtual object" which can be studied, analysed, modified and duplicated prior to costly manufacture. This cycle enables a reduction in risk for a design in terms of cost and schedule.

The construction of a three dimensional model can be a simple process. This process basically involves four steps. The steps are:

a. an important feature of the real item is selected;

b. physical measurement of the feature is conducted with an instrument such as a vernier caliper;

c. this data is entered into the cad program; and

d. step (a) through (c) is repeated until the object is completely described in the application.

These four steps are quite easy to execute for simple objects. But objects with more complex shape require more features to be selected, more data to be entered and possibly more sophisticated measuring equipment.

So the problem arises: Is there a method which can take a large number of data points from a complex object and can this method be accomplished in a cost effective manner?

In solving this problem, it seems intuitive to replace the human-dependant operation with a mechanised operation. The logical approach to the problem is to develop a machine that attempts mimic the steps that the human performs. The machine must hence be able to recognize, manipulate and measure the object and then enter the data into the software application.

1.2. Project Aim and Objectives

1.2.2. Project aims

The aim of this project is to develop a method of generating a virtual 3 dimensional model of a small object using cheap and readily available components. The resulting data output from the system should be made suitable for use by common industry software such as MATLAB or Autocad to demonstrate usefulness of the design in areas such as virtual prototyping, non-contact metrology and artificial vision.

1.2.3. Specific objectives

The specific objectives of this project are:

a. to develop Visual Basic code to point a low power collimated light source at a diffuse reflective surface;

b. to develop Visual Basic code to acquire the reflected beam (target) using a commercially available Webcam and calculate the distance of the reflection in front of a screen;

c. to develop code to then traverse the incident beam across the field of view, and repeat the process outlined in (b); and

d. to construct a prototype system and evaluate it's effectiveness.

1.3. Project Methodology

Prior to commencement of the design and build phase of the task, a strategy or plan of attack was formulated. Figure 1.3 outlines the approximate methodology executed in this task.

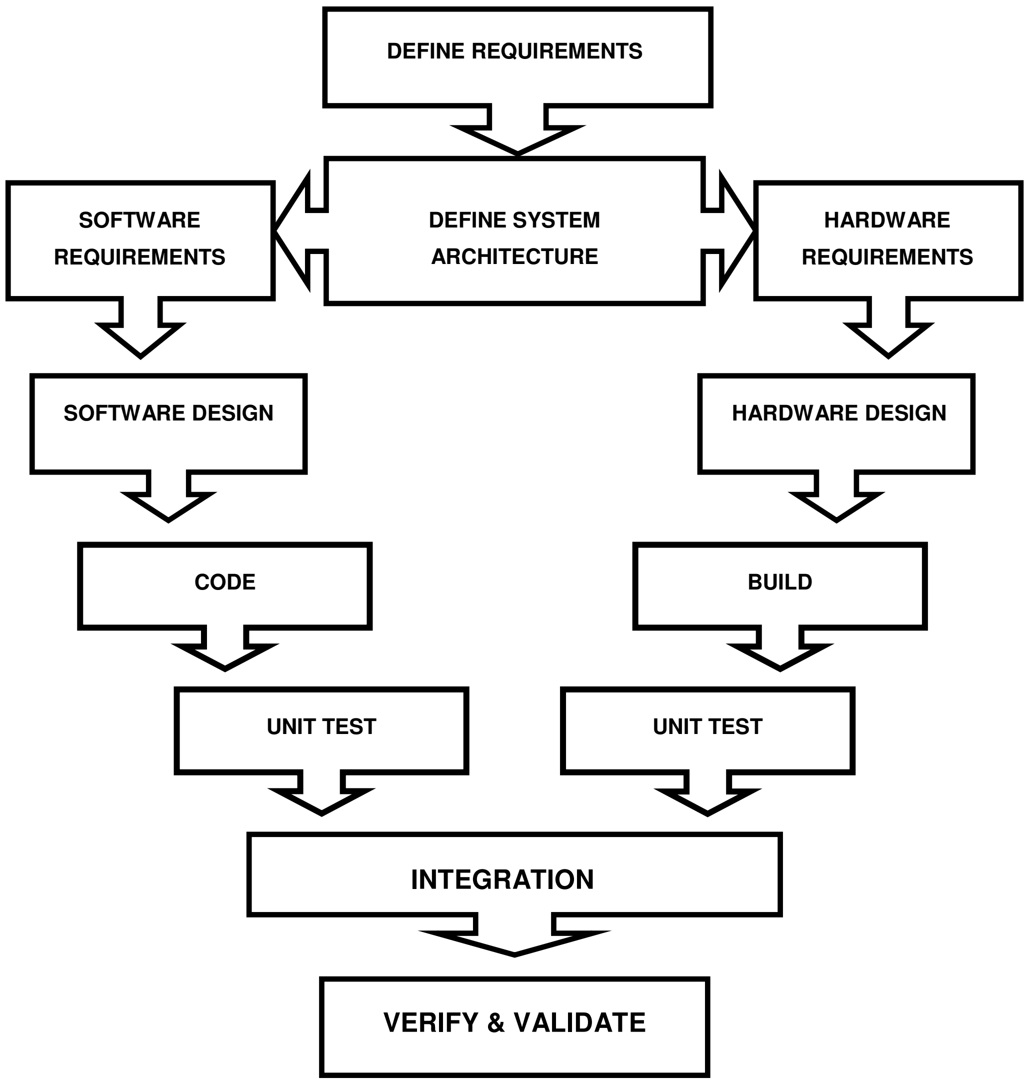

Figure 1.3 Methodology of Project Execution

Based on this methodology, the first step was to define the system level requirements. From these requirements, an initial system level architecture could be derived. Based on this architecture, it became apparent that system development could be divided into two distinct disciplines, hardware and software.

Sub-system level requirements, explicitly allocated to the two streams, were developed as the design decomposition proceeded. Separate design activity could be conducted for hardware and software sub-functions with the effects of schedule and resource interdependency reduced. This was a distinct advantage over a big bang approach.

These design activities proceeded in relative isolation as a result of the decomposition of the design and the definition of sub-function interfaces. Completion of sub-function design was evident with the completion of unit testing for the sub-function.

The advantages of a staged approach were also exploited the project task conducted by Knox (2005).

1.4. Aspects of Ethical Responsibility

The concept of Ethical responsibility has been applied in many professional endeavours for a long time. Most people at least aware of the centuries old Hippocratic oath and have an idea of it's impact on the medical profession. As time passed, many of the values and ideals which underpinned the concept of ethical responsibility had to be adapted to changing circumstances and technologies. As an example, the concept of bioethics did not have a notable impact until the 1960's. (Lozano, 2003)

Other professions where a sense of ethical responsibility has been developed include journalism, business science and research. Engineering is not alone.

Infamous examples of the failure of engineering as a profession to exercise ethical responsibility include the Challenger disaster and the Bhopal accident. This has led to leaders among the profession to adopt the approach ethical aspects of engineering practice are not only important but critical.

In practicing engineering at any level effort should be made to ensure the activity is performed with due respect to principles of human dignity, the environment and ethical behaviour. This project in is an engineering effort.

This project aimed to minimise any environmental impact by either careful selection of components which could potentially be recycled into other designs or simplification of the design to minimise construction. As an example, selection of a microcontroller was constrained to those types which can be flash programmed and hosted on a commercial off the shelf (COTS) evaluation board. This strategy avoided programming of single use devices, removed the need to manufacture a custom circuit board and enabled potential redeployment of the microcontroller and COTS evaluation board.

The risk Electromagnetic Interference as a result of poor EMI practices was managed in accordance with common design practices. These practices included design philosophies such as using only sufficiently high clock speeds and logic family components to accomplish the task and good circuit layout. Also the use of low as practical energy systems reduced consumption of power.

“Re-inventing the wheel” was deemed to be unnecessarily wasteful. Where a technique or finding has been previously explored, it would be unnecessary wasteful to replicate those conclusions unless some doubt is cast during execution. Similarly, unless information derived from this task is appropriately disseminated, subsequent project work conducted by other students will be at risk of replicating effort already expended here. For this reason adequate prior research was seen as a waste reduction strategy as was effective reporting of the results.

Consequential effects of this research were considered. It was difficult to pre-determine any potential impacts on fellow employees. The only possible impact considered was some minor degree of anxiety due to a resistance to change. The skill set required to draft in three dimensions are not yet strongly developed within the existing engineering teams and some resistance to acquiring these skills had already developed. This attitude has been underpinned with a record of successful performance of engineering activity without the use of advanced drafting techniques.

Another consequential effect was that on the customer. Under to the current contractual arrangement, the customer is able to exercise strong influence on how many aspects of engineering. Currently the customer believes that much of the legacy drawing cycle is an unnecessary expense and seeks reduce costs by eliminating drafting effort by increasing the use of written and verbal disclosure. In exercising this strategy, there have already been unsuccessful attempts to adequately describe conceptual designs using words-only disclosure. A strategy which seeks to return to a reliance on drafting would be likely to increase financial risk and hence customer anxiety.

If can be demonstrated that a three dimensional model of a complex object can be achieved inexpensively, then greater acceptance of three dimensional modeling of all mechanical design could be supported. As a consequence of this project, a company may be influenced to actually increase the rate of adoption of these techniques. This will place the company at odds with both the employees and the customer; making fellow engineers feel uncomfortable in doing tasks they believe are unnecessary and the customer believing he is paying too much for an engineering product.

Consequently, it would be prudent to engage both fellow engineers and the customer in the development of the project. By informing all parties and even have them participate, the potential outcomes of the task could become less threatening. This would also enable a sense of contribution to the organisational aims.

The instruments and techniques developed by this project may benefit persons engaged in the development of weapons for war. As “Warfare is inherently destructive of sustainability…”, any successful outcome would appear to be at odds with the peaceful aspect of sustainability. Conversely, It could be argued that an improvement in efficiency will reduce costs and may result in redeployment of public resources to other more peaceful uses. Also, historically many advances in peaceful science and engineering have been augmented by technologies spun from defence-initiated research.

Another potential ethical risk would be the potential for deliberate inaccurate disclosure by or knowingly take credit for others work. In the case of inaccurate disclosure, these risks will not be realised, as all academic citing will be conducted and raw data will be made available for review.

1.5. Dissertation Structure

This dissertation is broken into 6 Chapters. The first chapter aims to set the background of the task and define how the problem came to be.

Chapter 2 develops a Conceptual Design for the problem. This chapter explains some important background information and concepts required to understand the development of the solution. In this chapter the number systems and mathematics required to understand the problem are introduced. Chapter 2 also contains the Literature review which aims to look at how similar problems were solved.

Chapter 3 is solely devoted to the risk issues of the task. It is by nature linked to the aspects of ethical responsibility explained in Chapter 1 but is more specific to the defined physical risks associated with the task.

The detail design is disclosed in Chapter 4. This chapter works through each aspect of the design of both software and hardware.

Chapter 5 is discloses the results of subsystem and integration testing and Chapter 6 contains the conclusions and recommendations.

Chapter 2. Conceptual Design

2.1. Co-ordinate Systems

To describe a position of a point in three dimensional space a numerical language was needed. Two systems were studied, The Cartesian and cylindrical co-ordinate systems.

2.1.1. The Cartesian Co-Ordinate System

Cartesian co-ordinate systems are defined by three orthogonal axes x,y and z. these axes correspond with three physical dimensions of length, width and height.

Figure 2.1 shows two points plotted in a three-dimensional Cartesian coordinate system: P(3,0,5) and Q(−5,−5,7). The axes are conventionally drawn with the z axis upright. This is also known as the world co-ordinate system.

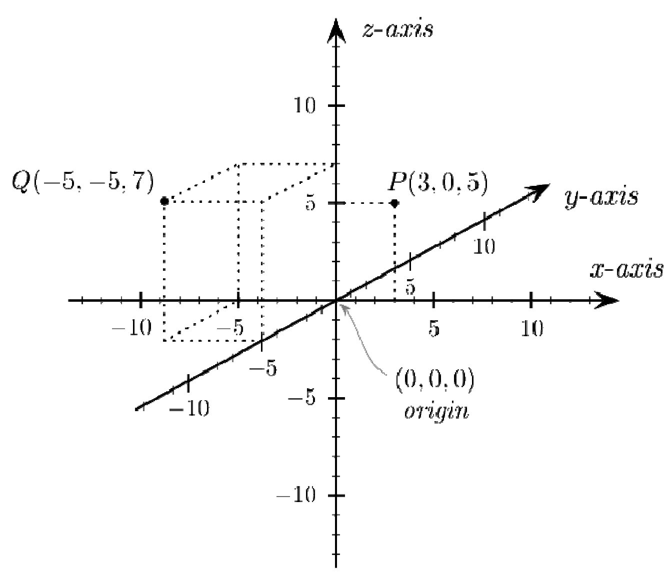

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Figure 2.1 Cartesian Co-ordinate System

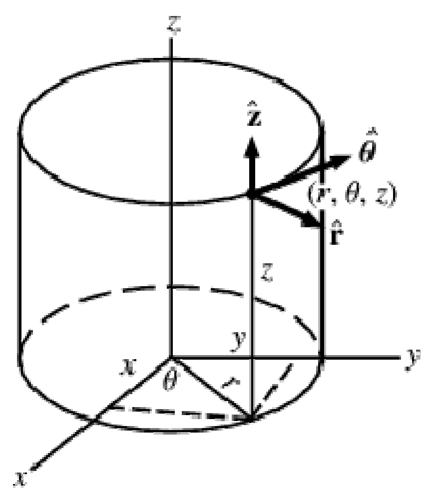
The displacement of a point in three dimensional space is can be represented by vector notation. In this case the x, y and z values are represented in terms of the unit basis vectors I, j and k.

$$\hat{r} = x\hat{i} + y\hat{j} + z\hat{k}$$

2.1.2. The Cylindrical Co-Ordinate System

The Cylindrical Co-Ordinate System was also studied as a candidate for describing the points in three dimensional space.

The cylindrical coordinate system is a three-dimensional coordinate system. This system relies on a definition in one plane, described by an angle and radius and the third dimension is disclosed by a height parameter above that plane. Thus point P is given by (r,θ,h).



Source: Wolfram Mathworld accessed www 26AUG07

Figure 2.2 Cylindrical Co-ordinate System

Figure 2.2 shows the arrangement of the Cylindrical co-ordinate system.

Thus, the conversion function f from cylindrical coordinates to Cartesian coordinates is:

$$f(x, y, z) = (r\cos\theta, r\sin\theta, h)$$

Similarly the vector form of the conversion is given by:

$$\begin{bmatrix} \hat{\rho} \\ \hat{\phi} \\ \hat{z} \end{bmatrix} = \begin{bmatrix} \cos\phi & \sin\phi & 0 \\ -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \hat{x} \\ \hat{y} \\ \hat{z} \end{bmatrix}$$

2.2. The Pinhole Camera

Light travels in straight lines. The simple concept of the pinhole camera has been used to teach this basic phenomenon in elementary physics courses and was also employed in developing an understanding of how the system would derive a measurement from an image. Figure 2.3 shows the relationship between an object in the real world and one in the two dimensional image. Note that for the purposes of this explanation the z axis is aligned to the optical axis.

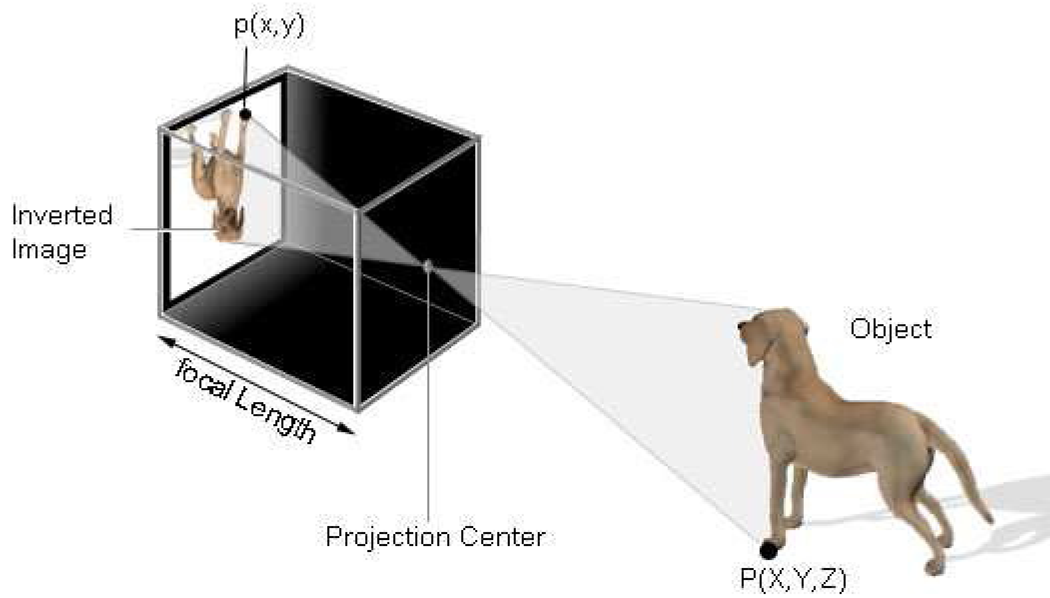
In this case the dog's foot at point P, can be described in the real word by the Cartesian co-ordinates P(X,Y,Z). The pinhole camera image is shows the dog is inverted and somewhat reduced in size. The location of the dog's foot in the image plane is described by p(x,y).

To derive the actual co-ordinate data the equation for the translation are:

$$x = \frac{Xf}{Z}$$

$$y = \frac{Yf}{Z}$$

where f is the effective focal distance of the camera.



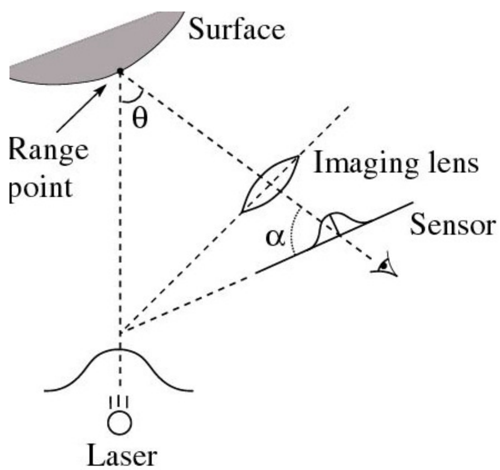
Source: (Entner, 2005)

Figure 2.3 Pinhole Camera Topology

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \frac{f}{Z} & 0 & 0 & 0 \\ 0 & \frac{f}{Z} & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

2.3. Triangulation

Having established a mathematical language to communicate position, the principle of operation was derived. Figure 2.4 shows a plan view of the basic Triangulation principle.



Source: (Curless, 1999)

Figure 2.4 Basic Triangulation Principle

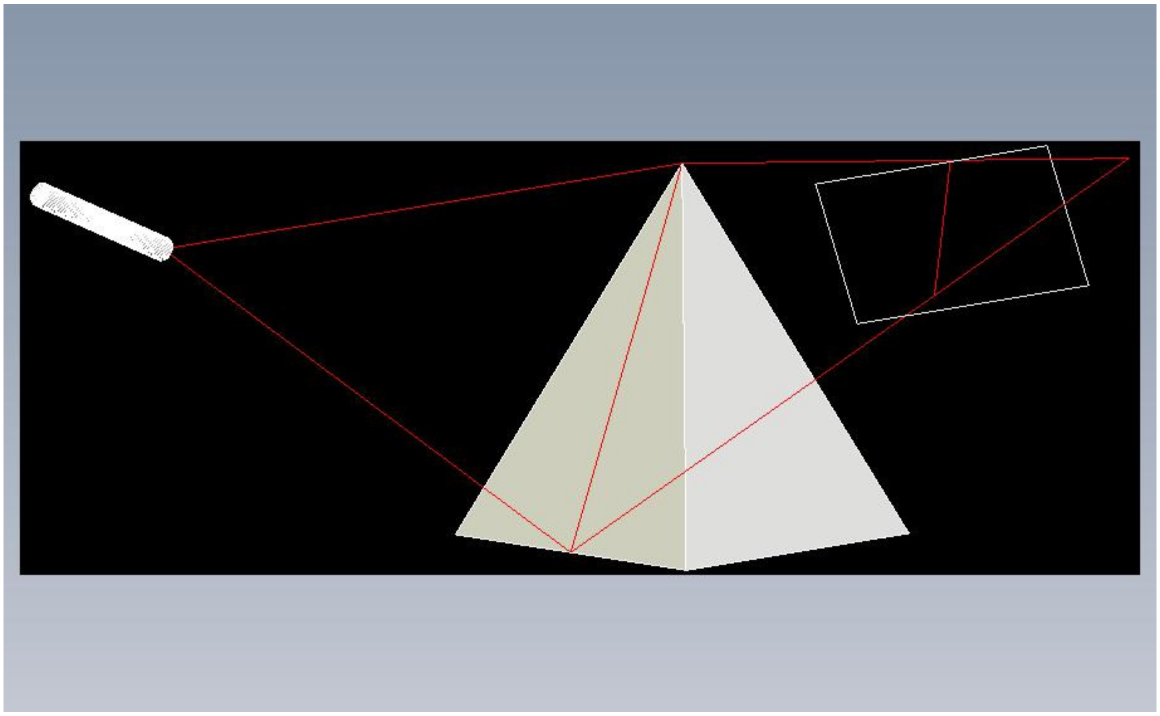


Figure 2.5 A Three Dimensional Extension of the Basic Triangulation Principle

First Impressions

The objective is to prove that an optical measurement and position control system can be implemented from cheap, readily available components and the use of such a system would reduce the time required to manually draft a 3D model.

The system must be able to recognize, manipulate and measure the object and then record the date in a manner suitable for entry into an external software application.

2.4. Relevant Literature

A library survey of techniques used to accurately measure position and displacement was conducted to see if any techniques could be useful in conducting the project.

As a significant portion of this task could be defined as a non-contact measurement of distance, previous works published in this area were sought. Chakravarthy et al., (2002) developed a method of measurement where a light source illuminated the surface of a liquid in the tank with a predefined pattern. The reflected light pattern was then captured by a CCD camera and analysed. The positions of the lines in the image plane varied with the position of the lines on the surface of the liquid. The relationship between the positions of the lines corresponded to a simple principle of perspective geometry. This relationship is used to accurately determine the depth of the liquid in the tank.

In order to determine distance, and hence depth of fluid in the tank, the images required processing. The steps used by Chakravarthy were:

(a) Thresholding: computation is reduced by converting the grayscale images into a 2 level binary image. The threshold is the value of grey which determines whether a pixel becomes black or white;

(b) Thinning: Thick multi-pixel lines are are thinned so that a single pixel line may be obtained. In this manner, the image is reduced to essential information; and

(c) Median Filtering: Artifacts from the process of thinning are produced. These artifacts are noise and are removed by the application of a median filter.

After the image was processed in the above manner the range was finally determined by averaging the coordinate of every point on the offset line. This final averaging was used to effectively remove distortion to the line caused by an irregular surface.

Other authors wrote of other techniques to speed up the computing process. Dias. et al.(2000) used a process called a Gaussian pyramid algorithm to speed-up computation. For the same reason that Chakravarthy employed thinning, the Gaussian pyramid algorithm was required to reduce the number of pixels manipulated without the loss of significant information from the image. Each pixel in one level of the pyramid is obtained by applying a mask to the group of pixels of the image directly below it. The mask is behaved as a low pass filter thus also smoothing the images and reducing the noise.

Lang (2000) successfully implemented a navigation system based on inexpensive CMOS cameras. Lang's method also cited the use of thresholding and edge detection to increase processing rates. Lang recommends further improvements in running time and memory requirements using code optimization techniques such as combining loops, reusing memory used for image calculations optimizing numerical representations using look-up tables. These may be effective areas for investigation in this project, should the processing speed be an issue.

In a similar ranging method to that used by Chakravarthy et al., (2002), Ming-Chih et. al (2006) projected two laser pointers onto one surface. These lasers were set up to produce a triangle, and the distance between the two points is related to distance by the following relationship:

$$\frac{D_K}{D_{\max}} = \frac{H_K}{H_{\max}}.$$

This can be illustrated by Figure 2.6.

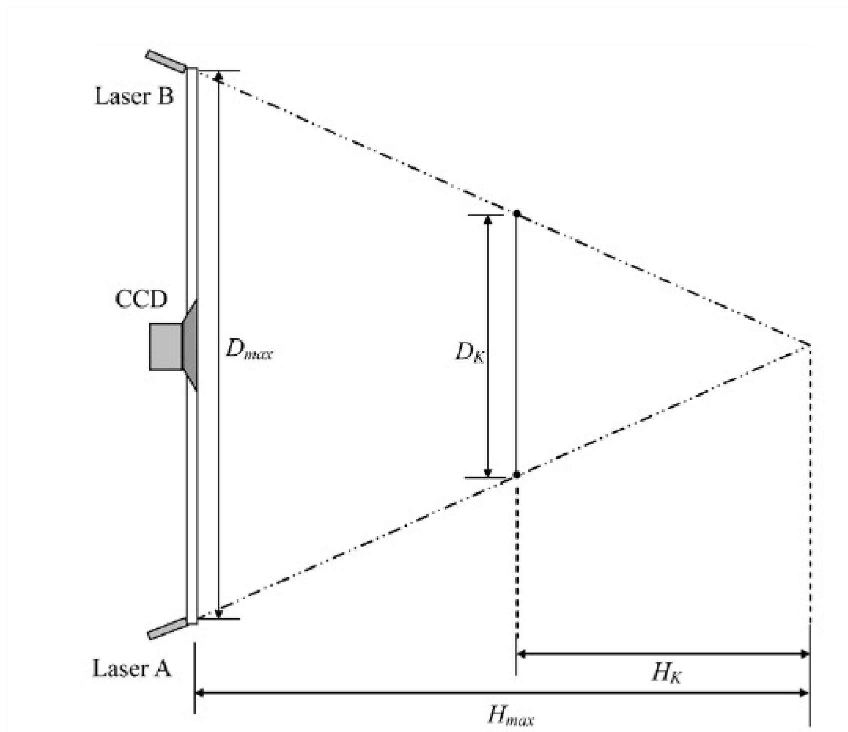


Figure 2.6 Triangle Method

This method, whilst simple requires the target object to present a relatively large surface parallel to the CCD image plane. That makes the image unsuitable for small or curved surfaces.

Noteably, Ming-Chih et. al (2006) was of the opinion that the method discussed in his paper, avoided the use of expensive high-speed DSP microprocessors or resource intensive pattern recognition algorithm to process pixels in an image. Rather Ming-Chih opted for simple circuits, geometrical relationships and counter circuits to determine distance.

Intuitively it would seem that the ultimate accuracy of the system may be limited by the resolution of the camera. An option was sought for improving the accuracy of the system to sub pixel uncertainty. Sandoz. et al. (2000) reported a highly accurate vision technique for position and displacement measurement of moving targets. Claimed uncertainties in the order of 10^{-2} pixels were reported.

This technique involved the use of a phase reference pattern, consisting of a pair of complementary strips, fitted to the object of interest and the whole scene is observed with a static camera. The strip sets correspond to a narrow spectral band in the spectral domain, and space-frequency analysis is performed through a wavelet transform. This analysis similar to the Image Pattern Recognition process described by Leis (2002).

In the method reported by Sandoz. et al. (2000), the analysis of the phase deviation corresponding to each strip set enabled determination of the strip centre and the determination of the object position to within less than a pixel in the recorded image. Displacements are computed from positions computed before and after the object motion. For measurement in two axes, two sets of strips would be fitted.

This technique whilst extremely promising in regards to improving the accuracy of a low resolution camera, would not be unsuitable for this project if the object was to be repeadedly manipulated to measure a new aspect. Each time the object was moved the reference strips would need to be reaffixed..

Another method of achieving sub-pixel uncertainty was briefly explained by Dias et al. (2000). In this approach, a quadratic interpolation was applied. Whilst this did not yield the accuracy of the Sandoz approach, an interpolative method is could seen as easier to implement.

Further reading was conducted to determine the effectiveness and usable techniques of vision-controlled robotic systems.

Dias. et al.(2000) published a report on their attempts to perform the pursuit of a moving target. In their work they used two visual-based control schemes. One was use of a “visual fixation control” and the other was a trajectory control system. In their implementation, the visual fixation control, by the vision system, continuously tracked the target providing information about its position. The system then uses the positional information as a feedback to maintain position with respect to a moving target.

Diaz made use of filtering and prediction methods to estimate the present and the future values of the target parameters of position, velocity and acceleration. The use of filters was particularly useful for compensation for the delays in the system. This conclusion was also reached by Lang (2000) in his paper on Visual Measurement of Orientation Error. Whilst these conclusions are valid for dynamic systems, filtering and prediction methods of the types discussed Diaz and Lang are probably unnecessary in a target that will be static during the position acquisition cycle.

Ellerton (2002), used an optical system to take cross-sectional measurements of dingo teeth. In this paper the process used a non structured light approach to measure the width of a dingo tooth silhouette. The tooth was then rotated and a tomagraphic model was produced, based on a series of tangential measurements.

Of particular interest of the Ellerton scheme was the use of a simple light source and an inexpensive Webcam as the optical sensor.

Also noted was the purpose built turntable arrangement, controlled from the parallel port.

An internet search was also conducted. A number of interesting options for range measurement were found. One scheme of note was that published on the internet by Danko (2003). In this scheme a laser diode is placed next to the Webcam. The boresight axis for both laser and camera are parallel to the target surface. The crux of this solution is the displacement of the image from the camera centre field of view as the target surface approaches the camera. This effect is exploited by developing a linear mathematical relationship between the pixel offset of the camera image and the distance to the camera. A calibration is used a line of best fit supplies function coefficients.

The major limitation of this method would be the need to scan the range sensor over the surface.

2.5. Design Requirements

To bound the design problem and begin the Project Methodology as defined in Chapter 1, a set of requirements were derived. As a starting point was decided that the prototype system should be:

a. able to support/manipulate an object of less than 5 kg in weight;
b. the physical size of the object shall fit in a cube with a side of 150mm;
c. the system shall be able to resolve the surface at a resolution of not less than 30mm; and
d. the system shall be portable.

2.6. Constraints and Alternatives

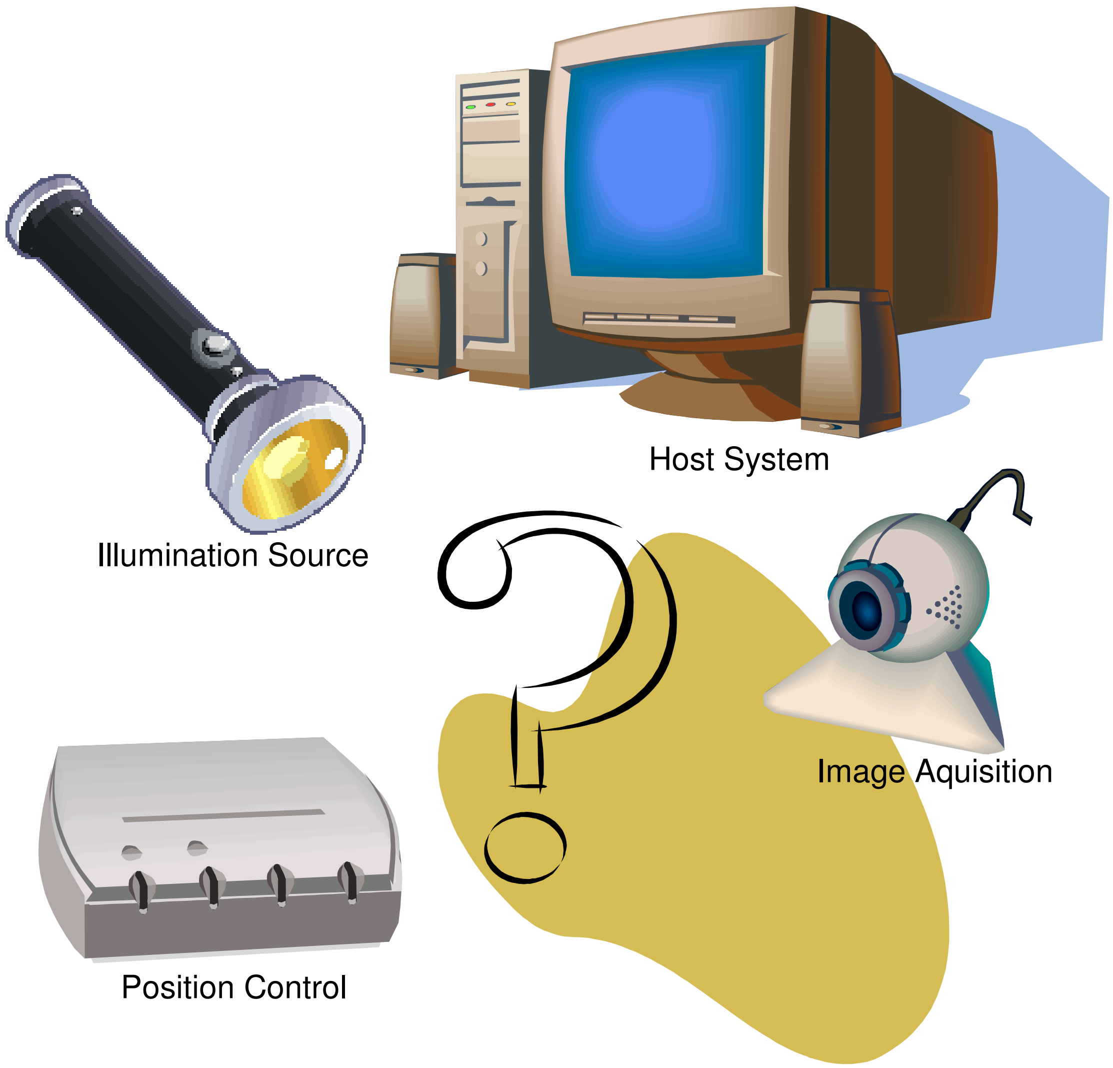


Figure 2.7 Common Topologies with Scanned

Most of the systems studied, exhibited a topology as similar to that shown in Figure 2.7.

In these systems the functional allocation was seen to be divided into four sub-systems:

a. position control system;
b. image acquisition system;
c. host or main control system; and
d. an illumination source.

2.6.3. Position Control System

The position control system is responsible for the orientation of the target with respect to the image acquisition system. A number of alternate methods were considered.

Servo based systems- particularly those which employed model aircraft servos, had been applied in mechanisms which left the target stationary and scanned the illumination source. In one particular solution examined, the position data was commanded from a host system using the serial communication port. This allowed the illumination system to be commanded to 1 in 256 positions within the 180 degree arc of rotation of the servo output shaft. A limitation of this system was the need to manually reposition the target to gather surface data for the rear of the object. This was seen as an unnecessary constraint.

Another position control system mounted the target directly onto the output shaft of a small stepper motor. The stepper motor control was accomplished using the parallel port to drive each phase of the stepper motor using a darlington driver to provide the necessary current gain. As the target was directly mounted in this system, a half-step drive scheme was adopted to give the system the necessary resolution.

Whilst this system was very successful, a number of constraints prevented a direct reimplementation of this scheme. Firstly, a self-imposed requirement for a load of 5 kg would place too much longitudinal load on the shaft of a device designed for radial loading. Also this mass would require a large amount of starting and holding torque to reposition. As a third constraint, use of the parallel port was considered undesirable as this port is obsolete in many computer systems.

The preferred technique used in this design was for the system use the serial or USB port, mount the target on a robust table and rotate the table using a reduction drive scheme.

2.6.4. Image Acquisition System

The function of the image acquisition system was to digitise the real image into a array suitable for processing. Two techniques considered were physical scanning of a sensor element and use of a solid state array sensor such as CMOS or Charge Coupled Device (CCD) typically used in digital cameras.

Physical scanning systems use simple sensors and mechanically scan the image. These systems use many moving parts and typically are not robust, do-not and difficult to align and synchronise.

The use of the solid state sensor –based system overcomes the issues of fragility and synchronization. By using this type of sensor pre-packaged in a camera, issues of design and construction are simplified.

At hand, prior to design of the system, was a Logitech Express Webcam. It uses a CMOS sensor and connected to the PC via the USB port. It was capable of a still shot with a resolution of 640 by 480 pixels, was manually focused and could stream video in near real time.

The use of a USB controlled webcam was selected on the basis of simplicity and cost.

2.6.5. Host Or Main Control System

There are three critical sub-functions to be performed by the Host or Main Control System. They are:

a. process the image

b. store the resultant data

c. control the sequence of operation of the system.

Only two options were considered.

A dedicated Digital Signal Processor could perform the image processing of the data stream and even store the resultant data for future use. This type of system would also prove portable due to small footprint and low power consumption. However the disadvantage of this system is the difficulty in providing a user interface and complexity in programming.

The other option considered was to use a PC to perform image processing, data storage and sequence control. The distinct advantage of this system was the ease at which a man-machine interface could be provided. Portability concerns are also easily addressed if a notebook form of PC was used.

As a result, a notebook computer was selected to perform the functions of the Host and Main Control System.

2.6.6. An Illumination Source

Illumination was required to enhance the contrast of the target's profile within the image. Three options were considered as the illumination source:

a. illuminated against a black background using simple white light;

b. illumination by a "half plane" of light using a slide projector; and

c. illumination with a focused monochromatic light.

Illumination using simple white light has been previously used with success in scanning dingo teeth (Ellerton, 2002). In this method a light source was used to contrast the object against a black background. This method, whilst simple and proven, was not implemented in this project as a black background was considered an unnecessary constraint.

Half-plane illumination places a contrast boundary onto the object to aide detection of the profile. This boundary is able to employ triangulation as it cuts the target at an angle to the direction of observation. This method was more desirable than the previous, as it did not constrain the system to dark background. It did have the significant disadvantage of requiring the use of a strong shaped light source such as a slide projector. Consequently this option would disadvantage the design in terms of portability.

It was seen that many of the range scanners analysed used laser illumination instead of incandescent or fluorescent light.

One principle reason for this was a laser devices ability to hold a focus for a distance. This provides distinct resolution and discrimination advantages, thus improving resolution of laser based systems.

Another reason was a low bandwidth. This property was reported to provide a high immunity to ambient light interference if the system employed high quality optical filters tuned to the wavelength of the laser used.

Finally, illumination with a focused monochromatic light was considered. In the most common form of this technique a common laser diode is used to provide a sharp contrast point on the surface of the target. Like half plane illumination, the method employs triangulation as the beam paints the target at an angle to the direction of observation. This method is compact and simple but has a requirement for reposition as only a small point is illuminated at each acquisition cycle. This characteristic can be overcome by ether adding a method of repositioning or reshaping the beam into a stripe to avoid additional mechanical complexity.

A laser diode, was selected based upon cost and availability. The point source was converted to a stripe to avoid the need to physically scan a point source up and down the target as it is rotated.

Chapter 3. Project Risk

The risk management process adopted by this project follows the methodology outlined in AS/NZS 4360:2004. Its main elements are shown in Table.3.1 below.

Hazard	**Risk/Consequence**	**Control**
Laser Radiation Exposure	Slight/minor injury	• Use of non-specular reflection • Aversion response due to wavelength • Use of class1 laser • Operator controlled environment.
Electric Shock	Extremely slight/ Possible death	• Designed to use plugpack/low voltages only. • Only serviceable equipment to be used in manufacture. • Only qualified personnel to manufacture. • Manufacturing instructions to be provided
Burns (soldering iron)	Extremely slight/ minor injury	• Only serviceable equipment to be used in manufacture. • Only qualified personnel to manufacture. • Manufacturing instructions to be provided

Hazard	Risk/Consequence	Control
Cuts from moving parts	Extremely slight/ minor injury	• Use of safety guards intrinsic safety • Only qualified personnel to operate. • Use minimal forces/velocities in mechanics
Poisoning (soldering)	Extremely slight/ minor injury	• Only qualified personnel to manufacture. • Manufacturing instructions to be provided • PPE to be used • Relevant Material Safety Data Sheets (MSDS) to be read and understood • Adequate disposal instructions
Injury to operator (RSI/posture)	Extremely slight/ minor injury	• Only qualified personnel to operate. • Adequate instructions (Warnings for excessive operation time) • Adequate ergonomics • Low glare monitors
Software not used for the purpose it was intended	Extremely slight/ major injury	• Only qualified personnel to operate. • Adequate instructions/ documentation • Password protection • Version control

Hazard	Risk/Consequence	Control

Table 3.1 Safety Assessment

Chapter 4. Detailed Design

4.1. Hardware Design and Implementation

4.1.1. Scanner control board

The Scanner Control System is required to perform the following functions:

a. turn the light source on and off

b. provide a heart-beat indicator to the user; and

c. provide the correct switching sequence for stepper motor operation.

The Scanner Control Board is based on an ATMEL AT90S8535 Microcontroller.

This microcontroller device is a CMOS 8-bit microcontroller based on the AVR Reduced Instruction Set (RISC) architecture. This device contained many features, including:

a. 8Kbytes of in system programmable Flash memory;

b. 512 bytes of both EEPROM and SRAM memory;

c. a programmable serial UART;

d. 8-channel 10-bit ADC; and

e. internal and external interrupts.

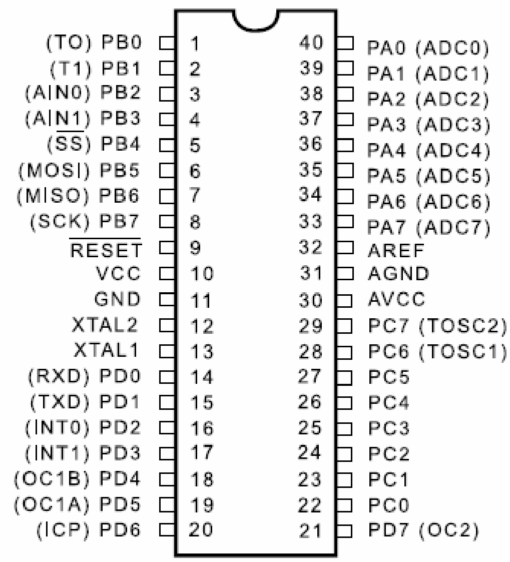


Figure 4.1 Pinout of the AT90S8535

Although the range of functions provided by this device far exceeded that which was anticipated by the early design scope, it was decided that the risk of unforeseen design changes would best be mitigated by selecting a more capable device outright.

The microcontroller is mounted on an STK 500 development board. This circuit board assembly was selected as it provides the ideal environment to prototype the system. The STK system is the recommended companion to the Studio 4 software which is also made by the microcontroller Original Equipment Manufacturer (OEM), ATMEL. This combination reduces project risk associated with incompatible software and hardware interfaces.

The STK 500 provides access to all ports through integral header pins. Also provided, is a bank of eight light emitting diodes and eight switches for hardware development. The UART can be accessed to by either direct connection off the board, from port D header connector or via a MAX 202 integrated circuit to the auxiliary 9 pin connector. The Max 202 changes the TTL levels of the microcontroller output port to those required to interface with the RS232 serial communication port of a Personal Computer.

In the initial implementation of this design it was decided to leave the microcontroller resident on the development system and develop the rest of the Scanner Board functionality as plug-in additions. There were a number of reasons for this decision.

Firstly, the development board was small and consumed little power. This meant the requirement for portability would not be compromised due to packaging and power supply size. Also, no significant advantage could be identified by producing a dedicated prototype circuit card if all necessary ports and peripherals could be easily accessed. In fact, more time resources could be spent on critical areas of the systems, rather than re-inventing that which was already provided.

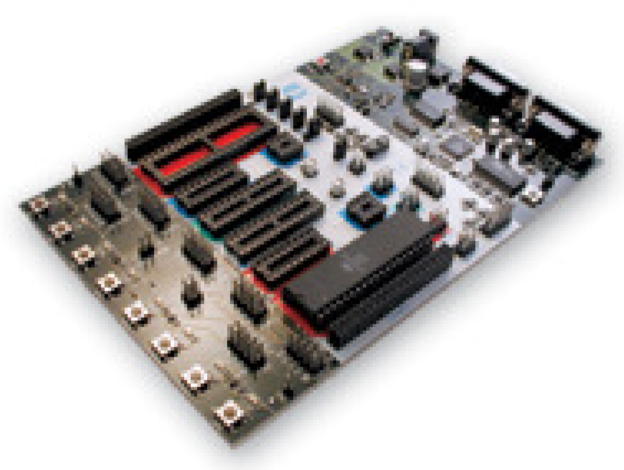


Figure 4.2 STK500 Development Board

Both manual and remote switching of the laser light source was provided by the system. This was accomplished by feeding a regulated 3 volt power source through a single pole double throw switch. With the switch in the remote position, the laser would be actuated by a relay controlled by port D pin 5. In the manual position the diode is fed directly from the power source. In the centre position the laser is off.

A heart beat function is also provided by the system. Port D pin 4 is strobed at a one cycle per second rate. The output of the microcontroller is capable of driving a LED directly but it was not recommended. Consequently, a transistor was provided for switching to aide microcontroller longetivity.

4.1.2. Step Motor Drive Board

A stepper motor consists of a strong permanent magnet shaped into a toothed rotor and a number of wire coils forming the stator. They deliver torque which has a tendency to diminish as shaft speed is increased. Due to the way they are actuated they divide a rotation into a number of discrete steps. They are widely used in printers, plotters and other consumer machinery and hence are readily available in discarded electronic goods.

The particular step motor used in this project was recycled from a spares box and an internet search based on the part number was unable to return useful design data. Labeling showed that the operating voltage for the motor was 10.9 volts and six wires presented a high probability that the motor was a four phase type. The output ports of the microcontroller were only marginally capable of driving a LED. Consequently, buffering and current drive functions must be provided to the system.

Some research was conducted on the internet and various flexible designs were considered. The final design developed for this project is best described as an amalgam of the designs seen.

Refer to the schematic shown in Figure 4.3 for an overview of the Step Motor Drive Board. The Step Motor Drive circuit is required to provide sufficient current to step a four phase step motor and isolate the microcontroller from the essentially inductive load.

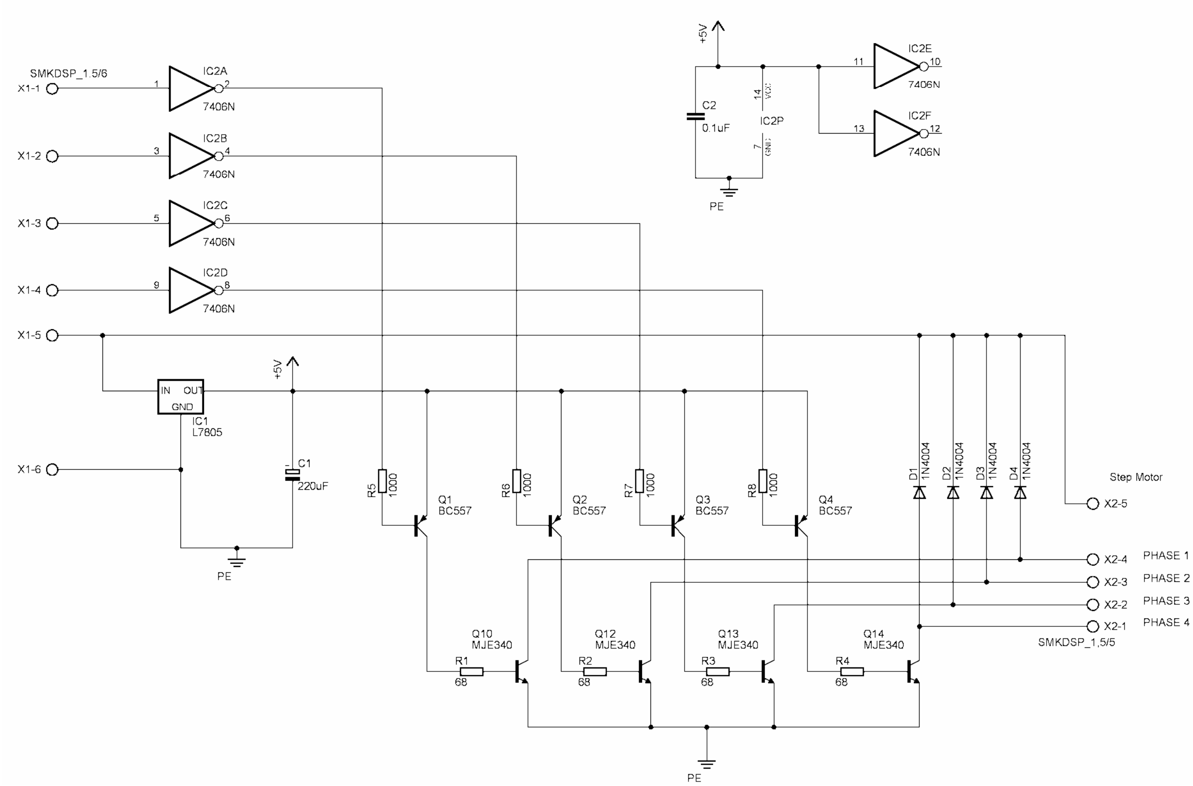


Figure 4.3 Step Motor Drive Board Schematic

The input to the Step Motor Drive Board is a 7406N inverter buffer. These gates are open collector type recommended for interfacing with high current loads. The purpose of this device is to provide the initial isolation of the microcontroller outputs from the load. This logic device operates from a 5 volt supply which is decoupled by C2. Unused gates in the device have been tied to logic high to avoid oscillation and excessive power consumption.

IC1 is a three pin voltage regulator which converts the input supply of 12 volts to 5.

Transistors Q1 to 4 are used to invert the signal and drive the output switches.

Q10, Q12, Q13 and Q14 act as switches for each phase of the stepper motor. Diodes D1 to D4 are used to suppress back EMF thus protecting the output switches.

The output connector was deliberately chosen as a screw type device. This allowed interchanging of the stepper motor leads during testing as the lead configuration could not be confirmed prior to assembly.

4.1.3. Turntable

The turntable is a 250mm custom built rotary table, designed to support in excess of 5 kg. The general arrangement of the turntable is shown in figure 4.4. The table is a disk of 2024-T3 aluminium, 6mm thick supported on a bearing system recycled from a discarded stepper motor.

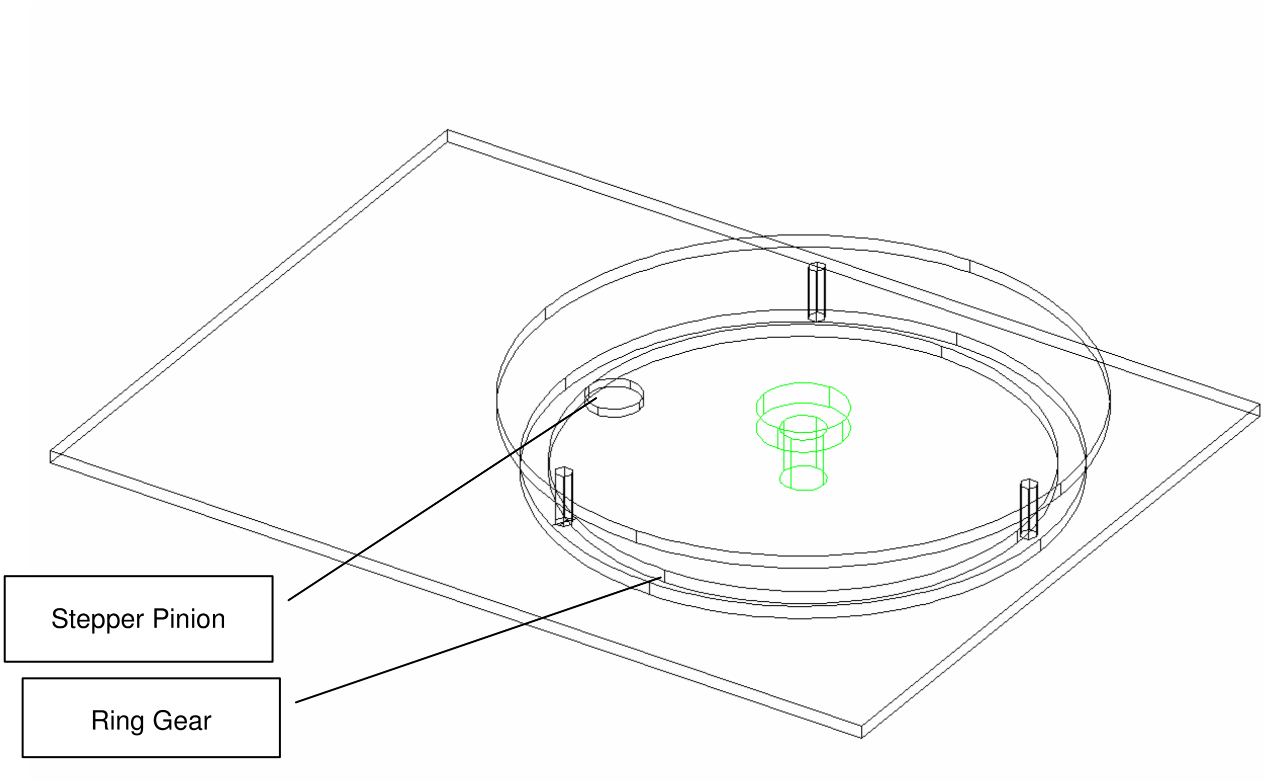


Figure 4.4 Turntable Assembly

Fixed to the underside of the table is a 215mm diameter ring gear, also recycled from obsolete aircraft components. Torque is transmitted from the ring gear to the turntable by 3 M4x20mm stainless steel hexagonal standoffs.

This ring gear is driven by a 25mm pinion which is directly coupled to the shaft of a bi-phase stepper motor scavenged from a discarded photocopier. The stepper has a resolution of 1.8^0/step and shaft input, actuated through the geared reduction, will yield a rotation of 0.2^0/step.

The whole turntable assembly is mounted on a 6mm thick baseplate of 2024-T3 aluminium. This baseplate is required to provide sufficient rigidity to the recycled flatbed scanner which is the base.

4.1.4. Optical Sensor

It was decided that a webcam would provide the optical sensor for the project. A Logitech Express webcam was used based primarily on availability and cost. This camera features:

a. CMOS sensor;

b. 640 x 480 pixel resolution;

c. 30 fps video;

d. manual focus; and

e. USB connectivity.

The Logitech camera is based on a CMOS sensor as opposed to the CCD devices used in many of the projects researched.

The CMOS sensor is much cheaper than CCD technology as the production process uses standard microprocessor technology. This has seen a reduction in cost of image sensors which are based on this technology.

A typical CMOS sensor consists of a number of transistors located on a photosite. These transistors amplify and transfer the charge produced by the photons. This allows the pixels to be read individually.

Unfortunately, CMOS image sensors operate at a lower gain and also produce more noise than a CCD imager. This often results in a poorer image quality.

A photosite measures intensity and cannot determine colour. To transduce a colour image a filter system is employed to discern the light into the three primary colours. The reconstruction of the image then becomes a process of recombining the three primary colour signals.

A colour filter array is used over each photosite. A common pattern of filters is the Bayer filter pattern. This pattern alternates a row of red and green filters with a row of blue and green filters. Due to the human eye having inconsistent sensitivity to each of these colours, the filter is characterised as having an uneven distribution of red green and blue.

Figure 4.5 Logitech Express Webcam

The video streaming feature of the camera could be employed during a focus cycle as the focus and alignment operations were conducted.

4.1.5. Light source

A laser diode-based laser pointer was used for the light source for the system.

The light source assembly was custom built for this project. The main component of the assembly is a modified class 2 red laser pointer.

Figure 4.6 Laser Pointer

The light source was a modified laser pointer. Modifications of the device included:

a. machining of the rear cap;

b. removal of the front cap; and

c. replacement of the batteries with a custom remote switchable power source.

To avoid the need for mechanical scanning a means of projecting a stripe was required. The normal output of the laser pointer was a slightly elliptical collimated beam.

Examination of other applications employing a laser stripe, showed most employed a special lens arrangement to form the circular beam into a stripe.

The modified laser diode was installed in an adjustable housing. This housing also has a specially-built lens assembly which converted the point source into a laser stripe.

4.2. Software Design and Implementation

4.2.6. Embedded Software Development

The embedded software was developed on the Studio 4 software supplied free from ATMEL. This software is a front end program for both C and the AVR family assembler. It is an Integrated Development Environment (IDE) which enables the designer to code, simulate debug and download from the one graphical interface.

The five stages of coding this microcontroller were:

a. determine the program interfaces;

b. design the program flow;

c. code the program in assembler;

d. simulate the program and debug; and

e. download the code to the device.

Program Interfaces

The first program interface specified was a simplex communication channel to the host system. The specification chosen was a 9600 baud rate, 1 stop and no parity bit. The protocol used was a simple “S” character to command a step, a “L” character to switch the laser.

The next interface defined was the scanner man machine interface. This interface consisted of output port pin used to interface with a simple LED circuit to give the instrument a heart beat. Similarly, control of the laser state was also accomplished with an output port pin.

Finally, and most crucially the interface to the stepmotor driver board used four output pins to drive the phases in the correct sequence.

Program flow

A strategy for handling the interfaces was determined prior to the initial flow chart development. As the simplex communication would involve an on-demand response from the system, it was decided to implement an interrupt-based rather than polled UART scheme. This allowed the laser switch function, and step functions to be part of the interrupt service routine and the heart beat indication would naturally be allocated to the normal wait loop. The resulting program flow chart is shown in Figure 4.7

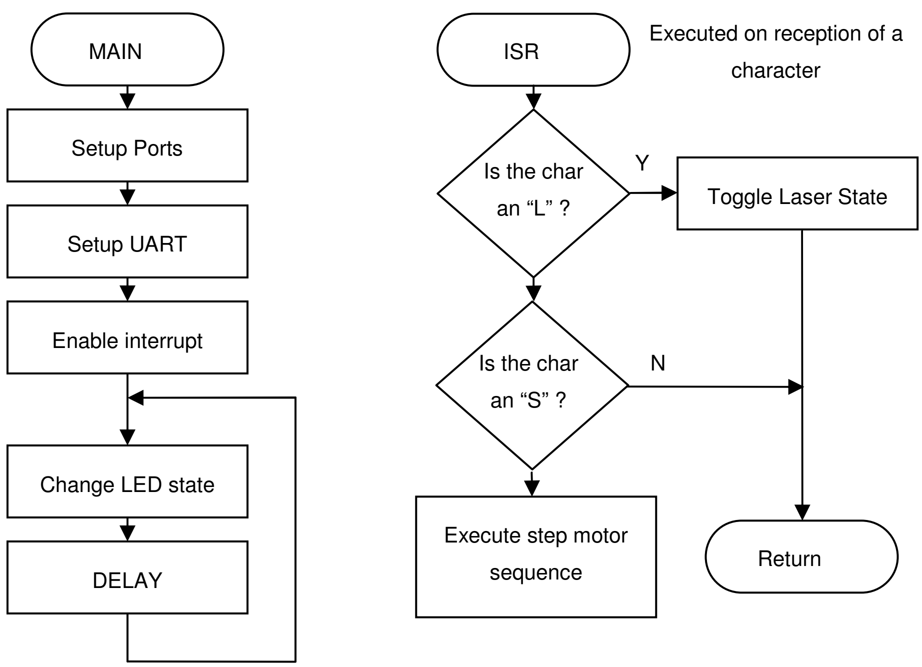


Figure 4.7 Embedded Software Flow

To drive a bi-phase stepper motor in a full step mode, a four byte sequence was implemented. Some memory was allocated and the required sequence was stored in what is referred to as a look-up table. This method was used to facilitate the future ability to step forward and backward in a partial cycle. This bidirectional step function was not yet implemented in the first incarnation of the project.

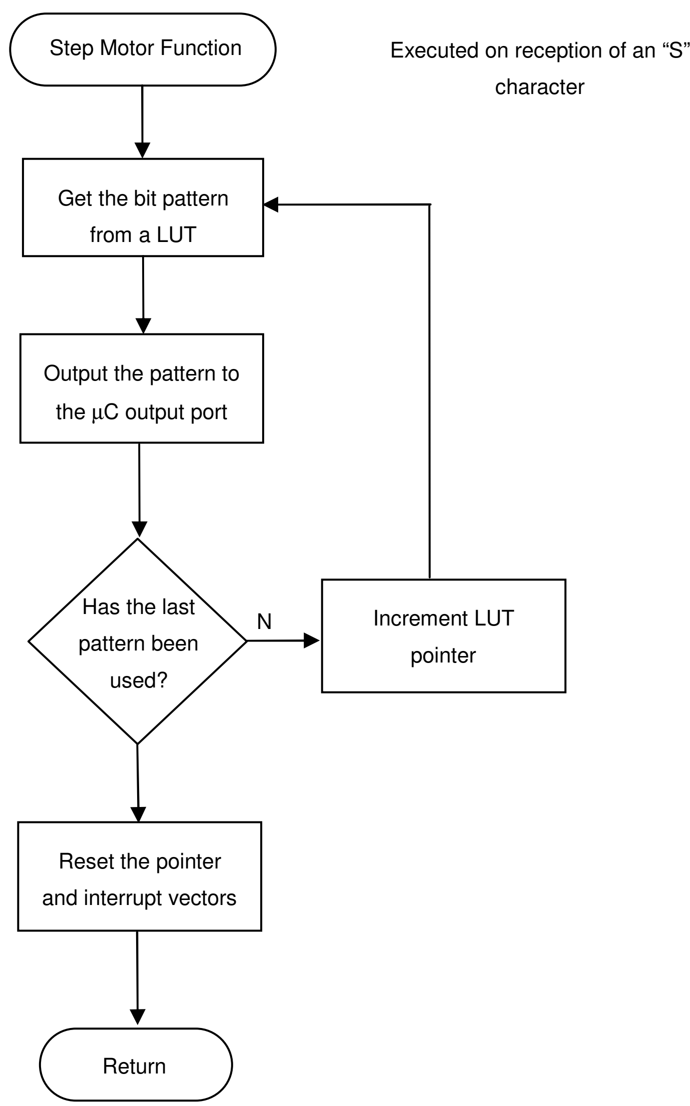


Figure 4.8 Step Motor Embedded Program Flow

Assembler Code

The above software flow was coded in AVR Assembly Language in accordance with the ATS90S8535 instruction set.

The resulting code listing is shown in Annex B.

Debugging the Firmware

The code built without errors and was the debugged with the Studio 4 simulator until expected operation was observed.

Download of code

On completion of the coding and debug cycles the code was down loaded into a ATS90S8535 microcontroller mounted in the STK500 development kit. LEDs were connected to the appropriate output ports, the secondary serial connection was setup and test stub software which could issue the necessary commands was executed. The result was the LEDs behaved as expected.

4.2.7. Host Software Development

The host software was developed on the Microsoft VisualBasic.net Express edition software supplied free from Microsoft. VisualBasic.net is an object-oriented computer language that has evolved from earlier versions of VB in an attempt to provide greater usage of the .NET framework.

Initially it was intended to use Visual Basic 6 in this project. By commencement of the task, that version was no longer supported. Unfortunately, the introduction of the new variant has not been without problems with backward compatibility, thus introducing a risk that some functions and libraries no longer exist or will not work in the new version.

This software is a provides another Integrated Development Environment (IDE) which enables the designer to code, simulate ,debug and deploy the finished code from the one graphical interface.

The six stages of coding the host software were:

a. determine the program interfaces;

b. design the form;

c. install the appropriate controls;

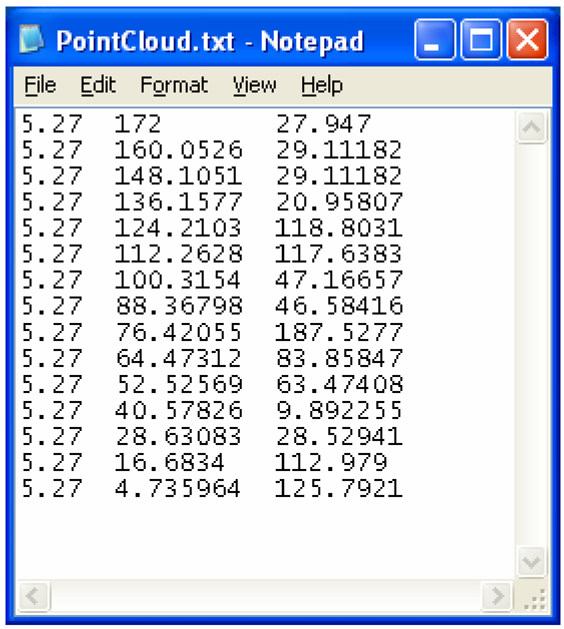
d. code the program modules;

e. simulate the program and debug; and

f. deploy the code.

The Host Program Interfaces

The host program interfaces were included a serial port to communicate with the instrument, a camera control to use the webcam to acquire the data, and a text file interface to write the data to an output record.


PointCloud.txt - Notepad

File Edit Format View Help

5.27	172	27.947
5.27	160.0526	29.11182
5.27	148.1051	29.11182
5.27	136.1577	20.95807
5.27	124.2103	118.8031
5.27	112.2628	117.6383
5.27	100.3154	47.16657
5.27	88.36798	46.58416
5.27	76.42055	187.5277
5.27	64.47312	83.85847
5.27	52.52569	63.47408
5.27	40.57826	9.892255
5.27	28.63083	28.52941
5.27	16.6834	112.979
5.27	4.735964	125.7921

Figure 4.9 Output Record Format

The output record is a space delimited text file called PointCloud.txt. A screenshot of the data is shown in Figure 4.9. The data is recorded as a 3 x n array of cylindrical co-ordinates with the first element being the angle in degrees, the second is the height and the third is the radius in millimeters. A text file was used to simplify the transfer of data to either Matlab or Autocad.

The serial communication specification previously chosen was a 9600 baud rate, 1 stop and no parity bit. The characters “S” and “L” would be transmitted in response to the host software cycle.

The webcam is connected to the PC via a USB port. Unlike the serial port, a camera API was used and all issues associated with communication to the camera could be handled through this interface.

Design of the Host Program Form

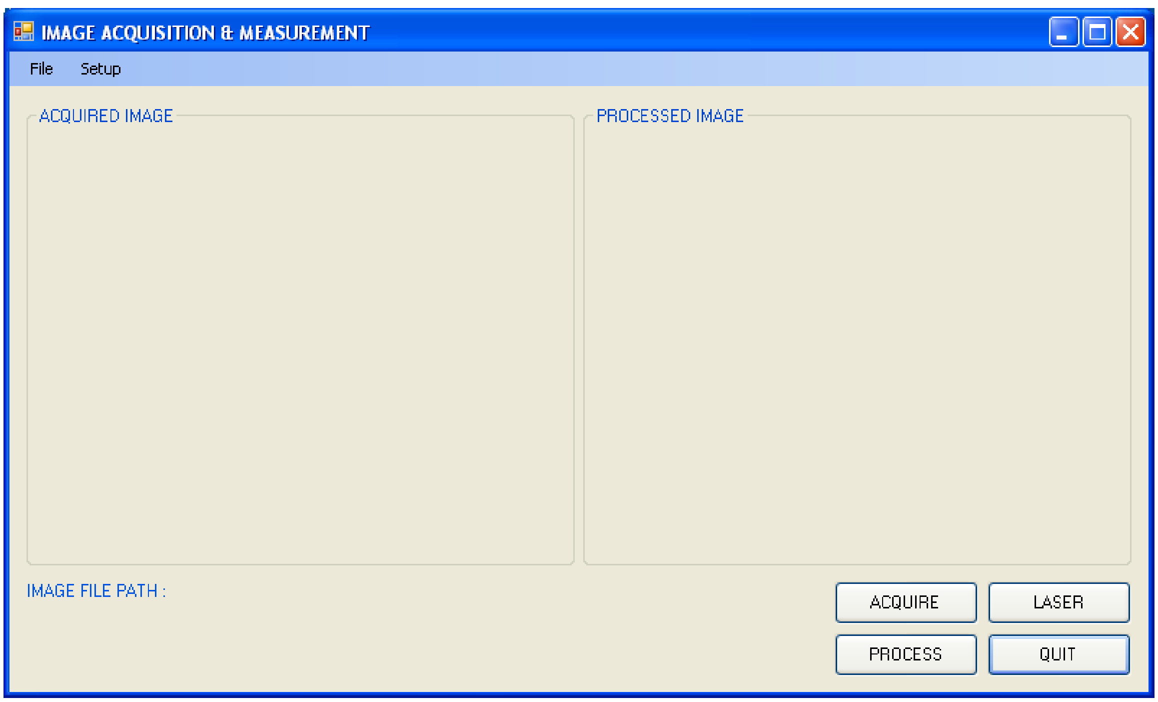


Figure 4.10 Main Form View

Figure 4.10 shows the screen shot of the main Host program form. The form was designed to have a similar operation to many windows graphic user interfaces. This strategy was adopted to minimise the learning time of any novice operator as the control would feel intuitive.

The frame on the left is the viewing pane for the acquired image. After pressing the acquire button at the bottom of the form, the array appears as a still picture.

Similarly, actuating the process button at the bottom of the form initiates the analysis and processing of the previously captured image, and displays it in the right hand viewing pane. It is after this cycle that the table position is incremented through the issue of a step command on the serial port.

The image displayed in this pane paints the detected pixel in yellow. This allows immediate determination of outlier data in the output file.

The Laser button issues a laser on/off command through the serial port.

The quit button exits the form.

Installation of Controls

The Microsoft Windows Image Acquisition (WIA) interface was used to access and control the Logitech camera. The WIA is both an API and a Device Driver Interface (DDI). The WIA API was used in this program to enumerate available image acquisition devices and create the connection. Once the connection was created data transfer was also accomplished using this interface.

The API also provided a useful means for notification for a variety of device events such as inadvertent disconnection.

The WIA DDI significantly reduced the amount of code a required compared to using the Logitech SDK.

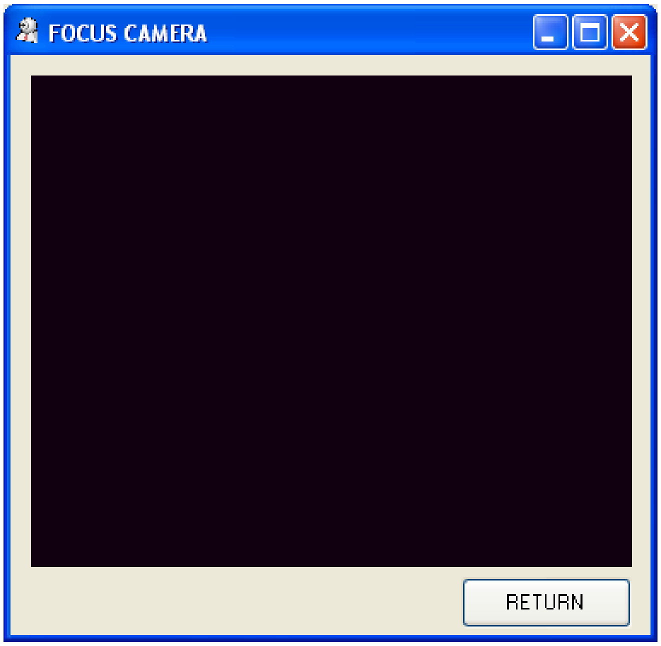


Figure 4.11 Camera Focus Dialog

Figure 4.11 shows the camera focus dialog was accessed from a drop down menu. Due to the nature of it's operation a real-time image capture is not shown. This function allowed the system to be manually focused by streaming webcam video to the pane in real time. The focus ring was then accomplished by rotating the lens ring for best picture. Camera alignment was also accomplished with the aid of this form. Clicking the return brought the operator back to the main form view. Failure to actuate the return button prior to an acquisition cycle would cause a software exception.

Deployment of the code.

A formal code deployment process was not conducted during this task. All execution runs were performed satisfactorily from within the design time mode.

Chapter 5. Analysis and Performance

Figure 5.1 General Setup of the System

The system was setup in as per figure 5.1. A notebook computer was used in lieu of the desktop PC to aid with portability. Minor changes were required in the host software to enable use with the differing port numbers.

A suitably sized object was selected and set-up on the table. The object used was a vase shaped object as shown in Figure 5.2.

Figure 5.2 Target Object

The system was setup to scan at a 20 pixel vertical resolution to reduce the output data size. The table rotation is hard coded to at 5.27^{o} of rotation per image.

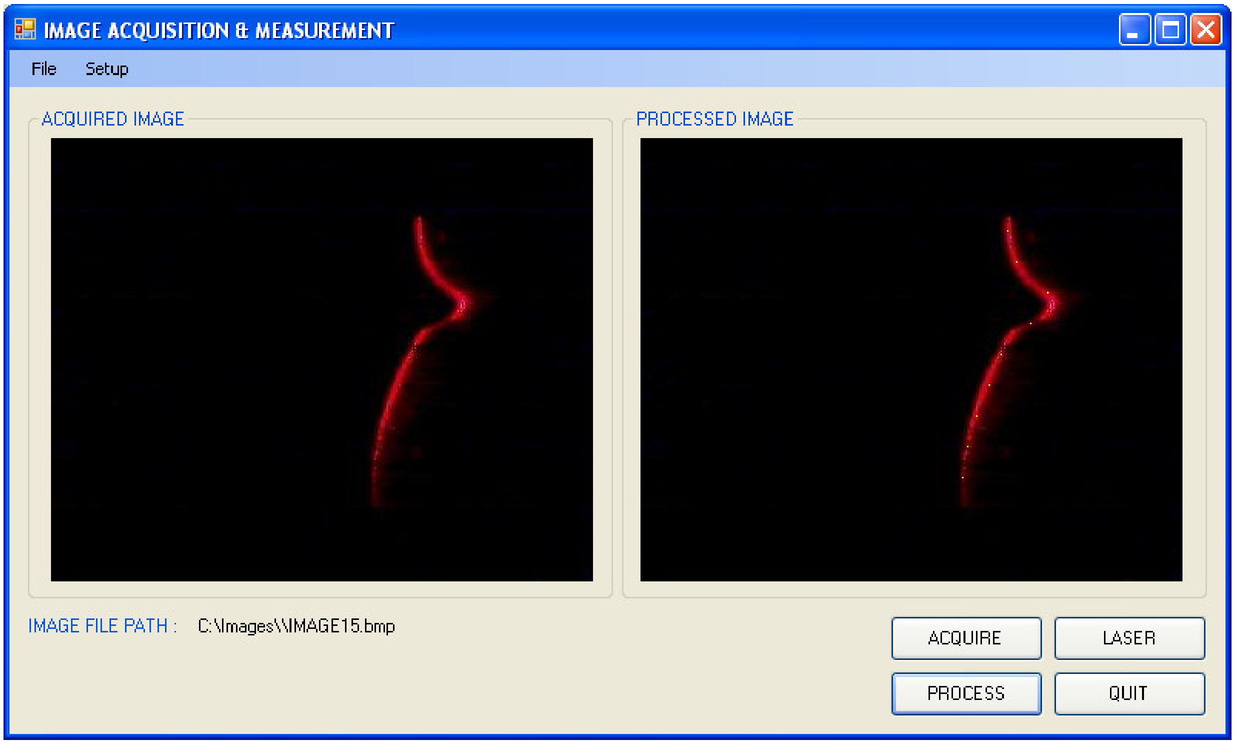


Figure 5.3 Example Data Run

Figure 5.3 shows a screen capture of the scan in progress. In the Acquired Image pane, the laser illumination of the object is shown. In the Processed Image pane the image shows where the pixel position has been detected by painting yellow dots. The effect of the red threshold setting of 20% is illustrated by the absence of any yellow artifacts in the top and bottom 40 pixels of the processed image.

Chapter 6. Conclusions and Recommendations

6.1. Achievement of the Project Specification Objectives

The task was planned and executed in accordance with the methodology outlined in Chapter 1. Documentation was conducted through this dissertation and project appreciation conducted in Semester 1.

Information on three dimensional modelling techniques was conducted. Sources of data were found in textbooks, journals and the internet. The details of this research and a critical evaluation were disclosed in the Relevant Literature section of Chapter 2.

Firmware was designed and coded for an ATMEL AT90S8535 in assembly language. The code was tested using a combination of the native simulator in the Studio 4 IDE and once downloaded, stub test software was written to verify operation in the STK500 development system.

Host system software was designed and coded using the Microsoft Visual Basic.net Express Edition. The use of the WIA application programming interface was used in preference to video OCX code implemented in previous Visual Basic 6 programs. Stub test code was also written to verify operation of the host software. Test data in the form of dummy images were created to assist in the development of the image processing code within the host system software.

Mechanical and electrical interfaces were designed, and a prototype system was built.

6.2. Limitations of the Project

The methodology employed by this design has a number of inherent limitations.

Firstly the scanning method chosen can only around object placed on the turntable. Consequently surface data for the top and bottom of the target object are not recorded.

The quality of the laser line image is adversely affected by the degree of specular reflection from the target object. It was observed that in the worst case, sufficient light could be reflected to cause host software to process an artifact in preference to the correct profile line. Such a condition induced gross errors and required manual intervention to remove the error from the data.

The system was unable to discriminate the difference between the bright red light of the laser stripe and bright ambient light. This was mitigated by covering the system with a cardboard box.

Lastly, the recycled ring gear and pinion arrangement suffered from backlash which could not be easily adjusted out. This backlash was measured at 85% of the total uncertainty at the circumference of the turntable.

6.3. Recommendations and Further Work

Constraints upon the design included time and money. Recommendations to improve this project will require the expenditure of both and may defeat the original intent of the task.

The image quality suffered due to the effects of noise. Some photo-astronomy user's of the Logitech camera have reported improved performance with the implementation of CMOS sensor cooling. This strategy adds to the complexity of the camera setup and increases the risk of failure. Alternatively, a reduction of image noise could be effected by simple substitution of the Logitech Webcam with a camera of better quality.

The location of the laser stripe on the target was relatively inaccurate. Image pre-processing techniques should be employed to more accurately locate the centriod of the laser stripe.

The mechanical coupling of the stepper to the table was accomplished using a recycled avionic ring gear. This arrangement exhibited significant backlash and would be difficult to source should another system be built. The use of a different transmission type such as a toothed polymer belt will improve backlash and hence accuracy.

The current stepper control algorithm completes five four step cycles, in one direction per commanded step. An improvement could be made to allow the system to respond to varying numbers of steps in both directions.

Communication with the host is accomplished with a simplex serial protocol. The incorporation of a duplex protocol would allow system self test functions to be incorporated as well as simple positional feedback.

The system could not measure surface on the top or bottom of the target. A system of position registration should be incorporated so the target could be tipped on it’s side so surface data for the top and bottom surfaces could be measured.

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Appendix A Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR	Bryan Patrick WALKER
TOPIC	**COST-EFFECTIVE 3D MODELLING**
SUPERVISOR	Prof. J. Billingsley
PROJECT AIM:	The aim of this project is to develop a method of generating a virtual 3 dimensional model of a small object using cheap and readily available components. The resulting data output from the system should be made suitable for use by common industry software such as MATLAB or Autocad to demonstrate usefulness of the design in areas such as virtual prototyping, non-contact metrology and artificial vision.
PROGRAMME:	Issue A 27 Mar 2007

1. Plan and document a small-scale project task.
2. Research information on 3 dimensional modelling techniques.
3. Critically evaluate alternatives for generating 3 dimensional models.
4. Simulate, where appropriate, subsystems to validate design decisions.
5. Design mechanical and electrical interfaces.
6. Design and code firmware.
7. Design and code host sytem in C++ and/or Visual Basic.
8. Construct a prototype system and evaluate against paragraph 3 of the Proposal Specification.

As time permits:

9. design and implement changes to improve performance of the prototype.

AGREED:

________________________ ________________________ STUDENT

________________________ ________________________ SUPERVISOR

Appendix B

SOFTWARE PROGRAM-

```
;****Laser_System************************************************************
;*
;* Title                              : Laser System Control
;* Version                            : 1.0
;* Last updated                       : 25/4/2007
;* Target                             : AT90S8535
;*
;* Support email              : bryanwalker@bigpond.com
;*
;* Code Size                  : 160 Bytes
;* Low Register Usage  : 0
;* High Register Usage : 4
;* Interrupt Usage            : UART Rx
;*
;* DESCRIPTION
;* This program enables RS232 control of the turntable using
;* memory byte by byte writing to port B.
;*
;******************************************************************************

.include "8535def.inc"
.device AT90S8535                          ; Specify device
.def    temp    =r16                  ; Define temporary variable
.def    Rxd_Char =r17
.def    temp_SREG =r18

.ORG $0000
;
; Reset- and Interrupt-vectors
;
   rjmp   Reset  ; Reset-vector

  .org $000b

   rjmp   URxAv  ; Uart Rx char available

;
; ************** Interrupt service routines ***************
;
; External Interrupt 0
;
IInt0:
   reti
```

```
;
; External Interrupt 1
;
IInt1:
   reti
;
; Timer/Counter 1, Capture event
;
TCpt1:
   reti
;
; Timer/Counter 1, Compare match interrupt A
;
TCmpA:
   reti
;
; Timer/Counter 1, Compare match interrupt B
;
TCmpB:
   reti
;
; Timer/Counter 1, Overflow interrupt
;
TOvf1:
   reti
;
; Timer/Counter 0, Overflow interrupt
;
TOvf0:
   reti
;
; SPI Serial Transfer Complete interrupt
;
SIStc:
   reti
;
; Uart Rx Complete Interrupt
;
URxAv:

               in              Rxd_Char, UDR
               ldi     temp, $90
               out     UCR, temp
```

```
                cpi             Rxd_Char,'L'
                brne    not_L

;---Laser Control----------------------------------------

                sbic    PORTB,5
                rjmp    bitset_b5
                sbi             PORTB,5
                rjmp    finish

bitset_b5:
                cbi             PORTB,5
                rjmp    finish
;-----------------------------------------------------------
not_L:
                cpi             Rxd_Char,'S'
                brne    finish
                rjmp    motor_step
finish:
                ldi     temp,$90                        ;Enable UART receiver and
                out UCR,temp                    ;Rx Interrupt
                reti
;
; Uart Data register empty interrupt
;
UTxDe:
   reti
;
; Uart Tx complete interrupt
;
UTxCp:
   reti
;
; Analog comparator interrupt
;
AnaCp:
   reti
;
; **************** End of interrupt service routines ***********

;Step motor lookup table
stepper_lut:
```

```
.db     0x09,0x05,0x06,0x0A
.db             0x00,0x00

.cseg

Reset:  ldi     temp,low(RAMEND)
                out     SPL,temp                        ; Set stack pointer to last internal RAM
location
                ldi     temp,high(RAMEND)
                out     SPH,temp

                ldi     temp,$3f
                out     PORTB,temp                      ; Set lower 4 pins at port B high
                out     DDRB,temp                       ; Set port B as output

                ldi     temp,$17                        ; Set UART to 9600bd
                out     UBRR,temp

                ldi     temp,$90                        ; Enable UART receiver and Rx Interrupt
                out UCR,temp

                ldi     temp,$00                        ; disable Watchdog Timer
                out WDTCR,temp
                out ACSR,temp
                sei                                             ;global interrupt enable

; Load the address of Step Motor Look-up table into the Z register.

                ldi             ZH,high(stepper_lut<<1)         ;Load high part of byte address
into ZH
                ldi             ZL,low(stepper_lut<<1) ;Load low part of byte address into ZL

wait_loop:

                sbic    PORTB,4
                rjmp    bitset_b4
                sbi             PORTB,4
                rcall   one_sec_delay

bitset_b4:
                cbi             PORTB,4

                rcall   one_sec_delay
                rjmp    wait_loop
```

```
motor_step:
        lpm                             ; Load byte from program memory into r0
        tst     r0                      ; Check if we've reached the end of the message
        breq    recycle         ; If so, quit

        ;com r0
        out     PORTB,r0                ; Put the character onto Port B
        rcall one_sec_delay     ; A short delay

        adiw ZL,1                       ; Increase Z registers
        rjmp motor_step
recycle:
        subi ZL,4
        ldi     temp,$90                ; Enable UART receiver and Rx Interrupt
        out UCR,temp
        sei
        ret

one_sec_delay:
        ldi     r20, 10
        ldi     r21, 255
        ldi     r22, 255

delay:
        dec     r22
        brne    delay
        dec     r21
        brne    delay
        dec     r20
        brne    delay
        nop
        ret
;-------------------------------------------------------------------------
```

C:\Documents and Settings\HP_Owner\My Documents\Visual Studio 2005\Projects\USQ Project\USQ Project\bin\Debug

```
Public Class MainDisplay
    Private SelectedDevice As WIA.Device
    Private SavePath As String
    Private SavedFilePath As String
    Private Counter As Integer 'counter in loop appended to filename

    Private Sub frmMain_Load(ByVal sender As System.Object, ByVal e As System.EventArgs)
 Handles MyBase.Load
        GetDevice() 'gets device
        SavePath = "C:\Images\"
        'SavePath = Application.StartupPath 'sets savepath to application directory
    End Sub

    Private Sub GetDevice()
        Dim MyDevice As WIA.Device

        Dim MyDialog As New WIA.CommonDialogClass
        Try

            MyDevice = MyDialog.ShowSelectDevice(WIA.WiaDeviceType.VideoDeviceType, False,
 True)
            If Not MyDevice Is Nothing Then

                SelectedDevice = MyDevice

            End If
        Catch ex As System.Exception
            MessageBox.Show("Problem! " & ex.Message, "Problem Loading Device",
 MessageBoxButtons.OK, MessageBoxIcon.Warning, MessageBoxDefaultButton.Button1,
 MessageBoxOptions.DefaultDesktopOnly)

        End Try
    End Sub

    Private Sub cmdExit_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
 Handles cmdExit.Click

        End
    End Sub

    Public Sub New()

        ' This call is required by the Windows Form Designer.
        InitializeComponent()
        ' Add any initialization after the InitializeComponent() call.

    End Sub

    Private Sub cmdAcquire_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
 Handles Button1.Click
        Dim item As WIA.Item
        Try
            'executes the device's TakePicture command
            item = SelectedDevice.ExecuteCommand(WIA.CommandID.wiaCommandTakePicture)
        Catch ex As System.Exception
            MessageBox.Show("Problem Taking Picture. Please make sure that the camera is
 plugged in and is not in use by another application. " & vbCrLf & "Extra Info:" & ex.Message,
 "Problem Grabbing Picture", MessageBoxButtons.OK, MessageBoxIcon.Warning,
 MessageBoxDefaultButton.Button1, MessageBoxOptions.DefaultDesktopOnly)
            Exit Sub
        End Try
        Dim bmpGuid As String
        'retrieves bmpKey from registry, used in saving BMP
        Dim bmpKey As Microsoft.Win32.RegistryKey =
 Microsoft.Win32.Registry.ClassesRoot.OpenSubKey("CLSID\{D2923B86-15F1-46FF-A19A-
 DE825F919576}\SupportedExtension\.bmp")
        bmpGuid = CType(bmpKey.GetValue("FormatGUID"), String)
```

```
        'loops through available formats for the captured item, looking for the BMP format
        For Each format As String In item.Formats
            If (format = bmpGuid) Then
                'transfers image to an imagefile object
                Dim imagefile As WIA.ImageFile = CType(item.Transfer(format), WIA.ImageFile)
                Dim LoopAgain As Boolean = True
                'searches directory, gets next available picture name
                Do Until LoopAgain = False
                Dim Filename As String = SavePath & "\" & "IMAGE" & Counter.ToString & ".bmp"

                    'if file doesnt exist, save the file
                    If Not System.IO.File.Exists(Filename) Then
                        SavedFilePath = Filename
                        imagefile.SaveFile(Filename) 'saves file to disk
                        Label3.Text = FormatPath(Filename)
                        picCap1.Image = Image.FromFile(Filename) 'loads captured file to
picturebox
                        LoopAgain = False
                    End If
                    Counter = Counter + 1
                Loop
            End If
        Next

    End Sub

    Private Function FormatPath(ByVal FilePath As String) As String
        'procedure formats the label displaying the save path. If over a 50 characters, parses
string
        'in order to fit nicely inside the label
        If Len(FilePath) > 50 Then
            Dim MyNewString As String = Strings.Left(FilePath, 15) & " ... " &
Strings.Right(FilePath, 30)
            Return MyNewString
        Else
            Return FilePath
        End If
    End Function

    Private Sub FOCUSToolStripMenuItem_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles FOCUSToolStripMenuItem.Click

    End Sub

    Private Sub FOCUSCAMERAToolStripMenuItem_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles FOCUSCAMERAToolStripMenuItem.Click
        FocusDisplay.Show()
    End Sub

    Public Sub btnProcess_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btnProcess.Click
        Dim xmax As Integer
        Dim ymax As Integer
        Dim x As Integer
        Dim y As Integer
        Dim max_r, max_c As Integer
        Counter = Counter - 1
        Dim max_red As Integer
        Const c_RedThreshold As Single = 100

        Dim Filename As String = SavePath & "\" & "IMAGE" & Counter.ToString & ".bmp"

        Try
            Dim bm As Bitmap = CType(Image.FromFile(Filename), Bitmap)
            xmax = bm.Width - 1
            ymax = bm.Height - 1
            Dim ThisRed As Integer

            ' Convert the pixels.
            ProgressForm.Show()
```

```
            For y = 0 To ymax Step 20
                For x = 0 To xmax Step 1
                    ' Convert this pixel.
                    With bm.GetPixel(x, y)

                        ThisRed = bm.GetPixel(x, y).R
                        If ThisRed > max_red Then
                            max_red = ThisRed
                            max_r = y
                            max_c = x
                        End If

                    End With

                Next x

                If max_red > c_RedThreshold Then

                    bm.SetPixel(max_c, y, Color.Yellow)
                    myTextOut(y, max_c)
                Else

                End If
                max_red = 0
                max_c = 0
                Call IncreaseProgressBar(ymax)

            Next y

            ProgressForm.Hide()

            ' Display the results.
            picCap2.Image = bm
            mySerialOut() 'increment serial port

        Catch ex As System.Exception
            MessageBox.Show("ACQUIRED IMAGE CANNOT BE FOUND. " & vbCrLf & "Extra Info:" &
ex.Message, "ANALYSIS FAILURE", MessageBoxButtons.OK, MessageBoxIcon.Error,
MessageBoxDefaultButton.Button1, MessageBoxOptions.DefaultDesktopOnly)

            Exit Sub
        End Try
    End Sub

    Private Sub mySerialOut()
        'send a character out of com4 at 9600bd
        Using comPort As SerialPort = My.Computer.Ports.OpenSerialPort("COM5", 9600)
            comPort.DtrEnable = True
            comPort.Write("S")
            comPort.Close()
        End Using
    End Sub

    Private Sub myTextOut(ByVal y As Integer, ByVal max_c As Integer)


        Const c_heightcal As Single = 1.674
        Const c_radiuscal As Single = 1.717
        Const c_anglecal As Single = 5.27
        Dim Height As Single
        Dim Radius As Single
        Dim Counter2 As Single

        Height = 172 - y / c_heightcal
        Radius = 205 - max_c / c_radiuscal

        Dim dataPoint As String
        Counter2 = Counter * c_anglecal
        dataPoint = Counter2.ToString & "   " & Height & "   " & Radius & vbCrLf

        My.Computer.FileSystem.WriteAllText _
```

```
        ("C:\Images\PointCloud.txt", dataPoint, True)

    End Sub

    Private Sub btnLaser_Click(ByVal sender As System.Object, ByVal e As System.EventArgs)
Handles btnLaser.Click

        'send a character out of com4 at 9600bd
        Using comPort As SerialPort = My.Computer.Ports.OpenSerialPort("COM5", 9600)
            comPort.DtrEnable = True
            comPort.Write("L")
            comPort.Close()
        End Using


    End Sub

End Class
```