CHAPTER NO.1

1.0 INTRODUCTION

1.1 3D RANGING

A range-imaging sensor is any combination of hardware and software capable of producing a range image of a real world scene under appropriate operating condition. A rang image is a large collection of distance measurements from a known reference coordinate system to surface points on objects on the scene. Range map is also called depth-map, 3D-map, surface profile, contour-map and surface height map.

Such devices can be used in a large wide variety of application including machine vision, automatic cartography, robot navigation, inspection, shape acquisition, robotic assembly and medical diagnosis etc. Machine vision as a discipline and technology owes its creation development and growth to digital computers. Without computers machine vision is not possible. The main objective of machine vision is to extract information useful for performing some task from various forms of image inputs. For many applications three-dimensional (3D) descriptors of the scene are required. Conventional cameras capture 2D images and computational approaches are needed to infer the 3D descriptors from one or more images. Common approaches for this include the use of two or more cameras in binocular and photometric stereo. Approaches using single images include various techniques e.g. shading, texture, shadows, and motion techniques.

The above approaches share one very important common feature. They are all passive approaches i.e. they do not need a special source of energy to illuminate the scene. There are obvious advantages of this approach e.g. cost, simplicity of imaging hardware, compatibility with human visual processes etc. On the other hand these approaches need to also overcome some inherent challenges. These challenges arise from the loss of information i.e. inaccuracy in results. Challenges that face machine vision researchers are to increase the depth accuracy, noise immunity, input inflexibility and the speed. In some sense the advantages of simpler and low cost acquisition hardware is compensated with the need for sophisticated computational processing and analysis approaches.

Active approaches for 3D vision use specialized illumination sources and detectors. These techniques overcome the fundamental ambiguities associated with passive approaches. Some active techniques use laser radar whereas some use various forms of structured lighting. In general these methods are able to eliminate the ill-posed problems associated with passive approaches by modeling and observing the projected illumination. In the case of laser radar, a spot laser beam is steered across a scene. Range measurements are made by either AM or FM detection schemes. Structured Light techniques model the optical paths associated with emission and detection to compute range data by triangulation. Structured Light ranging has some particularly attractive features compared to laser radar approaches. Structured Light systems provide significant advantages for customizing the acquisition capabilities of a sensor for a particular application. Generally speaking Structured Light sensors are also more accurate and can be made more rugged and less expensively than laser radar devices.

In our project we will be using single-line light as our structured light. And the image-capture device will capture the image send it to the processor to extract the 3D coordinates from the series of images.

1.2 METHODS FOR DEPTH EXTRACTION

Range sensing techniques can be classified into two broad categories:

- **Active Technique**: uses active source of light

- **Passive Technique**: do not use active source

1.2.1 Active Methods

1.2.1.1 Structured Light Approach

The controlled lighting pattern is used and the projection/image is used to derive the depth from triangulation.

Advantage:

- Simplicity
- Low cost compared to radar
- Better accuracy
- Easy calibration for accuracy

Disadvantage

- Not suited in hostile environment

1.2.1.2 Direct range finder

Use radar to find ranges by time of flight.

Advantage

- Good accuracy
- Very less processing required

Disadvantage

- Costly
- Complex
- Lasers are hazardous to us

1.2.2 Passive Methods

1.2.2.1 Shape from shadow

Gray level in image along with information of light and surface reflectivity utilized to get ranges

Advantage:

- Simplicity

Disadvantage:

- More errors due to assumption of uniform reflectivity

1.2.2.2 Binocular Stereo Approach

Uses disparity images from left and right eyes to find ranges.

Advantage

- Wide coverage
- Less expensive

Disadvantage

- Relies on surface details
- Lengthy computation
- Not very refine depths

1.3 STRUCTURED LIGHT DEPTH EXTRACTION

Structured Light sensing is a well-established technique for ranging. A great variety of techniques in this general area have been developed. The common thread of all these approaches is the underlying use of triangulation. This ranging geometry can be seen in Figure1, which depicts the optical components in our built project. Here the laser is projected downward towards objects in the scene. Laser illumination striking an object is observed by the camera to reveal surface profiles, which can be converted into Cartesian range data.

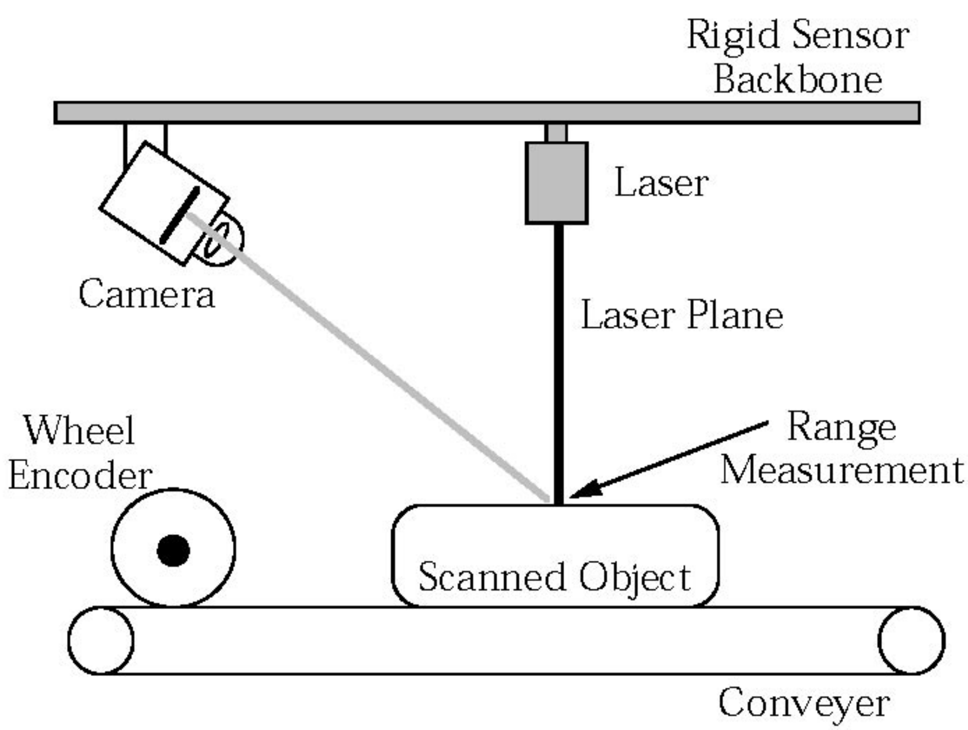


Figure 1.1

Structured Light systems use triangulation to acquire range measurements. The ranging geometry is formed by a laser emission. the reflected light observed by the camera and by a rigid backbone. A conveyer produces the necessary motion for 3D range data

1.4 APPLICATIONS OF 3D DEPTH EXTRACTOR

Many people still wonder that what might be the applications of 3D scanners. Such devices can be used in a large wide variety of application including machine vision, medical diagnosis etc. Typical applications include

- Animation, Gaming
- 3D Movies
- Virtual Reality
- Reverse Engineering
- Non-Contact Inspection
- Museums, Archeologists, Insurance (the acquisition of Cultural Heritage artifacts)
- Machine vision
- Robot guidance and controls
- Object orientation
- Medical Diagnosis

1.5 EQUIPMENT USED IN MAKING THIS PROJECT

To build this 3D profile scanner we needed the following equipment and tools

- A laser source, to provide a light source.
- A cylindrical lens, to convert spot to line source.
- A video capturing device/camera, to capture images.
- A stepper motor, to rotate belt.
- A conveyer belt, to move the platform horizontally.
- An electric circuit, for laser switching and motor driving.
- MATLAB data acquisition tool, for data acquisition and control of circuit.
- MATLAB Image processing tool, for image processing and displaying.
- MATLAB GUI for application program software.

1.6 ORGANIZATION OF THIS DOCUMENT

This document is organized into four more chapters. Brief description of each chapter is as follows;

Chapter 2 gives a brief review of literature studied before going on the practical side of the project. To study the theory of every component before integrating that hardware component was very important. This chapter will give a brief description on laser, stepper motor, camera, and image processing and image recognition.
Chapter 3 discusses and analyzes the reason that why we have chosen a particular equipment or algorithm amongst different available choices. We have discussed why we have given priority to analogue camera over digital camera, why median filter was chosen instead of mean filter to remove noise and so on.

Chapter 4 covers the procedural approach toward the project development. We have discussed the design and implementation of the 3D scanner by illustrating its block diagram and analyzing the circuit diagram and flow diagrams.

Chapter 5 concludes our project documentation by presenting the obtained results, discussing the fundamental limitations on obtaining results, and suggestions for further improving this project for next classes.

CHAPTER NO.2

2.0 LITRATURE REVIEW

2.1 INTRODUCTION

For the completion of our project detail study in certain fields were required, these fields are:

2.2 LASER

The invention of the LASER is one of the most significant developments in science and engineering. To enable us to understand and appreciate the operation of this unique device requires an understanding of the behaviors and the properties of light itself.

Light is the medium by which we carry information through an optical system. To understand the operation of the LASER and other light sources, we need to appreciate the unique character of the light emitted from gases and solids. All radiating bodies when viewed by the naked eye appear to possess a characteristic color e.g. sunlight is white, a piece of hot iron may be orange-red, a sodium street lamp is yellow.

If the light from any of these sources is passed through a prism it spreads out in a series of component colors known as a spectrum. Sunlight appears as a continuous band of colors ranging from red through to violet, a piece of iron also shows a continuum from dull red to orange, a sodium lamp displays a series of bright, narrow lines. Whether the spectral distribution is a continuous spectrum or in discrete spectral lines depends on the nature of the source, the temperature of the source

2.2.1 PHOTONS

Although light may be described as a traveling wave propagating through space but we can also discuss its behavior in terms of the amount of energy imparted in an interaction with some other medium. In this case, we can imagine a beam of light to be composed of a stream of small lumps or QUANTA of energy, known as PHOTONS. Each photon carries with it a precisely defined amount of energy. This energy depends only on its wavelength or frequency

The energy of a single photon is given, in terms of its frequency, f, or wavelength, λ , as,

$$W_{ph} = hf = hc/\lambda$$

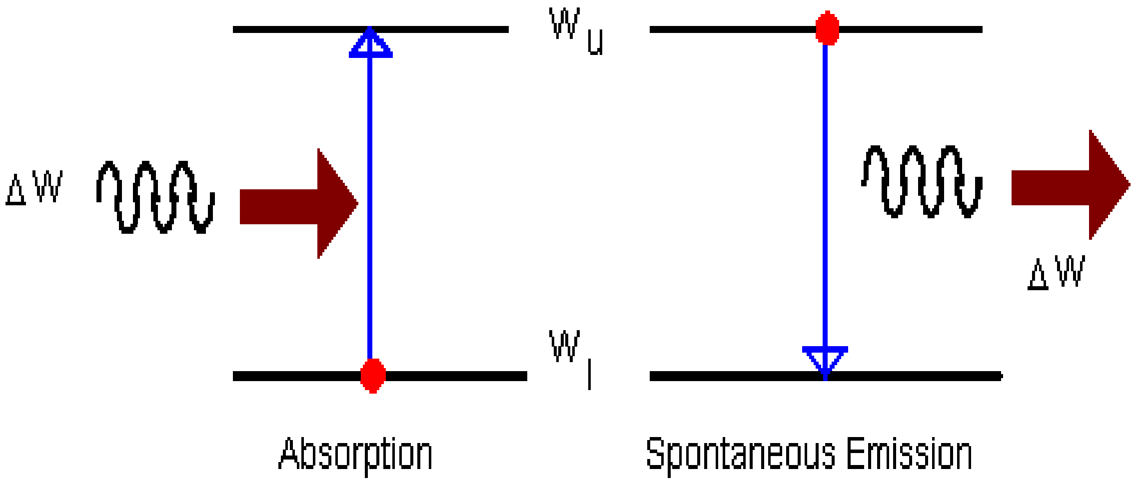
Where h is Planck's constant and c is the velocity of propagation of the photon in free space *Planck's constant*, h = 663×10^{-36} J s, velocity *of light in free space*, c = 300×10^{6} m/s. This equation shows how the energy and frequency of a photon are linked.

2.2.2 ABSORPTION AND EMISSION OF LIGHT

If an atom absorbs energy, the electrons are excited into vacant energy shells and the absorbed energy is equal in magnitude to the difference in energy between shells.

$$W = |W_u - W_l| \text{ Absorbed Energy}$$

Where W_l is the energy of the initial (lower) state and W_u is the energy of the final (higher) state.



2.2.3 SPONTANEOUS EMISSION

The excited atom can SPONTANEOUSLY (randomly) de-excite to a lower level if a vacant site permits. The average length of time an atom stays in excited state is tens of nanoseconds. The corresponding emission of energy is given by,

$$W = |W_u - W_l| \text{ Emitted energy}$$

We clearly see that the energy of a photon is defined by the energy emitted when an electron drops from an excited energy shell to one of lower energy this energy is, in turn, related to and defines the frequency (or wavelength) of the emitted photon.

2.2.4 STIMULATED EMISSION

For atomic systems in thermal equilibrium with their surroundings, emission of light is the result of two main processes. Although not a dominant process in thermal systems at room temperatures, it is crucial to the formation of LASER action. This process is known as STIMULATED EMISSION.

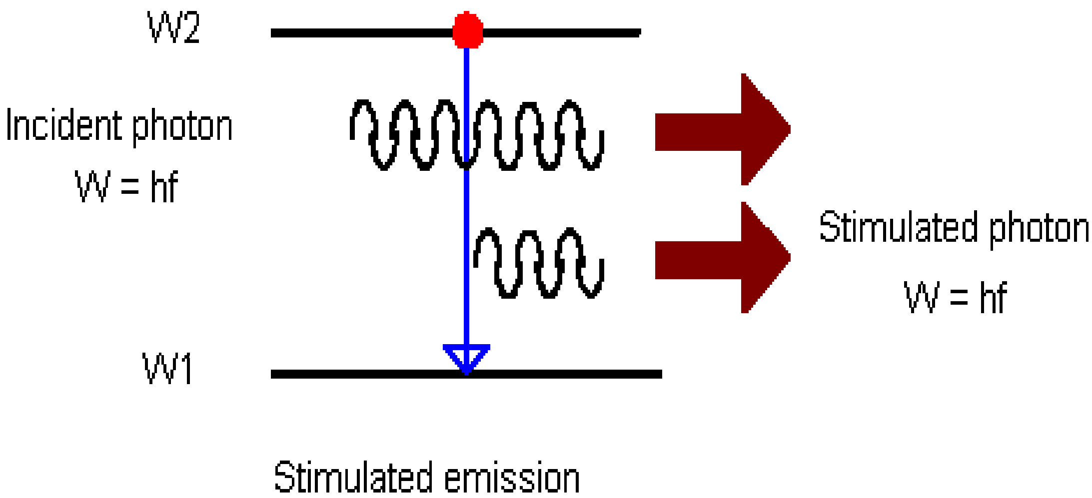


Figure 2.1

In stimulated emission, atoms in an upper energy level can be triggered or stimulated in phase by an incoming photon of a specific energy. The incident photon must have an energy corresponding to the energy difference between the upper and lower states. The atom de-excites with the consequent release of photons of the same energy as the incident photon.

The stimulated photons have unique properties:

- The emitted photon is in phase with the incident photon
- The emitted photon has the same wavelength as the incident photon
- The emitted photon travels in same direction as incident photon

The emitted photons all possess the same wavelength and vibrate in phase with the incident photons. The above behavior forms the basis of laser action and gives us the origin of the name ***LASER*** i.e. **Light *A*mplification by *S*timulated *E*mission of *R*adiation**

2.2.5 POPULATION INVERSION

The above mechanism on its own is not enough to ensure laser action as we have described it above; we have only created two photons from one to be really called an amplifier we need to produce millions of photons. We need a mechanism by which we can add more and more atoms to the upper metastable state and hold them long enough to store energy allowing the production of great numbers of stimulated photons.

Because of the existence of the longer lifetime states described earlier it is possible to create a situation where the rate at which atoms are PUMPED into one of these states exceeds the rate at which they leave a large number of atoms can be excited into, and held in, the upper state leaving an almost empty state below them. Atoms can stay in this metastable state without de-exciting while the population is being built up. This is known as a POPULATION INVERSION. A population inversion arises when more atoms are in a higher state of excitation than the one below. This situation is in violation of the conditions relating to thermal equilibrium. In practice, it is not possible to create a working laser based on absorption and emission between only two energy levels as described above. For any pair of levels the rate at which the upper level is populated by absorption equals that at which atoms leave by stimulated emission the best we can hope for in a two-level system is an equality of populations in the upper and lower levels population inversion cannot be achieved. Laser systems utilizing three or four energy levels are needed.

In a three level system atoms are pumped into the highest of the three levels called the pump level. Spontaneous de-excitation occurs from the pump level to the metastable level, which lies between the pump level and ground and serves as the upper level of the laser transition. Laser emission occurs between the metastable level and the ground state.

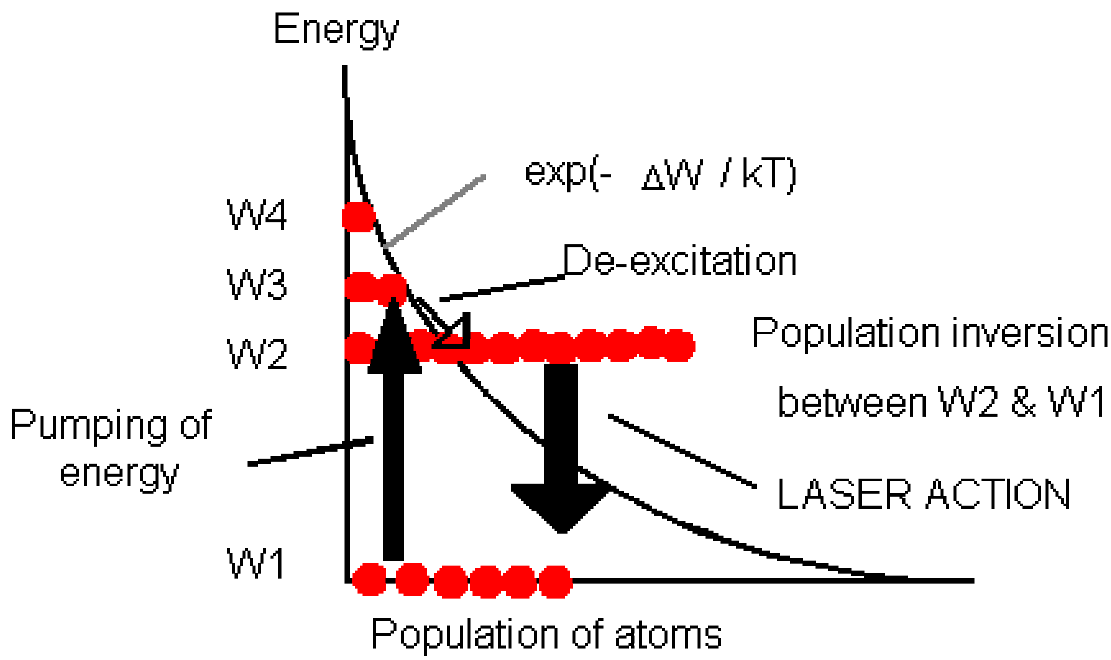


Figure 2.2

A four level laser structure

2.2.6 ENERGIZING THE AMPLIFYING MEDIUM (PUMPING)

Increasing the intensity of a light beam that passes through an amplifying medium amounts to putting additional energy into the beam. This energy comes from the amplifying medium which must in turn have energy fed into it in some way. In laser terminology, the process of energizing the amplifying medium is known as "pumping".

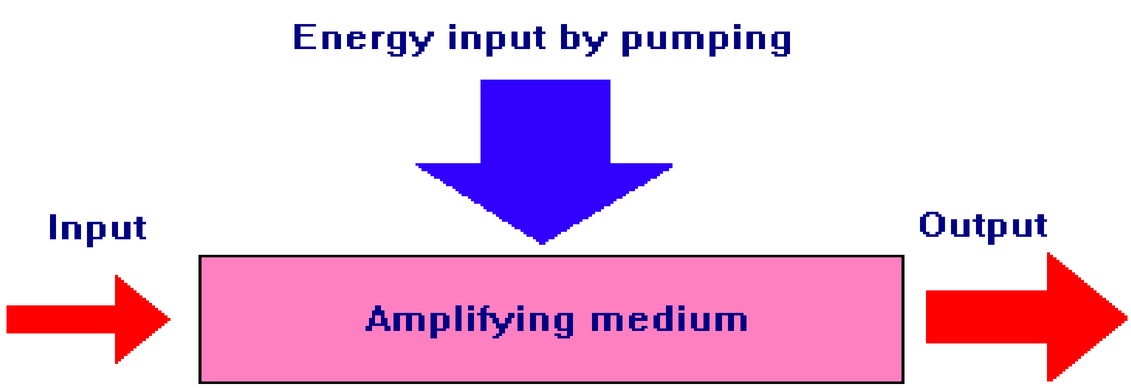


Figure 2.3

There are several ways of pumping an amplifying medium. When it is a solid, pumping is usually achieved by irradiating it with intense light. Xenon-filled flashtubes are used as a simple source of pumping light. Passing a high voltage electric discharge through the flashtubes causes them to emit an intense flash of white light, some of which is absorbed by the amplifying medium.. A laser that is pumped in this way will have a pulsed output.

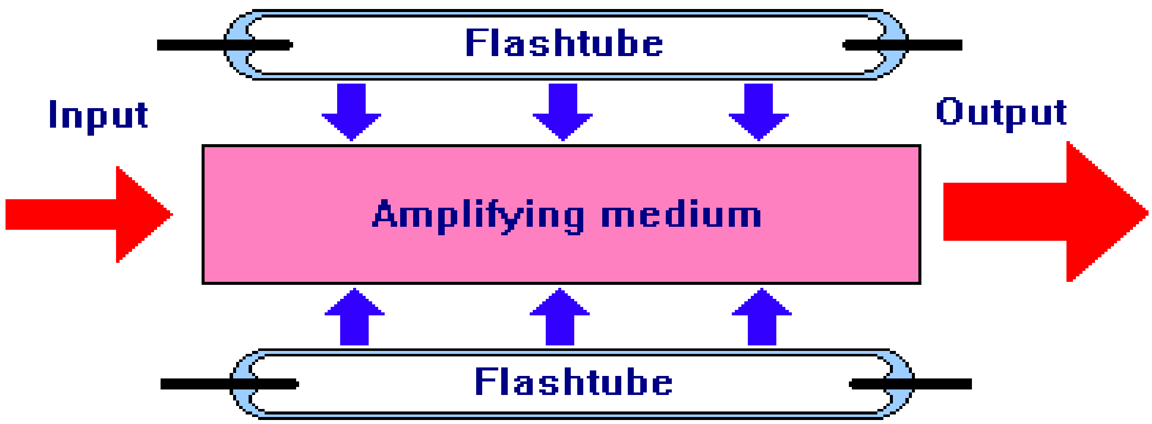


Figure 2.4

2.2.7 OPTICAL RESONANT CAVITY

In practice, photons need to be confined in the system to allow the number of photons created by stimulated emission to exceed all other mechanisms. This can be achieved by bounding the laser medium between two mirrors this forms an OPTICAL RESONANT CAVITY. One mirror is totally reflecting and the other partially reflecting. The reflectivity of the partial reflector is normally between 10 to 90 %. This is necessary to ensure that some laser light can escape and provide useful optical power

The cavity provides a method of OPTICAL FEEDBACK such that the stimulated beam is made to pass backwards and forwards several times it stimulates further emission as it goes. Stimulated photons can bounce back and forward along the cavity, creating more stimulated emission as they go. Any photons that do not travel along the optical axis are lost. Any photons that are not of the correct frequency are also lost

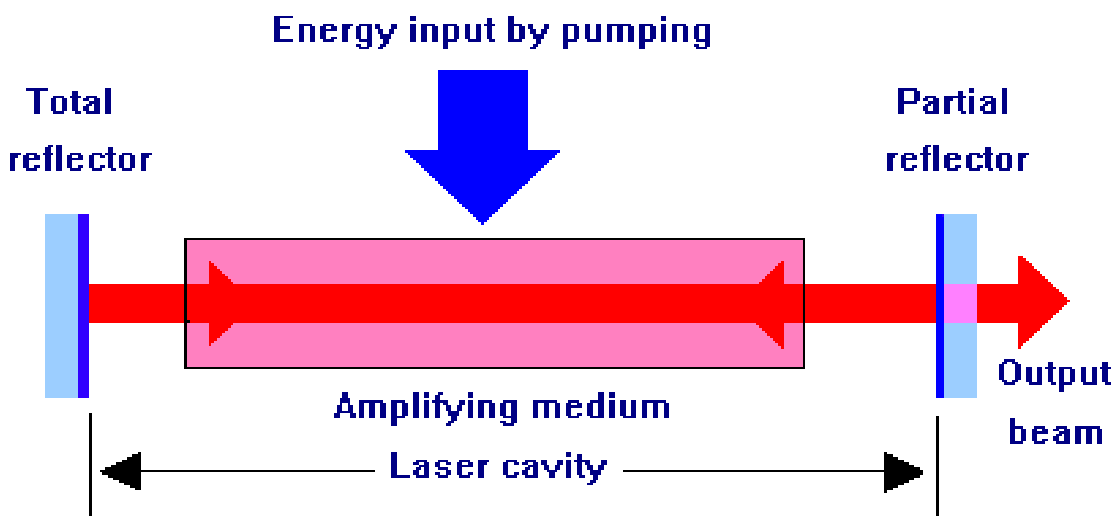


Figure 2.5

When the number of photons produced by stimulated emission exceeds that produced randomly, the system gain exceeds the losses laser action can precede.

2.2.8 PROPERTIES OF LASER LIGHT

2.2.8.1 Monochromatic

- Laser light is concentrated in a narrow range of wavelengths.
- Lasers produce the purest (most MONOCHROMATIC) light available.

2.2.8.2 Coherence

- All the emitted photons bear a constant phase relationship with each other in both time and phase therefore the light is said to be COHERENT

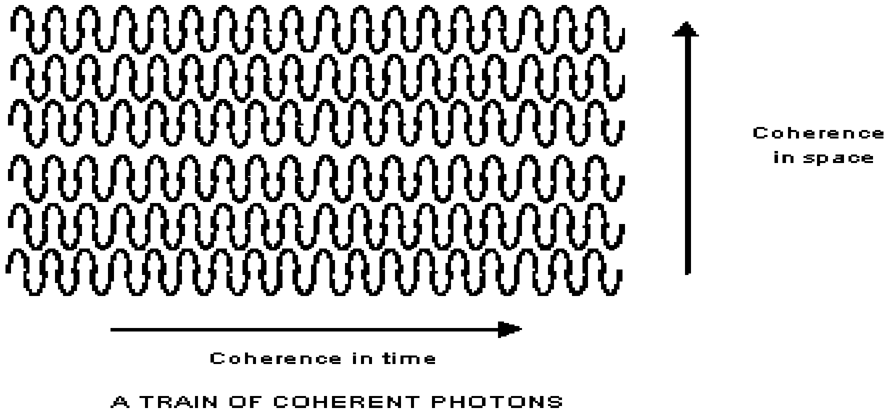


Figure 2.6

2.2.8.3 Beam divergence

- All photons travel in the same direction ie the light is contained in a very narrow pencil
- Almost COLLIMATED
- Laser light is low in divergence (usually)

2.2.8.4 High irradiance

- All the light is concentrated into a narrow spatial band.
- Light possesses high radiant power per unit area (i.e. high irradiance)

2.3 STEPPER MOTORS

Stepper motor can be viewed as electrical motors without commutators. Stepper motors consists of permanent magnet rotating shaft, called the rotor and electromagnets on the stationary portion that surrounds the motor called stator. Typically al windings in the motor are part of the stator, and the rotor is either a permanent magnet or in the case of variable reluctance motors, a toothed block or some magnetically soft material. To move the rotor the electric magnets on the motor are activated in the right order. Every change in this process moves the motor one step. The order in which those electromagnets are activated determines the rotation direction. The motor controller must handle all the commutation externally and typically the motor and controllers are designed so that the motor may be held in any fixed position as will as being rotated one way or the other. With and appropriate controller, they may be started and stopped on a dime at controlled orientations.

2.3.1 WHY IS IT CALLED STEPPER MOTOR?

For application where precise measuring of motors position is critical, a stepper motor is usually the best choice. Stepper motor operates different from other motors, rather than voltages being applied and the rotor spinning smoothly, stepper motors turn on a series of electrical pulses to the motors windings. Each pulse rotates the rotor by an exact degree. These pulses are called steps hence the name “stepper motor”.

2.3.2 WORKING OF A STEPPER MOTOR

Stepper motors produce, motion in discrete steps. Similar to brush less DC motors, stepper usually have permanent magnets on the rotor and coils on the stator with field movements provided by commutation from the power supply. Stepper motors are usually controlled by digital signals from the controller to power drive with one pulse corresponding to one step. Thus, the frequency of the digital signals controls the speed of the motor. Thus, the frequency of the digital controls the speed of the motor. In a stepper motor, if just one winding of the motor is energized, the rotor (under no load) will snap to a fixed angle and then hold that angle until the torque exceeds the holding torque of the motor, at which point, the rotor will turn, trying to hold at each successive equilibrium points.

2.3.3 APPLICATIONS OF STEPPR MOTOR

- Motion control applications
- Easy to wire and control
- Economical to implement
- Intuitive to control
- Have good low speed torque
- Ideal for much low power, computer-controlled application
- Interfaced to computer using few transistors and made to rotate using a small piece of software
- Provide good position repeatability
- Used in robotics control
- In computer accessories (disk drivers, printer, scanner)

2.3.4 LIMITATION OF STEPPR MOTOR

- They are available in limited power (less than one horse power)
- Their rotation speed is limited (usually maximum speed limit is about 2000 rpm). The energy efficiency of stepper motors is low.
- Stepper motor has characteristics holding torque (ability to hold the position) and pullout torque (ability to move to the next position).
- Precise torque control is difficult with steppers
- Because of open loop nature of stepper motor controlling they are not very good to be used with carrying loads.

2.3.5 TYPES OF STEPPER MOTOR

The three primary types of stepper motors are *permanent magnet, variable reluctance* and *hybrid synchronous*

2.3.5.1 Permanent Magnet

Permanent magnet motors have a permanent magnet armature magnetized perpendicular to the rotation axis. By energizing four phases in sequence, the rotor will rotate as it follows the changing magnetic field. Typical step angles for permanent magnet motors are 45° and 90°. They step at relatively low rates but have high torques and good damping characteristics. Of the permanent magnet stepper motors, there are many other types are also available. These include

- Unipolar
- Bipolar
- Multiphase varieties

2.3.5.2 Variable Reluctance

Variable reluctance motors differ from permanent magnet motors by having a multi-tooth armature, each tooth being an individual magnet as shown in Figure 22. At rest, these magnets align themselves in a natural detent position providing larger holding torque.

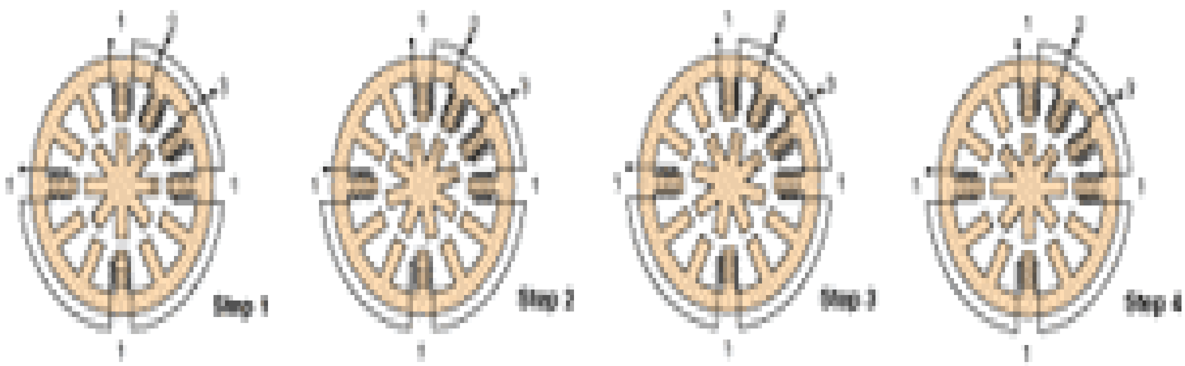


Figure 2.7

2.3.5.3 Hybrid Synchronous

The hybrid synchronous stepper motor combines the advantages of variable reluctance and permanent magnet stepper motors. The hybrid has multi-toothed stator poles and a multi-toothed armature. These types of motors exhibit high detent torque, excellent dynamic and static torque, and can achieve high stepping rates.

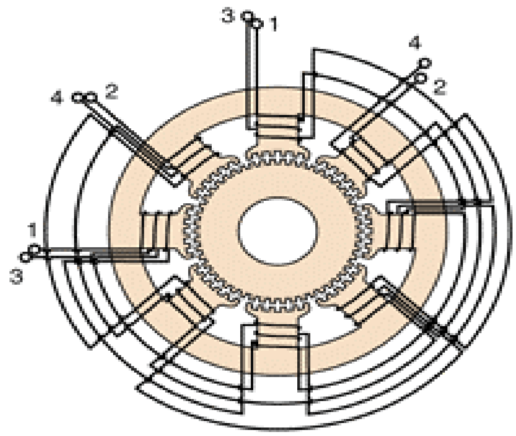


Figure 2.8

2.4 PARALLEL PORT

DB25 connector with an 8-bit data bus (Pin 2-7) that is more popularly used for computer printers while is still used for other devices.

The standard length of Printer Parallel cables is a maximum of 15 feet although there are 50-foot cables it is not recommended that these cables be used as it can create poor connection and data signals.

2.4.1 TYPES OF PARALLEL PORTS

2.4.1.1 Unidirectional

4-bit standard port that by factory default did not have the capability of transferring data both ways.

2.4.1.2 Bi-directional

8-bit standard port, which was released with the introduction of the PS/2, port in 1987 by IBM and are still found in computers today. The Bi-directional port is cable of sending 8-bits input and output. Today on multifunction printers this port can be referred to as a bi-directional, Centronics, PS/2 type or standard port.

2.4.1.3 EPP

The Enhanced Parallel Port (EPP) was developed in 1991 by Intel, Xircom and Zenith Data Systems and operates close to ISA bus speed and can achieve transfer rates up to 1 to 2MB/sec of data. **ECP -** The Enhanced Capabilities Port (ECP) was developed by Microsoft and Hewlett-Packard and announced in 1992 is an additional enhanced Parallel port. Unfortunately with ECP it requires an additional DMA channel which can cause resource conflicts.

2.4.2 LAYOUT

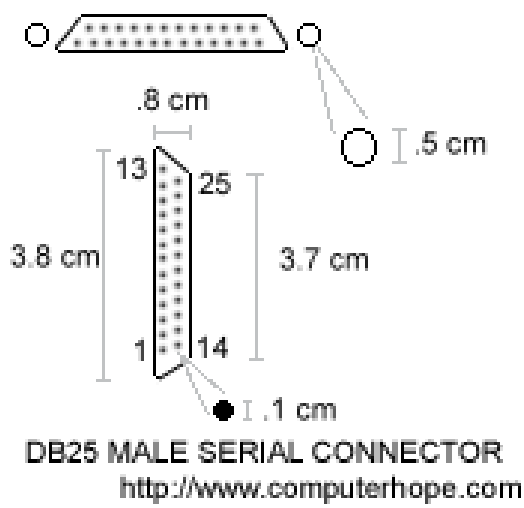


Figure 2.9

PIN	PURPOSE
Pin 1	-Strobe
Pin 2	+Data Bit 0
Pin 3	+Data Bit 1
Pin 4	+Data Bit 2
Pin 5	+Data Bit 3
Pin 6	+Data Bit 4
Pin 7	+Data Bit 5
Pin 8	+Data Bit 6
Pin 9	+Data Bit 7
Pin 10	-Acknowledge
Pin 11	+Busy
Pin 12	+Paper End
Pin 13	+Select
Pin 14	-Auto Feed
Pin 15	-Error
Pin 16	-Initialize Printer
Pin 17	-Select Input
Pin 18	-Data Bit 0 Return (GND)
Pin 19	-Data Bit 1 Return (GND)
Pin 20	-Data Bit 2 Return (GND)
Pin 21	-Data Bit 3 Return (GND)
Pin 22	-Data Bit 4 Return (GND)
Pin 23	-Data Bit 5 Return (GND)
Pin 24	-Data Bit 6 Return (GND)
Pin 25	-Data Bit 7 Return (GND)

The following is an explanation of each of the above purposes.

Pin1 = Data acknowledgement when the signal is low.

Pin 2 - 9 = Data transfer pins.

Pin 10 = Acknowledge that the data has finished processing and when the signal is high indicates ready for more.

Pin 11 = When the signal goes high indicate that the printer has accepted the data and is processing it. Once this signal goes low and Pin 10 goes high will accept additional data.

Pin 12 = Printer paper jam when signal is high or no signal if printer jam.

Pin 13 = When high signal printer is indicating that it is on-line and ready to print.

Pin 14 = When low signal PC has indicated that the printer inset a line feed after each line.

Pin 15 = Printer sends data to the computer telling it that an error has occurred.

Pin 16 = When low signal PC has requested that the printer initiate a internal reset.

Pin 17 = When low signal the PC has selected the printer and should in return prepare for data being sent.

Pin 18 - 25 = Ground.

2.5 CCD AND CMOS

CCD (charge coupled device) and CMOS (complementary metal oxide semiconductor) image sensors are two different technologies for capturing images digitally. While they are often seen as rivals, CCDs and CMOS imagers have unique strengths and weaknesses that make them appropriate to different applications. Neither is categorically superior to the other, although vendors selling only one technology often claim otherwise. The choice depends far more on the application...and the vendor.

Both types of imagers convert light into electric charge and process it into electronic signals. In a **CCD** sensor, every pixel's charge is transferred through a very limited number (often one) of output nodes to be converted to voltage, buffered, and sent off-chip as an analog signal. All of the pixel can be devoted to light capture, and the output's uniformity (a key factor in image quality) is high. In a **CMOS** sensor, each pixel has its own charge-to-voltage conversion, and the sensor often also includes digitization circuits, so that the chip outputs digital bits. These other functions reduce the area available for light capture, and with each pixel doing its own conversion, uniformity is lower. But the chip requires less off-chip circuitry for basic operation CCDs have been the dominant solid-state imagers since the 1970s, primarily because CCDs gave far superior images with the fabrication technology available. CMOS image sensors required more uniformity and smaller features than silicon wafer foundries could deliver at the time. DALSA founder and CEO Dr. Savvas Chamberlain was a pioneer in developing both technologies in the 1960s, and his leadership helped bring CCD technology forward. Only recently has semiconductor fabrication advanced to the point that CMOS image sensors can be useful and cost-effective in some mid-performance imaging applications.

CCDs offer superior image performance (as measured in quantum efficiency and noise), and flexibility at the expense of system size. They continue to rule in the applications that demand the highest image quality, such as most industrial, scientific, and medical applications.

CMOS imagers offer more integration (more functions on the chip), lower power dissipation (at the chip level), and smaller system size at the expense of image quality and flexibility. They are well suited to high-volume, space-constrained applications where image quality is not paramount, such as security cameras, PC peripherals, toys, fax machines, and some automotive applications.

Costs are similar at the chip level. Early CMOS proponents claimed CMOS imagers would be much cheaper because they could be produced on the same high-volume wafer processing lines as mainstream logic or memory chips. This has not been the case. The accommodations required for good imaging performance have limited CMOS imagers to specialized, lower-volume mixed-signal fabrication processes. CMOS imagers also require more silicon per pixel. CMOS cameras may require fewer components and less power, but they may also require post-processing circuits to compensate for the lower image quality.

The larger issue around pricing is sustainability. Since many CMOS start-ups pursue high-volume, commodity applications from a small base of business, they must price below costs to win business. For some, the risk will pay off and their volumes will provide enough margins for viability. But others will have to raise their prices, while still others will go out of business entirely. High-risk startups can be interesting to venture capitalists, but imager customers require long-term stability and support.

The money and attention concentrated on CMOS imagers means that their performance will continue to improve, eventually blurring the line between CCD and CMOS image quality. But for the foreseeable future, CCDs and CMOS will remain complementary.

2.5.1 CMOS vs. CCD

	CMOS	**CCD**
Sensor Size	1/2", 1/3", etc.	1/2", 1/3", etc.
Integration	Amplifier present at each photo site, A/D converter and additional processing easily added	Requires separate components for amplification, processing, storage, etc.
Power Consumption	20-50 Mill watts	2-5 Watts

Manufacturing	Can be produced by any standard CMOS fab in great quantities	Requires a dedicated facility
Resolution	Up to one mega pixel	Up to six mega pixels
Signal Quality	Improved over non-APS CMOS	Historically the best
Output	Data accessed by row and column like RAM - no signal degradation	Data accessed by shifting rows and reading serially - subject to fading
Speed	Up to thousands of frames per second	Usually up to 100 frames per second - sensors above 2 mega pixels are often interlaced due to speed issues

2.6 IMAGE PROCESSING

Most of the digital image processing methods can be divided into phases as shown in Figure below. First, some hardware devices, usually camera or scanner captures the image, and then image has to be digitized both spatially and in amplitude to make it suitable for processing.

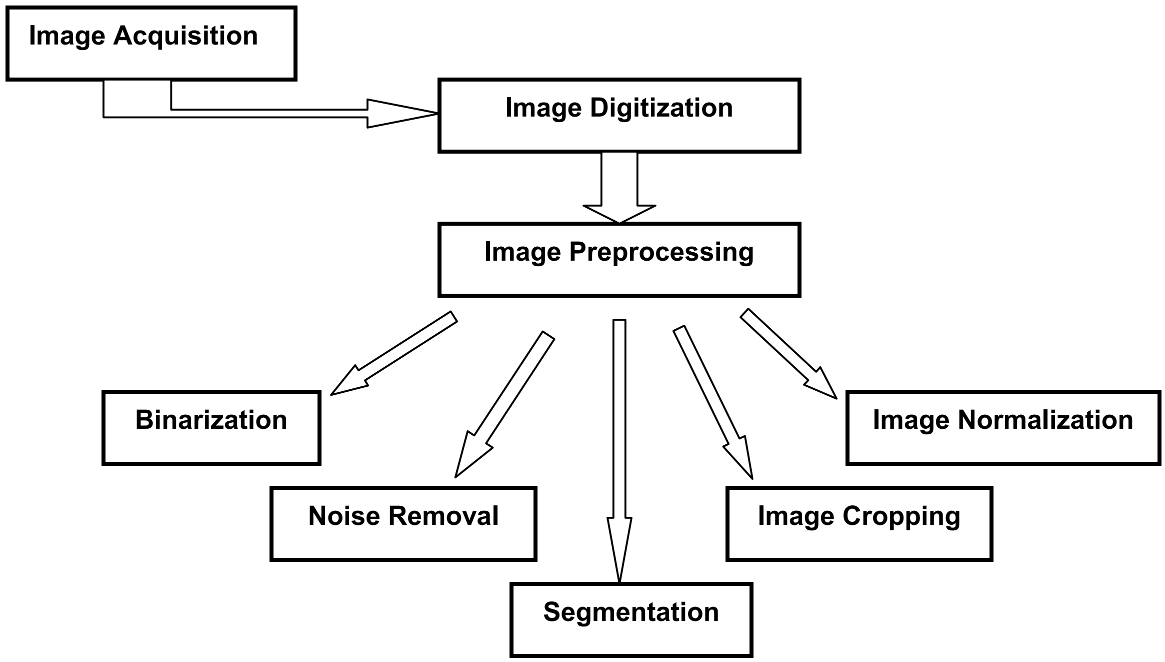


Figure 2.10: Phases in Digital Image Preprocessing

2.6.1 NOISE IN IMAGES

Various types of noise present in images are photon, thermal and quantization noise etc. Photon and thermal noise can be reduced effectively by using accurate and controlled 'sensing' devices. Quantization noise can be reduced by considering additional quantization levels. The error rate thus is reduced and is not very significant. The classification of noise is based upon the shape of the probability density function or histogram for the discrete case of the noise. When discussing image processing, we are interested in uncorrelated noise. In terms of a spatially sampled image, uncorrelated noise is defined as the random gray level variations within an image that have no spatial dependence from pixel to pixel. In other words, the gray level of a pixel due to uncorrelated noise does not depend on the gray levels of its neighboring pixels.

2.6.1.1 Salt and Pepper noise

Noise that commonly appears in images is salt-and-pepper noise. After binarization, images are usually filtered by applying spatial filtering techniques to reduce ‘Salt-and-Pepper’ noise also called ‘impulse’ and ‘speckle’ noise, or just dirt. This type of noise is a prevalent artifact in poorer quality images such as poorly thresholded faxes or poorly photocopied pages and is named for the salt and pepper appearance an image

Salt-and-pepper noise takes on two gray levels, L1 and L2. This appears as isolated pixels or pixel regions of ON noise in OFF backgrounds or OFF noise holes within ON regions, and as rough edges on character and graphics components.

2.6.1.2 Uniform Noise

The next type of noise to be presented is uniform noise, which occurs with uniform intensity variations in the image. The effect of this type of noise is not very significant and can be removed very easily

2.6.1.3 Gaussian Noise

Gaussian noise contains variations in intensity that is drawn from a normal distribution and is a good model for many kinds of sensor noise, such as noise due to camera electronics or incorrect focusing of lens

2.6.1.4 Spatial Noise Filtering

The next step in image preprocessing involves the techniques of spatial filtering. Use of ‘Spatial Mask (Kernel)’ for image processing is usually called as the ‘Spatial Filtering’ and masks used are called as the ‘Spatial Filters’. There are many spatial filters in use today and many studies have been done as to which one is the best. The task of finding the best filter becomes difficult, because each filter is used to obtain a certain effect.

2.6.1.5 Mean Filter

The most common use for the average filter is to reduce noise in an image. It is a low pass filter, which removes high spatial frequencies from an image

1/9	1/9	1/9
1/9	1/9	1/9
1/9	1/9	1/9

Or **(1 / 9) x**

1	1	1
1	1	1
1	1	1

Figure 2.11 : Averaging Filter

2.6.1.6 Median Filter

The low pass spatial filters are used to blur or rub the noise details rather than complete elimination, so an alternative approach is to use median filter. This method is particularly effective when the noise pattern is strong. The median filter is a nonlinear spatial filter

1	7	6
2	15	5
7	1	3

Figure 2.12: Noisy Image

2.6.2 EDGE DETECTION

Edge detectors are another form of image enhancement operators. An edge is as a place of local transition from one object to another. The purpose of an edge detector is to extract the edge or detect the boundary of an object within the image. Edges are characterized into following three types : -

- **Step Edge :** Sudden change or discontinuity in intensity values in an image is referred to as 'Step Edge' as shown in the Figure 2.13

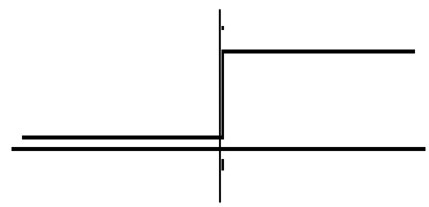


Figure 2.13 : Step Edge

- **Ramp Edge :** Intensity variations in the image are not instantaneous in the 'Ramp Edge' and occur over a finite distance. The value is different on other side of discontinuity as shown in Figure.

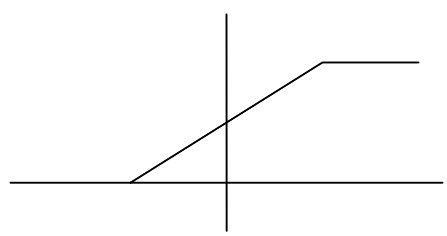


Figure 2.14: Ramp Edge

- **Roof Edge :** Intensity variations are not instantaneous but then returns to the starting value within some short distance as shown in the Figure 2.14.

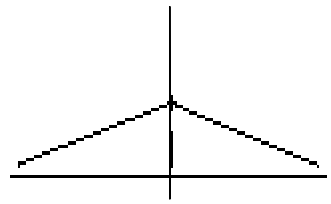


Figure 2.15 : Roof Edge

2.6.2.1 First Derivative Methods

Most edge detectors are based in some way on measuring the intensity gradient at a point in the image. Vector calculus and differential geometry describes the gradient as the change that is defined by gradient operator ∇ is:-

$$\nabla = \begin{bmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \end{bmatrix} \quad (3.1)$$

Numerous kernels (masks) have been proposed for finding edges, and we'll cover some of those here.

2.6.2.2 Roberts Kernels

The Roberts kernels 'g1' and 'g2' are : -

+1	
	-1

g_1

	+1
-1	

g_2

2.6.2.3 Prewitt Kernels

Two main kernels to detect changes or discontinuities in ‘x’ and ‘y’ direction as shown below.

-1	0	1
-1	0	1
-1	0	1

$\partial/\partial x$

-1	-1	-1
0	0	0
1	1	1

$\partial/\partial y$

Figure 2.16 : Prewitt Kernels

2.6.2.4 Sobel Kernels

The Sobel kernels also rely on central differences, but greater weight is given to the central pixels when averaging as shown in Figure 3.7.

-1	0	1
-2	0	2
-1	0	1

$\partial/\partial x$

-1	-2	-1
0	0	0
1	2	1

$\partial/\partial y$

Figure 2.17 : Sobel Operator

2.6.2.5 Second Derivative Methods

There are other operators that try to find these peaks in gradient magnitude directly. Finding optimal edges (maxima of gradient magnitude) is equivalent to finding places where the second derivative is zero.

2.6.2.6 Laplacian Operator

Laplacian edge detector has following properties; it must:

- operate locally,
- be efficient,
- be sensitive to the orientation and magnitude of an edge, and
- Work in the presence of noise.

The variations of second order Laplacian are shown in Figure 3.10:

0.5	0.0	0.5
1.0	-4.0	1.0
0.5	0.0	0.5

+

0.5	1.0	0.5
0.0	-4.0	0.0
0.5	1.0	0.5

=

1	1	1
1	-8	1
1	1	1

or

1	-2	1
1	-2	1
1	-2	1

+

1	1	1
-2	-2	-2
1	1	1

=

2	-1	2
-1	-4	-1
2	-1	2

Figure 2.18 : Laplacian Variations

2.7 IMAGE RECOGNITION

Many statistical features can be used as descriptors for regions in an image. There are boundary descriptors like the length of the contour or the diameter of a boundary, and regional descriptors like the area of a region or its compactness. In the last step the region, and hence its descriptor, has to be classified in order to recognize and interpret the image. Selection of feature extraction methods is probably the most important factor in achieving high recognition performance. Therefore, object recognition is the sequence of steps that must be performed after appropriate features have been selected and measured. Based on detected features of object in an image, recognition and classification of objects with optimal performance is achieved.

2.7.1 FEATURES

Features are “characteristics" that describe the pattern and are extracted from the image. They are grouped in a feature vector, which will be compared to the feature vectors of known patterns during classification. Features can be either numbers or more complicated structures.

2.7.2 FEATURES COMPARISON METHODS

There are several methods to compare an image to another. Few of them are mentioned below

2.7.2.1 Template Matching

Template matching, or matrix matching, is one of the most commonly used methods in pattern recognition. In template matching, the feature extraction step is left all together and individual image pixels of character image are used as features. Classification is performed by comparing an input character image with a set of stored templates (or prototypes) from each character class

2.7.2.2 Projection Histogram

Feature extraction using ‘Projection Histogram’ is mostly being used for segmenting characters, words, text AND line or to detect if an input image of a scanned page is rotated. For a horizontal projection $y(x_i)$ is the number of pixels with $x = (x_i)$. The features can be made scale independent by using a fixed number of bins on each axis and dividing by the total number of print pixels in the character image

2.7.2.3 Moment Analysis

Moment Invariants have been frequently used as features for image processing, remote sensing, shape or object recognition and classification. Moments can provide characteristics of an object that uniquely represent its shape. Invariant shape recognition is performed by classification in the multidimensional moment invariant feature space.

2.7.3 CLASSIFICATION

Classification is concerned with making decisions concerning the class membership of a pattern in question. The task in any given situation is to design a decision rule that is easy to compute and minimize the probability of misclassification relative to the feature extraction scheme employed. There are two approaches to classifiers

Mathematical Approach

- Deterministic Classifier
- Statistic Classifier
- Fuzzy mathematic Classifier
- Syntactic Recognition

Heuristic Approach

- Graph Matching
- Tree searching

CHAPTER NO.3

3.0 ANALYSIS

3.1 STRUCTURED LIGHT DEPTH EXTRACTION

Structured Light sensing is a well-established technique for ranging. A great variety of techniques in this general area have been developed. The common thread of all these approaches is the underlying use of triangulation. This ranging geometry can be seen in Figure3.1, which depicts the optical components in our built project. Here the laser is projected downward towards objects in the scene. Laser illumination striking an object is observed by the camera to reveal surface profiles, which can be converted into Cartesian range data.

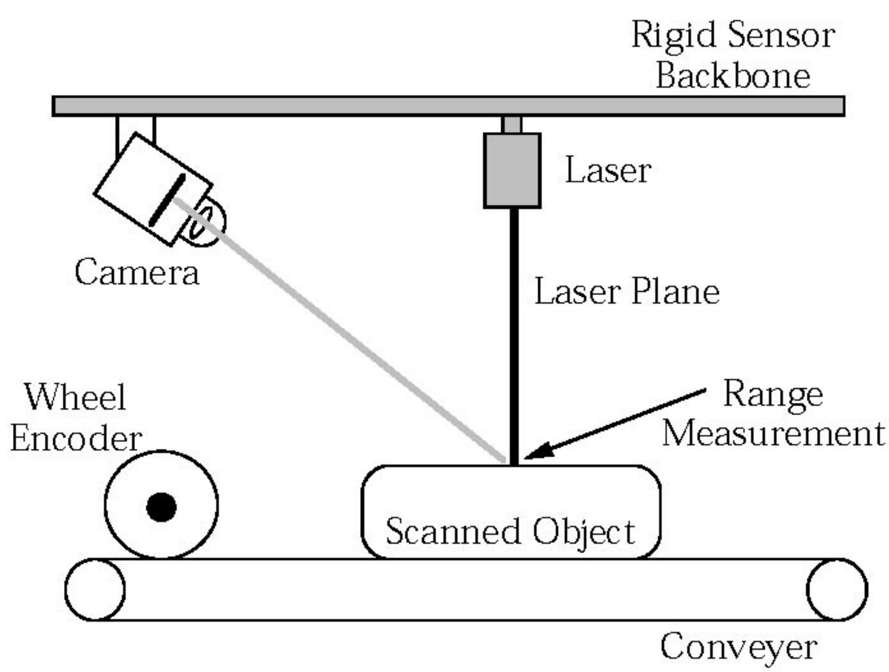


Figure 3.1: Structured Light systems use triangulation to acquire range measurements.

The ranging geometry is formed by a laser emission, the reflected light observed by the camera and by a rigid backbone. A conveyer produces the necessary motion for 3D range data

Above diagram shows our schematic approach. We had to select the best components to built this project while at the same time remaining in the limits bounded by financial constraints. Now we will be analyzing the components selection one by one.

3.2 HARDWARE COMPONENTS

3.2.1 CAMERA

Initially the “Logitec Digital camera” was selected for image acquisition. Initially the performance of camera was very good. But later on the performance of camera chip degraded. Even some cells in the sensor array were damaged causing permanent noises at that pixel. There is no way to compensate for such permanent noises in image processing. And the same thing could have happen to any of the digital camera. So we decided to go for analogue camera. In the figure below we have shown two pictures taken by Camera in the open light and in the dark. It can be seen that in the dark image still we find the white pixels due to damaged array of the camera. This will cause the scanning process of the system.

Figure3.2: Above picture shows the good quality and resolution of camera

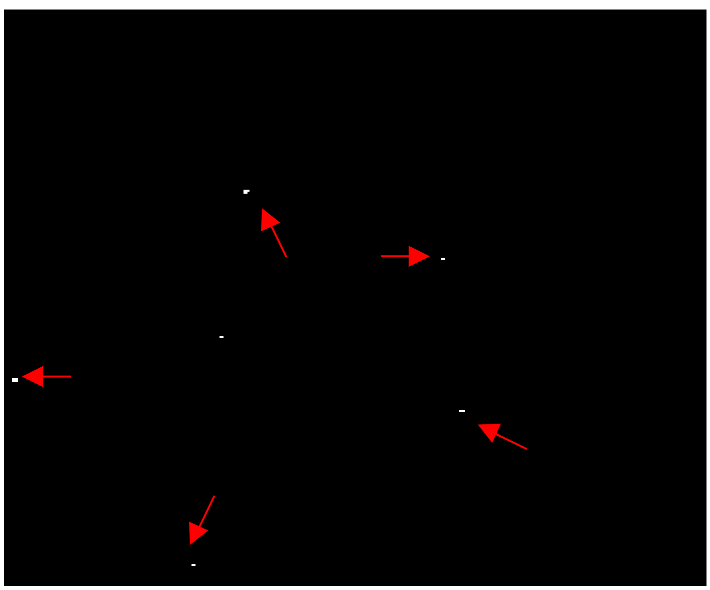


Figure3.3: This picture taken in total dark shows the damaged pixels causing permanent noises (pointed by red arrows)

So, we chose the analogue camera. The added advantage of analogue camera is that it can help reduce noise by adding multiple images of the same scene, and then averaging them out. Because noise on one pixel will not be there in the second image. While in digital camera if a cell is noisy it will always produce noise on that pixel, as indicated above.

In the figure below we show two further images. One image shows the single image taken open light, when the surrounding light illuminates the object. We can observe the good quality of the image. Second picture shows the single image of the same scene in the dark room (black box). The AGC(automatic gain control) has adjusted itself to avoid damage to the sensing element of the camera. Hence we see so much noise. The third image shows the noise reduction by adding ten images of the same scene and averaging them out.

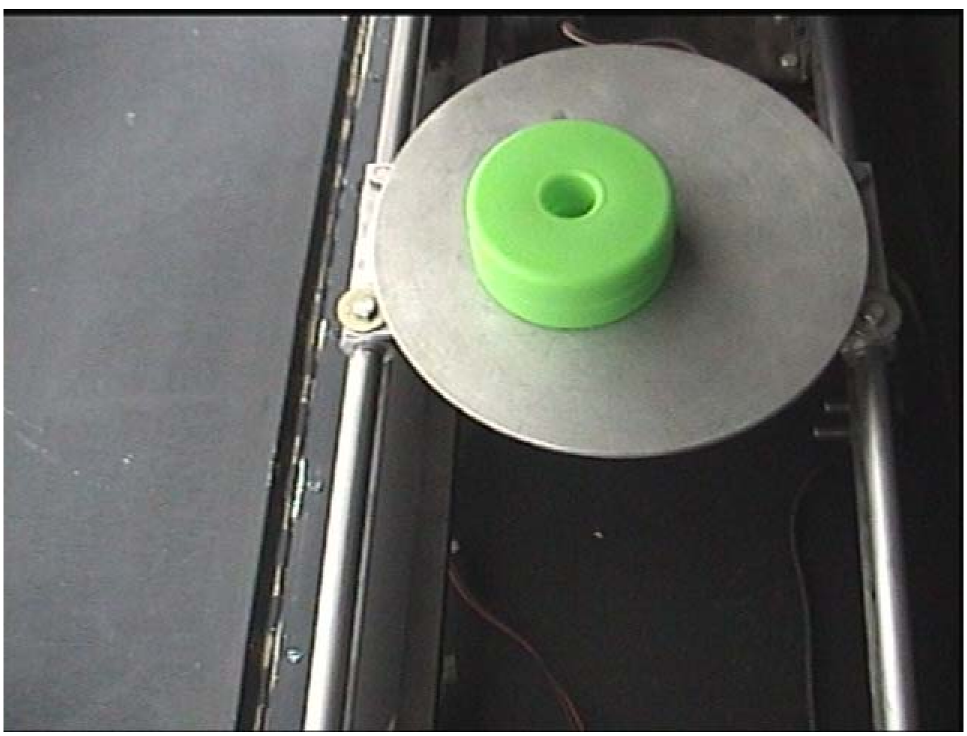


Figure3.4: Image taken by Sony camera(Analogue)

Figure3.5: Single image taken in the dark room. You can see how difficult is it to see the laser line

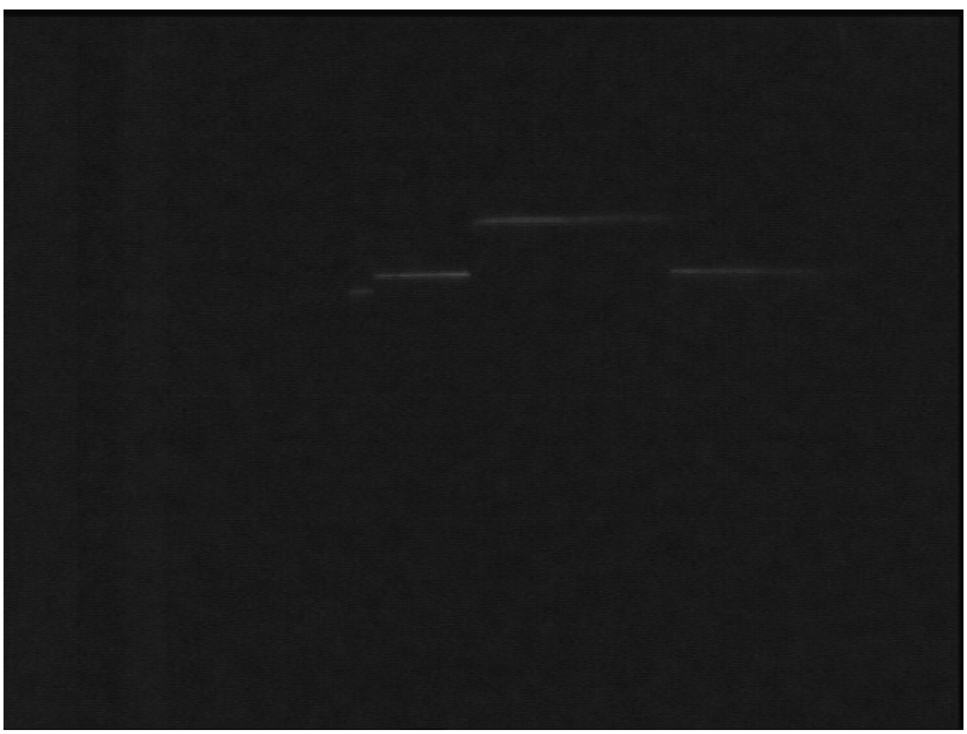


Figure 3.6: Effect of noise reduction by averaging

Three digital cameras (1.logitec click smart, 2 Logitech quick cam, 3.Intel) were tested and they did not give good results as compared to analogue camera from ‘Sony’. A high quality ‘Sony’ video camera was selected finally for image acquisition.

3.2.2 LENS

Since we had to convert the spot laser into line laser to scan the object , we needed a cylindrical lens. Though there are other ways as well to generate a line source, but it costs extraordinary high. The cheapest method was to use the cylindrical lens. The cheapest line source lens available was from ‘Edmond Optics’ costing retail price of 250pounds exclusive of shipment charges. And such lens is not available in Pakistan, and no one makes such a perfect lens in Pakistan. We had tried to get one lens from KRL (Kahota Research Lab) lab or PAC(Pakistan Atomic Commission), but to no vail.

Though we managed to get one cylindrical piece of glass from Karachi, but that piece of glass is not based on optical engineering. But still it worked well to generate a laser line, though of not very good quality.

The figures on the next page show two images. One shows the required level of line source intensity and the second picture shows the level of image we are getting by this local made lens.

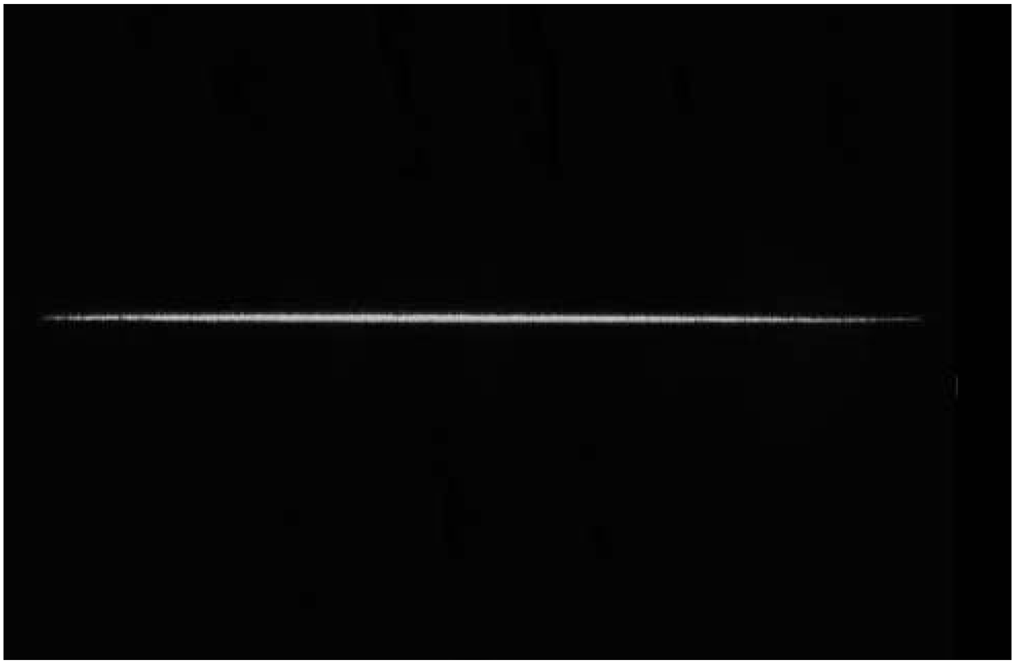


Figure 3.7: Ideal Line source that is achievable

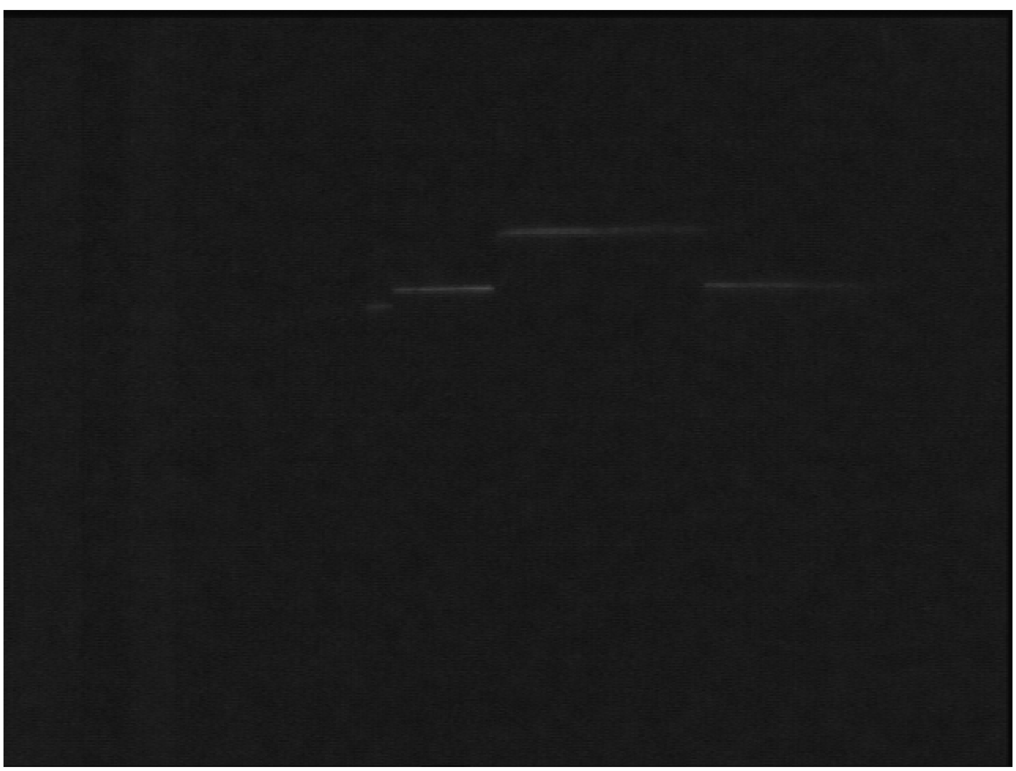


Figure 3.8: Practically achieved line-source achieved

The above figures show clearly the impact of this limitation on our resources. To solve this problem we had to resolve towards time consuming algorithms and processes.

3.2.3 CONVEYER SYSTEM

A platform was designed which was supposed to be moved horizontally under a controlled movement. Stepper motors were chosen because of its simple control circuit and still good resolution of 1degree per step, which on the circumference of conveyer belt makes 1mm a step. The comparison on the stepper motors and servomotors is given in the previous chapter. For our scope the use of stepper motor was sufficient because of its simplicity and accuracy. And the experiments have shown that it can slide the platform of object very well.

3.2.4 LASER

The commercially available laser was selected because of its easy availability and cheaper rates.

3.3 SOFTWARE COMPONENTS

3.3.1 NOISE REMOVAL AND EDGE DETECTION

Since the main task of our image processing was to remove the noisy background, and it was not quit an easy task. Several methods were used to remove the noise, and their results are also shown below. Since the sudden change in light intensity is an edge in the terminology of image processing, so different edge detectors were also used. Finally we resolved to unconventional median filter of size[16x4].

The result of few edge detectors and noise removal methods are shown below.

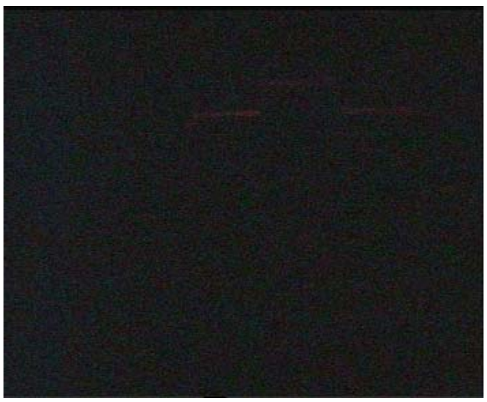
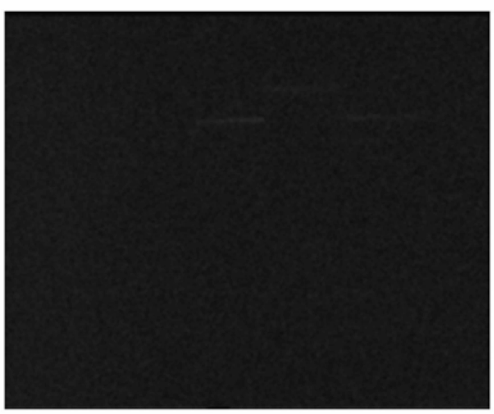


Figure 3.9: RGB image

Red portion of same image



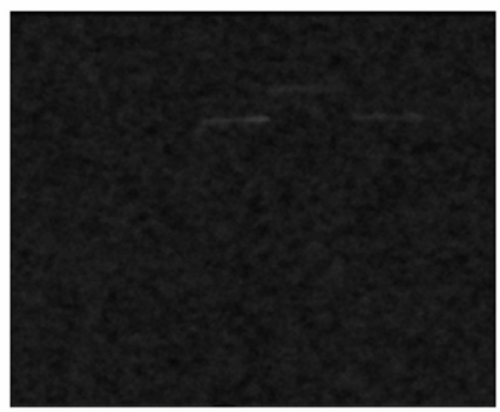
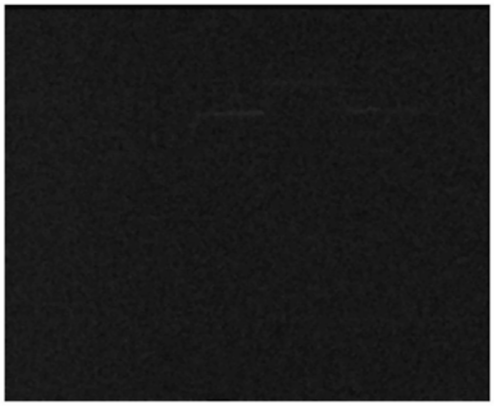


Figure 3.10

Mean filter of [3x3] of above image

Mean filter of [3x3] of above image



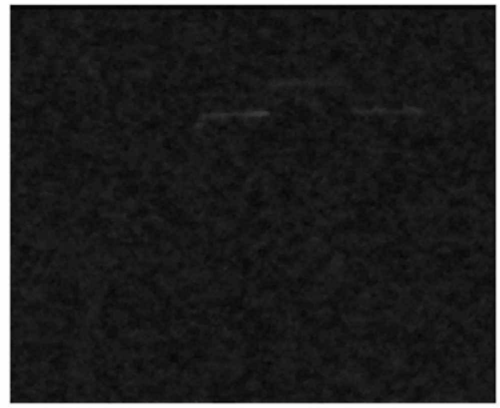
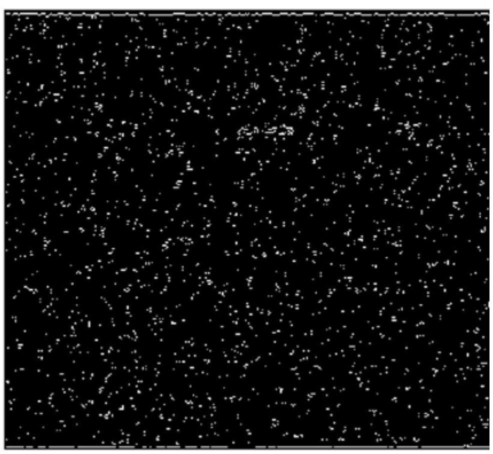


Figure 3.11

Median filtering of 3x3 of first Gray image

Median filter of 3x3 for Red



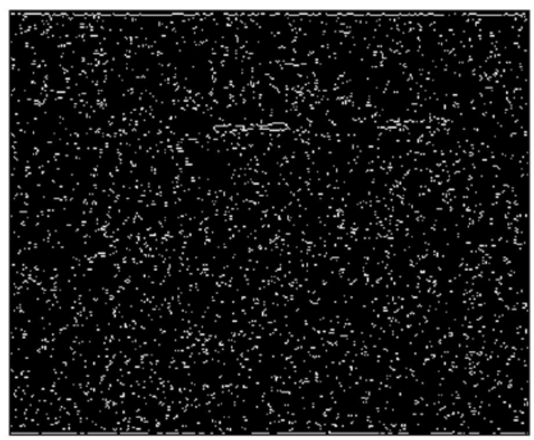
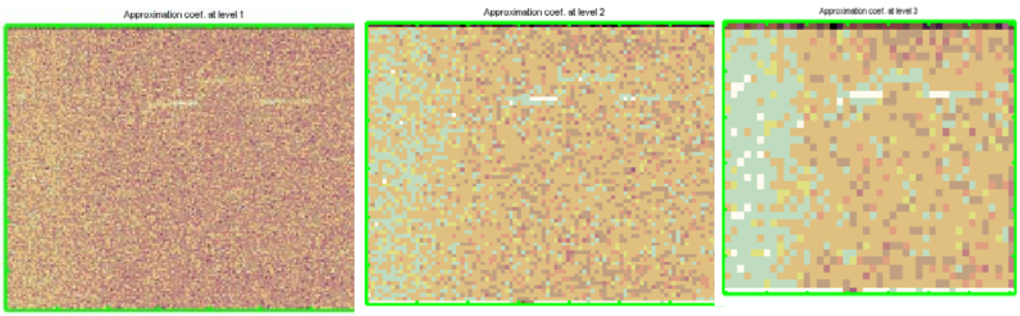


Figure 3.12

Sobel operator on Gray image

Sobel operator on Red image

The wavelet analysis of the image to extract the edge is as under



Wavelet Approx at level 1 **at level 2** **at level3**

From the above analysis it was observed that median filter will be giving better results. Since we knew that the light is falling downward only, so we decided to have median filter of size [16x4]. Then we applied a suitable threshold to retrieve the contour highlighted by laser. The results of this median filtering are shown below;

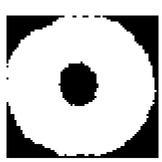
Figure 3.13

Median filter of [16x4] Thresh-holding image on left

3.3.2 FEATURE EXTRACTION IN REGION RECOGNITION

Since we have extended our project to the image recognition as well, we needed some features on which our classifier was supposed to recognize a region. Though we are doing 3D image acquisition, but are not doing object recognition in three dimensions. Presently we have limited ourselves to 2D region recognition. For region features, we chose the features such as area, centroid, major axis, minor axis, bounding box, equivalent diameter, center moments and projection.

The circular projection was a novel idea to implement, because no book/literature has given idea on circular projection, though we find literature on vertical and horizontal projection. In the figures below we show you the circular projection of a scanned object at different orientation. It can be seen that the patterns of these projections remains same for any of the orientation for one object. The straight line on projection shows a constant circumference/turning of the boundaries, while a sudden drop in projection shows the corners. The circular projections of few of the scanned images are shown below.



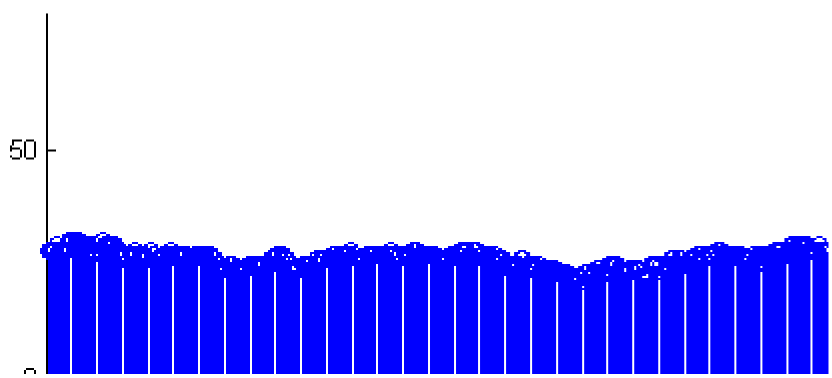


Figure3.14:
Circular region and its Circular projection

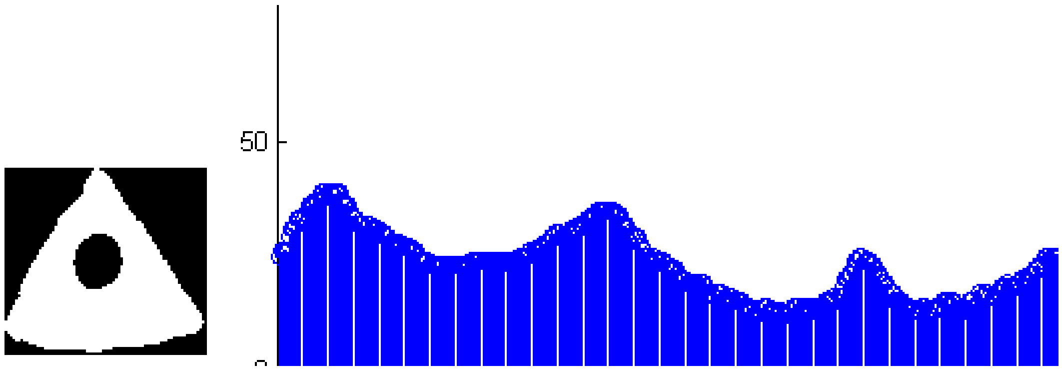


Figure3.15:

Triangular region and its Circular projection

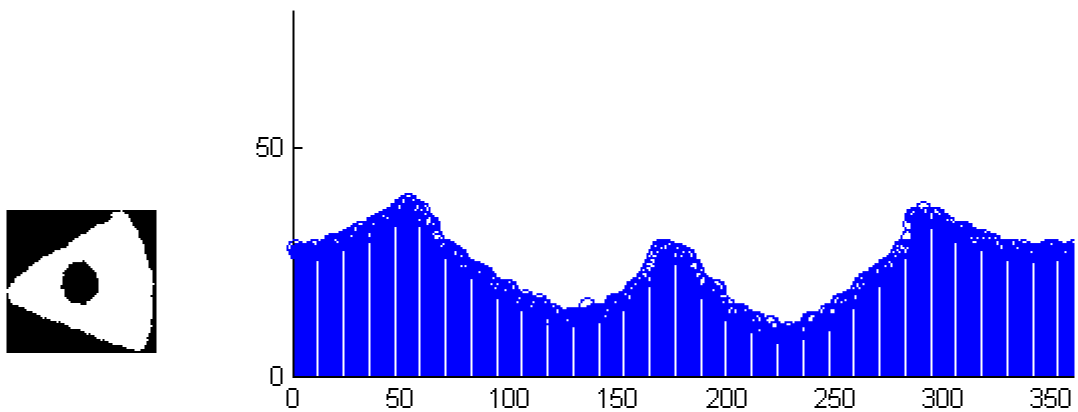


Figure3.16:

Circular region and its Circular projection

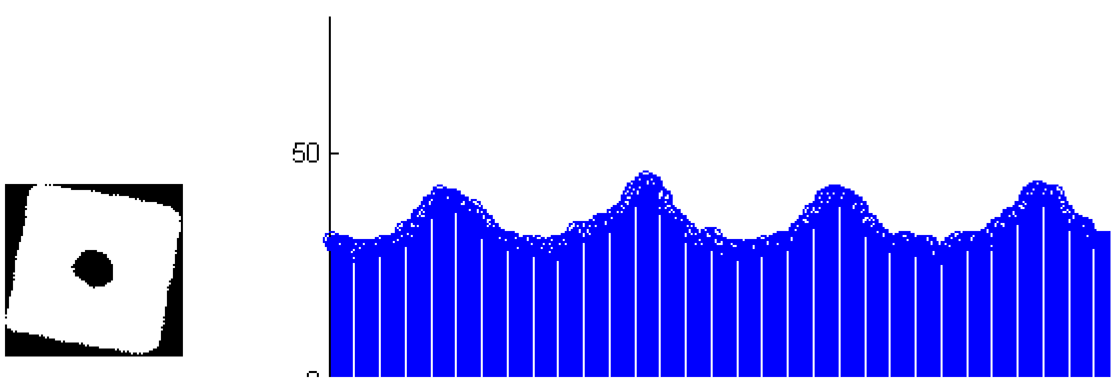


Figure3.17:

Square region and its Circular projection

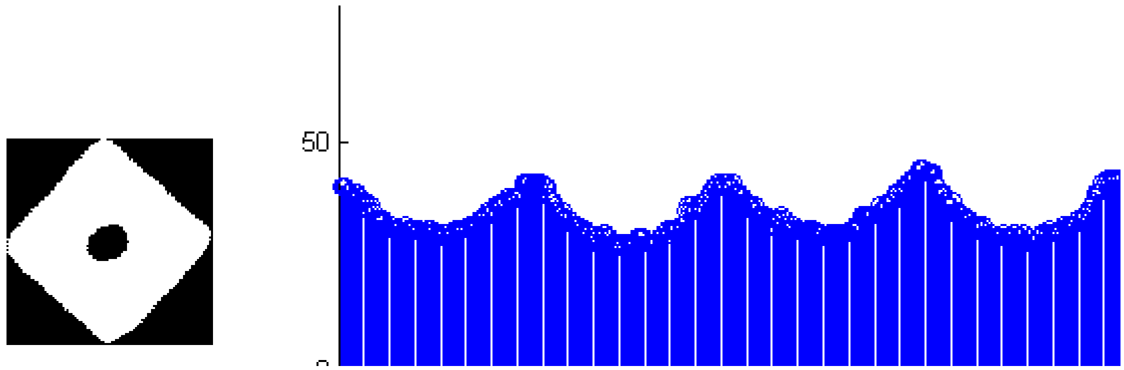


Figure3.18:

Squarer region and its Circular projection

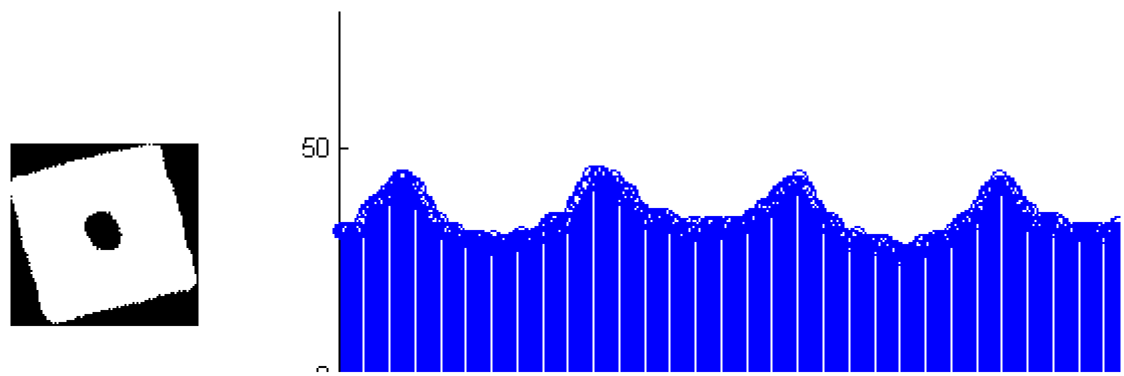


Figure3.19:

Squarer region and its Circular projection

The above results show that the circular region along with circular moments at the centroids, and other features will be very helpful for the classifier to recognize the object.

3.3.3 PROGRAMMING LANGUAGE

We have selected MATLAB as our programming tool because of its powerful graphics and a huge library of tools and functions

MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

- Typical uses include
- Math and computation
- Algorithm development
- Data acquisition
- Modeling, simulation, and prototyping
- Data analysis, exploration, and visualization
- Scientific and engineering graphics
- Application development, including graphical user interface building

MATLAB features a family of add-on application-specific solutions called toolboxes. Very important to most users of MATLAB, toolboxes allow you to learn and apply specialized technology. Toolboxes are comprehensive collections of MATLAB functions (M-files) that extend the MATLAB environment to solve particular classes of problems. Areas in which toolboxes are available include image processing, data acquisition, control systems, neural networks, fuzzy logic and many others.

The MATLAB Language is a high-level matrix/array language with control flow statements, functions, data structures, input/output, and object-oriented programming features. It allows both "programming in the small" to rapidly create quick and dirty throw-away programs, and "programming in the large" to create complete large and complex application programs.

We have used MATLAB to access the parallel port, to grab the images from camera, to process the images, to extract the features of images and have made pleasant to look at, GUI(Graphical User Interface) , all on the single platform of MATLAB6.5

Based on all the analysis we have made so far we will proceed to achieve our goal of designing and developing a 3D profile scanner.

CHAPTER NO.4

4.0 3D PROFILE SCANNER DEVELOPMENT

4.1 BLOCK DIAGRAM OF SCANNER

Structured Light sensing approach uses triangulation to find the ranges. This ranging geometry can be seen in Figure4.1, which depicts the optical components in our built project. Here the laser is projected downward towards objects in the scene. Laser illumination striking an object is observed by the camera to reveal surface profiles, which can be converted into Cartesian range data.

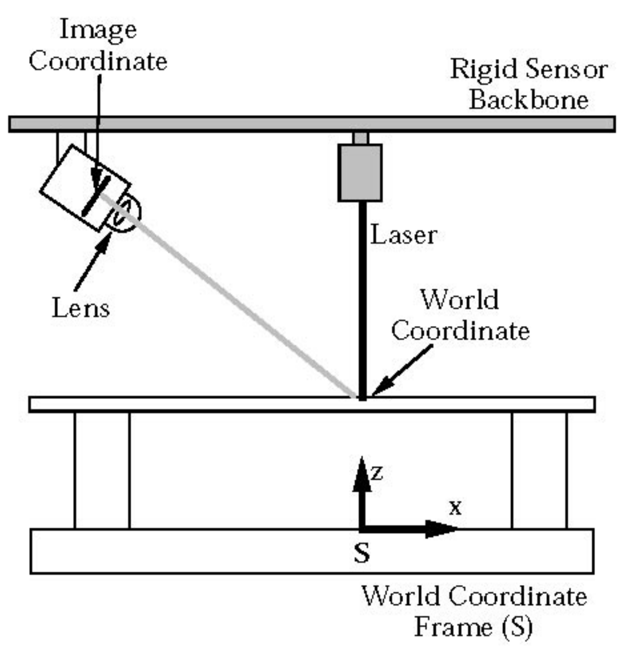


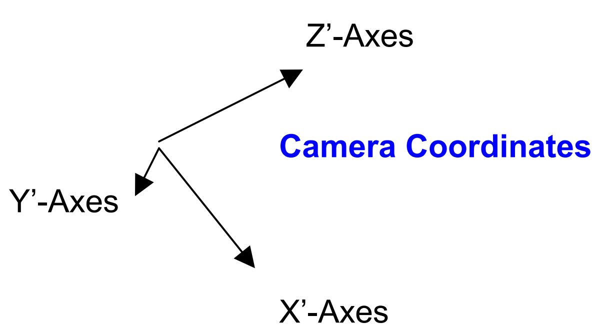
Figure 4.1: The purpose of sensor calibration is to find a mapping between image and world coordinates. In our project this relationship is fixed because of the rigid backbone between the laser and camera.

All the components shown above are enclosed in a black box to avoid stray light to be detected by camera. All the components will be discussed one by one.

4.1.1 BACKBONE GEOMETRY DESIGNS

The aspect of a Structured Light sensor design has to do with the geometry between the camera and laser plane. Fixed-Plane-geometries have advantages in calibration, simplicity and ruggedness due to the absence of any moving optical components. This necessitates some other source of motion in order to acquire range data in 3D. Here a fixed plane geometry is used in conjunction with a conveyer belt.

In a single image the camera capture 2D image of plane ZX. Planer reference geometry is also shown in the figure above. The stepper motor encoder keeps the record of the movement of conveyer along the Y-axes. It stamps each image with the position of Y-axes coordinate. Single image when processed, will give the profile of that section of object in XZ plane. When multiple images are processed and their profile data are placed in an appropriate Y-axes slot, will give a 3D profile of the object.



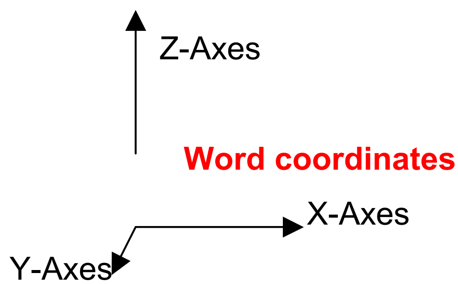


Figure 4.2: the world coordinates and the image coordinates

The angular distance between the laser and the camera is a critical issue. Lower the angle between camera and laser, lesser will be the depth resolution in the image, the camera will detect more intensity of reflected light, and less blind area will be present to the camera. On the contrary if the angle between the camera and the laser is more, it will increase the depth resolution and will give more blind area and less intensity of light will be detected.

We have placed the camera at 60 degrees from horizontal. The laser is pointed vertically downward. The image captured by the camera is in the image coordinates. The geometric relationship between the world coordinates and the image coordinates can be calculated. This is called the image transformation. The transformation matrix can be calculated as shown below.

The relation ship due to rotation around Y-axes is as under:

$$[x' \ y' \ z' \ 1]=[x \ y \ z \ 1] \times \begin{bmatrix} \cos\varnothing & 0 & -\sin\varnothing & 0 \\ 0 & 1 & 0 & 0 \\ \sin\varnothing & 0 & \cos\varnothing & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \text{Eq(4.1)}$$

Where (x , y , z) are points on the world coordinate system. And (x', y', z') are the points on the image coordinate system. And ∅ shows the angle of rotation along the Y axes.

The relation ship due to scaling/resizing, when world coordinates map onto the camera plane, is as under:

$$[x' \ y' \ z' \ 1]=[x \ y \ z \ 1] \times \begin{bmatrix} Sx & 0 & 0 & 0 \\ 0 & Sy & 0 & 0 \\ 0 & 0 & Sz & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \text{Eq(4.2)}$$

Here the SX, Sy and Sz denote the stretching/scaling along the respective axis.

If we know the coordinates (x' , y' , z') then we can calculate (x , y , z). In our case, because of fixed plane geometry, we always have z=0. So from eq(4.1) we derive the world coordinates as under:

$$x = x' / \cos \varnothing$$

$$y = y'$$

And the shrinking factors Sx and Sy can be calculated by simple calibration model, or from known focal lengths of camera. The Calibration model is presented in the figure below:

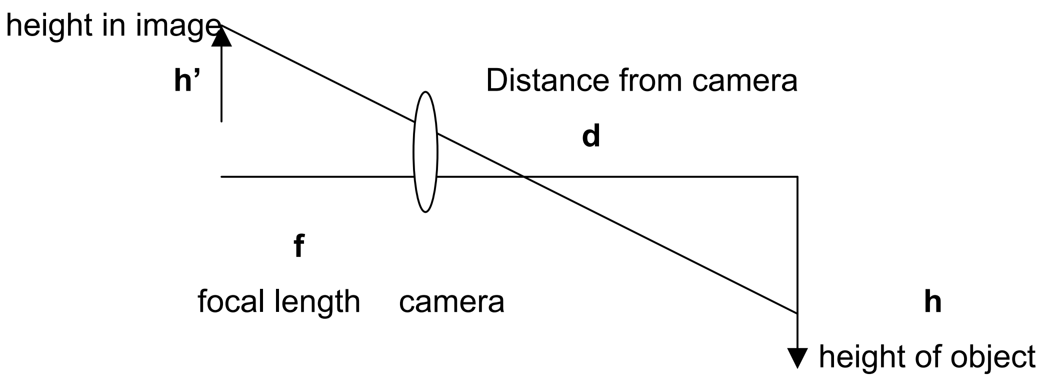


Figure 4.3: Image triangulation

then the stretching coefficients is

Si=h' / h

Or

Si=f / d

The above calculation also suggest that if we know the actual dimensions of the object and we also know the dimensions of object in the sample image then we can derive the coefficients of transformation. And these transformation coefficients can be subsequently applied on the next images.

4.1.2 CAMERA

The analysis on the selection of camera is given in the previous chapter. Initially we had selected the Digital camera for image acquisition. The performance of camera was very good at the start. But later on the performance of camera sensor chip degraded. Even some cells in the sensor array were damaged causing permanent noises at those pixels. This is shown in the previous chapter.

Three digital cameras (1.logitec click smart, 2 Logitech quick cam, 3.Intel) were tested and they did not give good results as compared to analogue camera from 'Sony'. A high quality 'Sony' video camera was selected finally for image acquisition.

We have made two software programs, one to run with the digital camera and other with the analogue camera. Since we managed to get a good quality Sony camera so our final program is based on Sony camera.

4.1.3 LENS

The major factor contributing towards error in our project is the lens. The line produced by the lens is about 3mm thick at the center and with high intensity. At the ends the intensity as well as the thickness of the line also decreases. This left us with smaller area of scan. In the figures below are shown the images of our lens.

Figure 4.4: Images of lens used in our project for line source

4.1.4 CONVEYER SYSTEM

A platform was designed which was supposed to be moved horizontally under a controlled movement. The stepper motor were chosen for this purpose. The step resolution of the motor is 1degree per step. The arc length for 1 degree is calculated as under

$$Arc = 2 \times \prod \times r \ / \ 360$$

For radius of 7mm, the arc length becomes

$$Arc = 2 \times \prod \times 7 / 360 = 0.1 \text{ mm}$$

If we move the motor in steps of ten, then for each large step the arc length will become about 1mm

$$Arc = 1\text{mm}$$

Hence by now we know that horizontal images which are processed, are 1mm apart.

4.1.5 STEPPER MOTOR DRIVER CIRCUIT

Since the parallel port of the computer is controlling the stepper motors, so we do not need a complex control circuit. However we need a driver circuit to drive the motors with appropriate current. For that we have used an array of Darlington pair to provide sufficient current. The circuit diagram is shown below

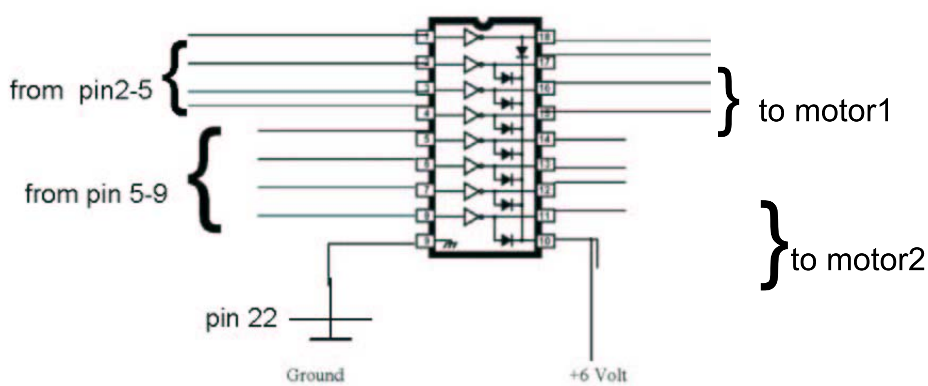


Figure 4.5: Circuit diagram to drive the motor

Each current buffer in the IC package of ULN 2803A consist of a Darlington pair. The circuit diagram of the Darlington pair is as under:

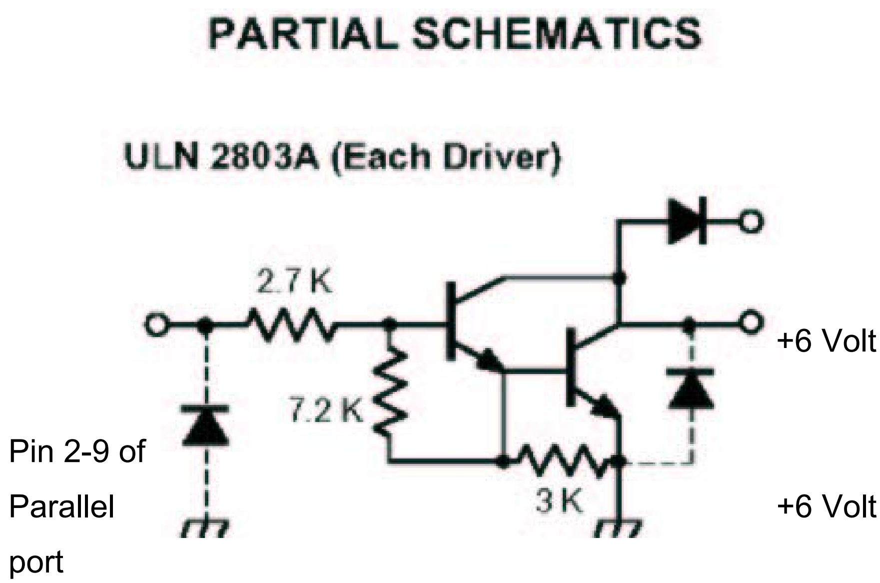


Figure 4.6: Circuit diagram of each buffer in above IC

The current through 7.2K will be

I = V / R
=0.7 / 7.2K
=97.2 microA

The current through 3K will be

I = V / R
=0.7 / 3K
=233 microA

The current through 2.7K will be

$$I = V / R$$
$$= (4.5-1.4) / 3K$$
$$= 1000 \text{ microA}$$

Hence current through base1 B1 is

$$I_{b1} = 1000-97$$
$$= 903 \text{ microA}$$

This will push the Tr1 near-saturation but not in saturation. The current through Emitter1 of Tr1 will be 180 mA (903micro x 200). Out of this 180mA, 136mA will pass towards 3K-ohm resistance and remaining 44mA is sufficient to drive the Tr2 into complete saturation.

$$I_{b2} = 44mA$$

For reference see the datasheet of the IC 2803A attached in the last of this document. Typical output saturation current is about 600mA which is sufficient to drive our motor

4.1.5.1 Stepper Motor control program

To control the stepper motor we are using the computer and its parallel port. Pin2-9 are controlled via a program in the MATLAB. The software initializes the port and sends a pattern of bits on the port. The bit pattern is [1 0 0 0]. To move motor1 one step toward right the above bit pattern is circular shifted to right and sent to the port. Similarly for left direction the same bit pattern is circularly shifted in steps towards left.

The following commands moves the motor to left by 10 steps in MATLAB

```
dio = digitalio('parallel','LPT1');

addline(dio,0:7,0,'out');

j=logical([0 0 0 1]);

for i=1:10,

   j=circshift(j,[1 -1]);
   putvalue (  dio.Line(0:4) , j );

end
delete(dio)
clear dio
```

Similarly we can control the direction and the precise number of steps to move a motor. Hence we do not need a separate hardware or circuit to drive the motor.

4.1.6 LASER

The commercially available laser was selected because of its easy availability and cheaper rates.

4.1.6.1 Laser switch circuit

The following circuit shows the diagram to control switching of the laser diode. Laser used is the commercial one and is operated on 5 Volts.

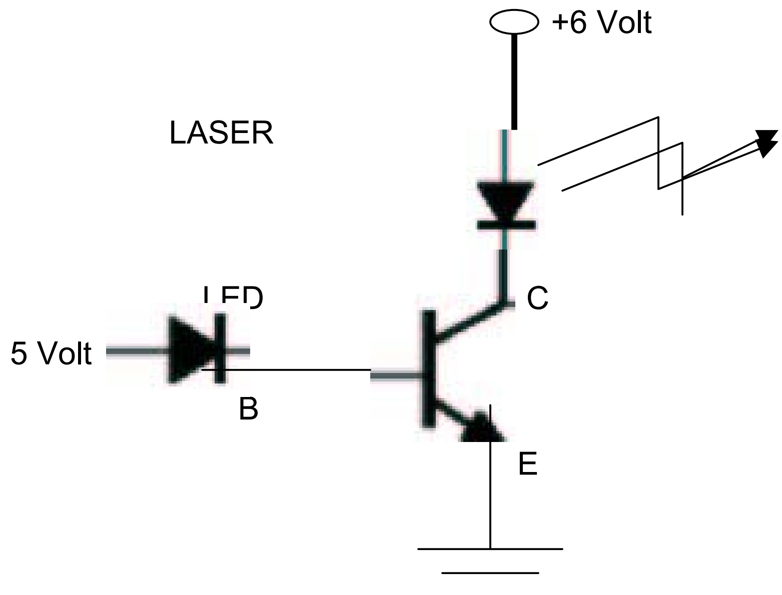


Figure 4.7: Circuit diagram to switch the laser on/off

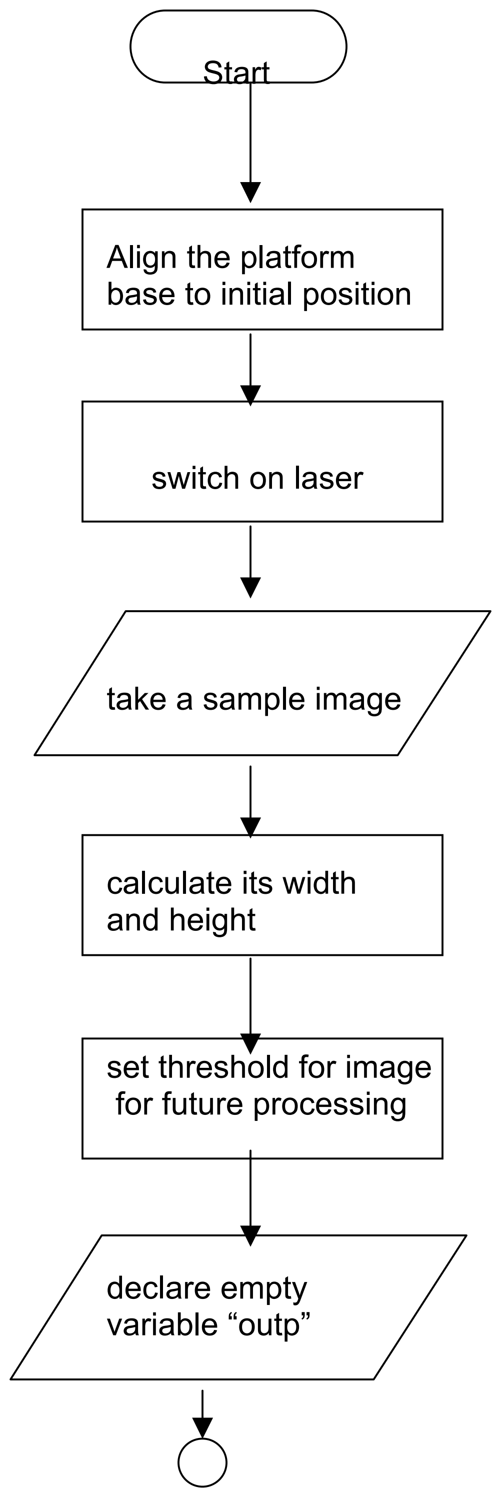
The parallel port gives an output current of 2mA at 5 volt. Hence at 2mA current at the base will cause the Transistor collector current to be

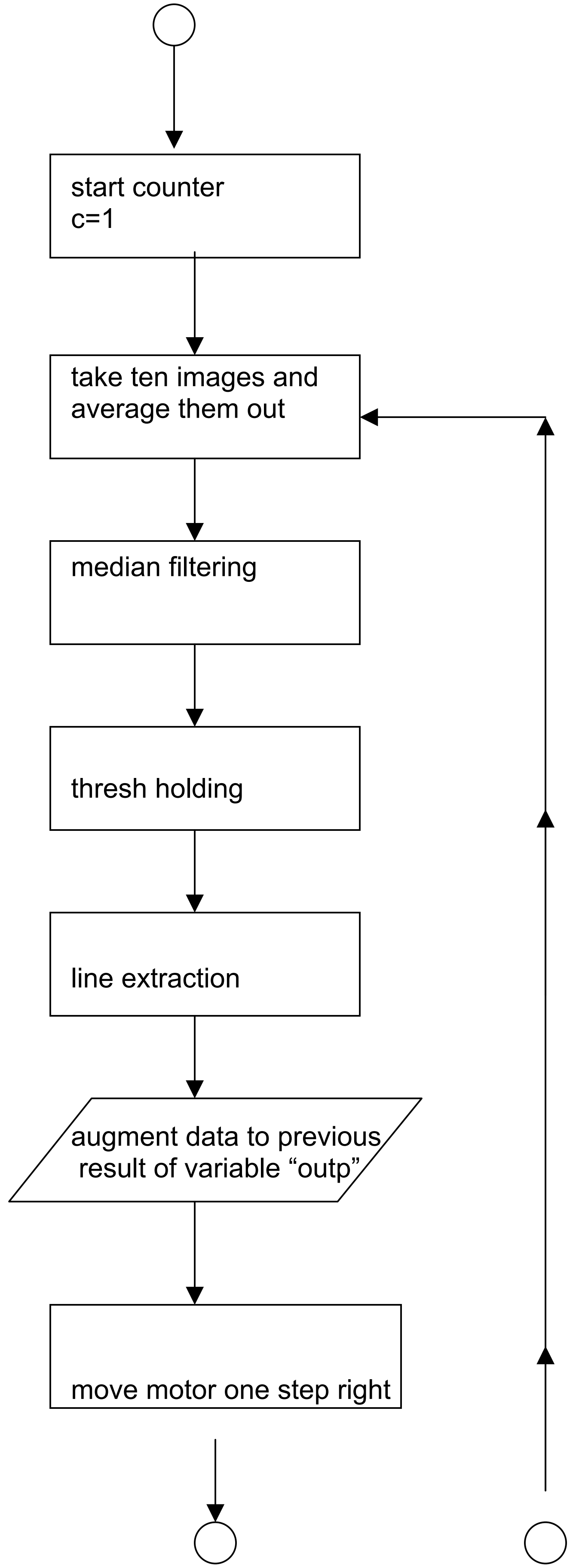
$$I_c = 200 \times 2m\,A$$
$$= 400mA$$

The laser diode will have voltage across it equal to 4.5volt. And the rest of the voltage will drop across V_{CE}. The parallel port will control the input to the base as we have controlled the motor.

4.2 FLOW DIAGRAM OF THE SYSTEM

The flow diagram of our system is as shown in the figure below.




start counter
c=1
take ten images and
average them out
median filtering
thresh holding
line extraction
augment data to previous
result of variable “outp”
move motor one step right

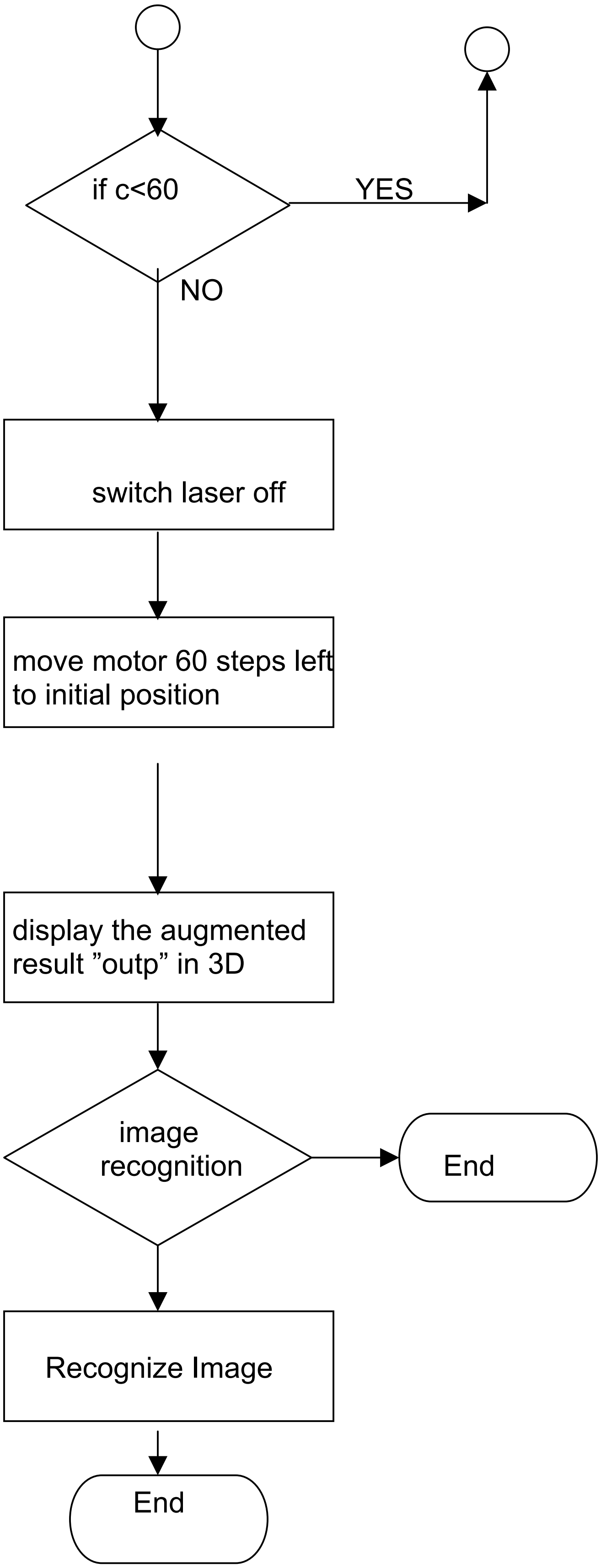


Figure 4.8: Flow diagram of sequences of scanner

4.2.1 Flow Diagram of the Image Processing

The software of the above flow chart and the software for the GUI are presented at the end of this document. The GUI is also created in MATLAB. The image processing flow diagram can also be represented as follows.

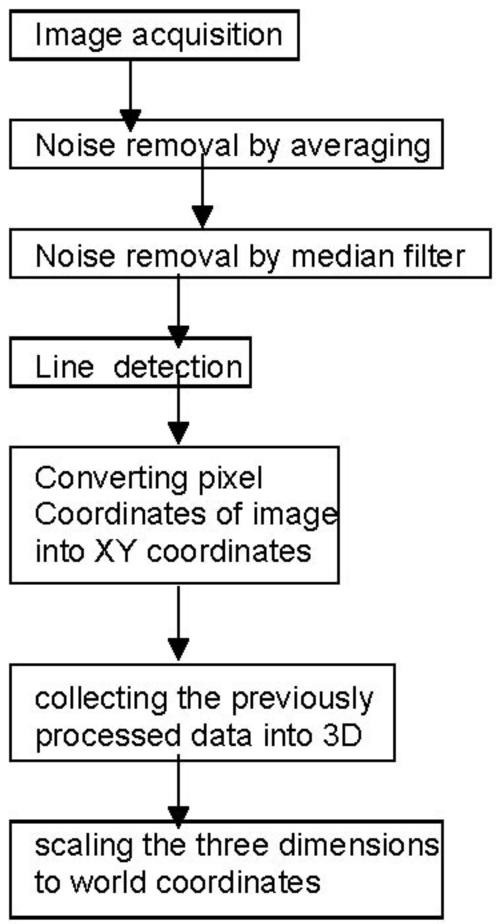


Figure 4.9: Flow diagram of Image processing events

4.2.2 Flow Diagram of the Image Recognition

As we have mentioned earlier that we have limited ourselves to image recognition in 2D only. So we designed the software for region recognition only. Following features were selected for recognition of the images.

- Distance of centroid
- Area of pixels
- Length of major axes
- Length of minor axes
- Equivalent diameter
- Area of bounding box
- Second moment from centroid
- Circular projections

The image recognition flow diagram is as under

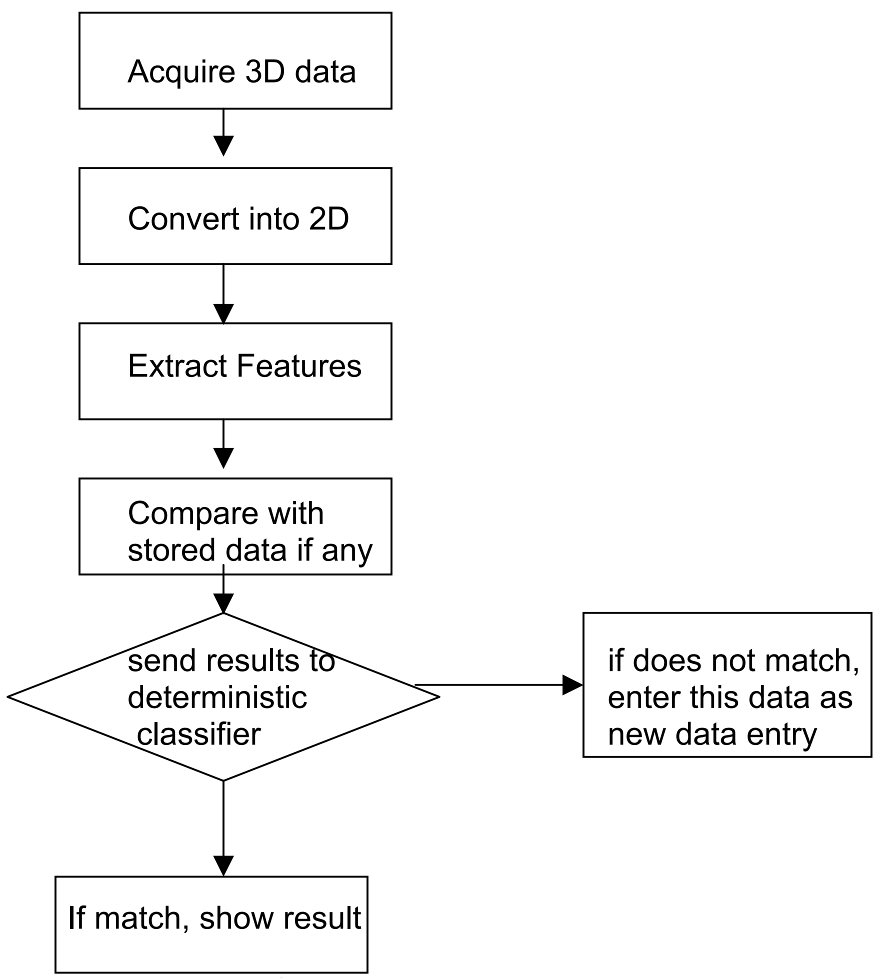


Figure 4.10: Flow diagram of image recognition

4.3 CALIBRATION MODEL

"Calibration" refers to a process in which the location of the world frame is defined locally to the sensor. Its position is established with the convenience of sensor calibration in mind.

Structured Light ranging is fundamentally a process of triangulation. Calibration is sometimes approached as a process of isolating explicit geometrical parameters of this ranging triangle. In general the range calculations are described using the law of sine together with a pinhole model of the camera. Note that this would necessitate two separate calibration procedures, each of which would contribute errors. These two steps are described at the start of this chapter under the heading of "Backbone Geometry Designs". These two steps are due to effects of rotation of camera axes and image scaling on the camera plane.

A one step calibration procedure has been developed for this project. This process is very similar to the Two Planes method of camera calibration. In general any Fixed-Plane Structured Light system can be calibrated in a one step procedure because of the rigid mapping between image and world coordinates. One step procedures have advantages in terms of accuracy and simplicity. Once you know the ratio between true length of a scanned object along X-axes in the world coordinates and its dimension on the image coordinates, then this scaling ratio will be applied for all subsequent images to calculate X-Axes scaling. The same procedure will be done for Y & Z-Axis.

For the purpose of calibration we use a circular piece of object (cylindrical), because it has same length along X and Y Axis. The following image show the un calibrated view of out object.

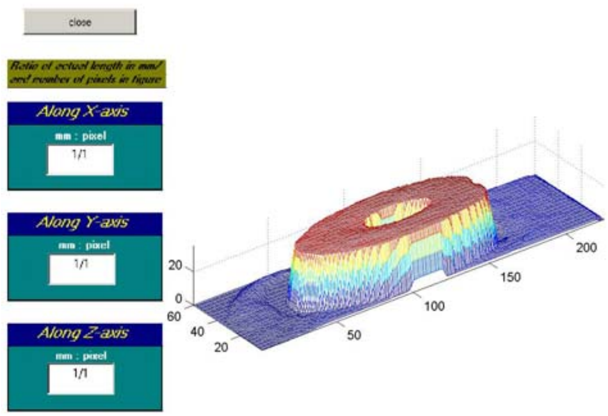


Figure 4.11: un-calibrated output of scanner for an object

And in the figure below we show the calibrated view of the same object.

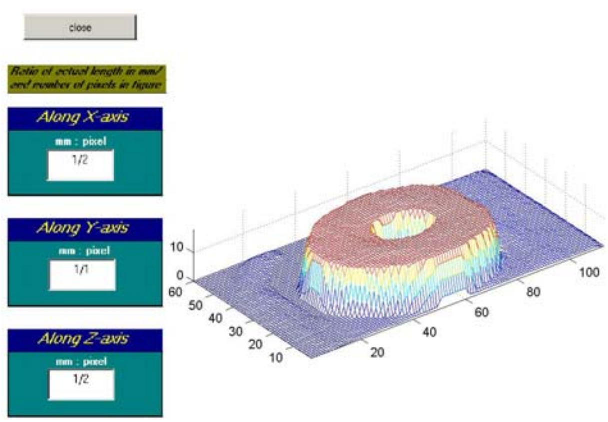


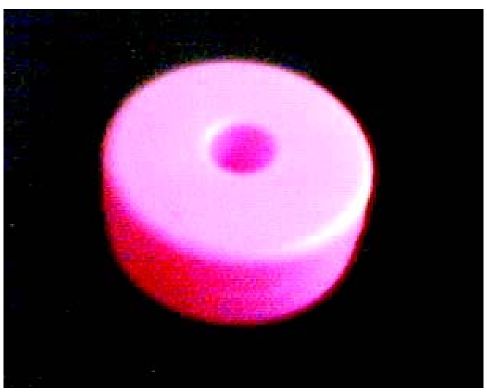
Figure 4.12: Calibrated output of scanner for the same object

CHAPTER NO.5

5.0 RESULTS AND RECOMMENDATION

5.1 RESULTS OF EXPERIMENTS ON APPARATUS

Performance benchmarks are very important during sensor research. These give measures that are vital for both automated and manual interpretation of data. In our defined goal we had mentioned that our objective was to design a scanner for simple geometric objects. That is input to the scanner is predefined and limited. We scanned few objects and successfully accomplished to obtain its surface height profile. Examples of three objects are presented here. The obtained range data and their respective scenes are presented in Figures below.



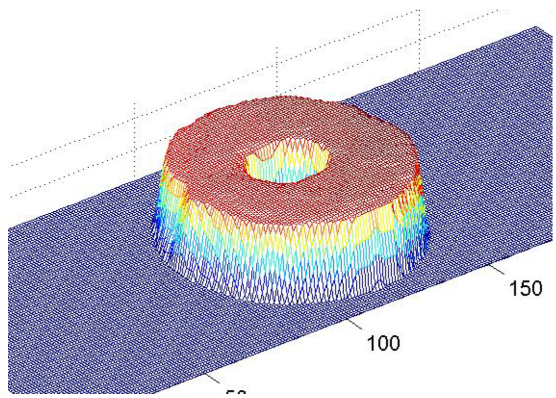
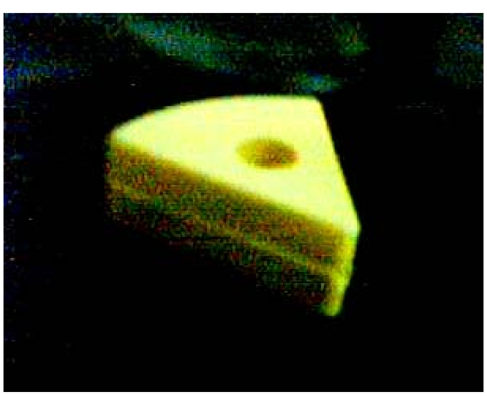


Figure 5.1 Original object scanned 3D presentation of scanned data



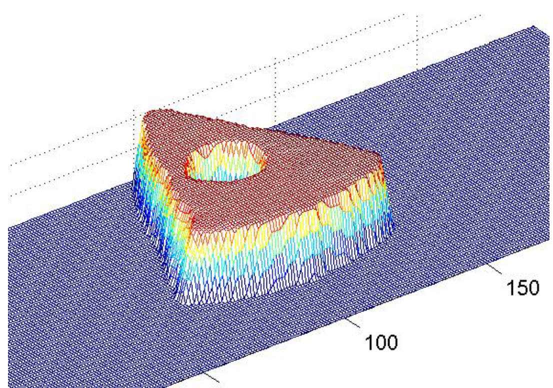
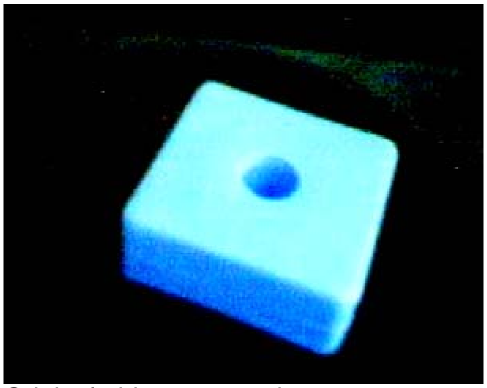
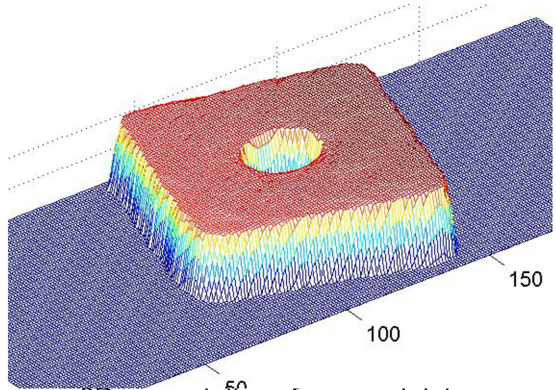


Figure 5.2 Original object scanned 3D presentation of scanned data



Original object scanned



3D presentation of scanned data

Since this project was very new in its kind and we were the first one to built this project in Pakistan at student level, so we had restricted ourselves to input of simple geometrical surfaces. As we were bounded by many limitations, so we had to restrict our input objects as well. There were few other fundamental limitations also on this system approach, which are discussed below.

5.2 FUNDAMENTAL LIMITATIONS

Some discussion is appropriate concerning the fundamental limitations of Structured Light ranging.

5.2.1 SURFACE REFLECTIVITY

Surface reflectivity is one such factor. For reliable range data, a scanned object should have surfaces with lambertian reflectivity. Specular surfaces will often reflect too much of the structured illumination away from the camera. This produces voids in range data. Note that the degree of surface reflectivity can be counter-intuitive when dealing with near-InfraRed (NIR) laser systems, since these wavelengths are beyond the human visual range.

5.2.2 SHADOWING

Shadowing is also a fundamental problem in Structured Light systems. This occurs when object geometries occlude the laser from the field of view of the camera. Shadowing effects can be reduced when the camera to laser baseline distance is shortened. However, this also increases the sensitivity of the system to measurement noise.

5.2.3 AMBIENT LIGHTING

Ambient lighting is an important design issue. It can be a limitation to Structured Light or other types of optical ranging if ambient sources are unfavorable and cannot be controlled. Monochromatic illumination and matched optical filters for cameras can be used to tackle this problem, provided the ambient lighting can be setup on a different wavelength. Florescent lighting and near-IR Structured Light ranging make a very nice complementary pair. This combination provides ample room light without contaminating range imagery. Incandescent light is a very poor choice for use with near-IR Structured Light systems.

5.3 SENSITIVITY ANALYSIS OF STRUCTURED LIGHT SENSORS

The question of sensitivity is concerned with the relationship between the accuracy of range measurements to sources of error in the acquisition process. The geometry of the optical paths involved in ranging plays an important role in determining how errors during acquisition are amplified in range measurements. For 3D profile scanner, a simpler approach has been taken. Referring to figure drawn below, variations in image coordinates, $d\theta$, produce a displacement of dw, at the standoff of the sensor. Because the laser profile is assumed to be roughly horizontal in each camera image and each column is analyzed individually during pixel-level processing, only the sensitivity of height variations to vertical image displacements is considered (actually in the center of the image dy = dw for lateral image displacements). The angle between the laser emission and the camera sighting determines the sensitivity of height errors. As seen in the figure, the amplifying factor is

$$dz / dw = 1 / \sin\theta$$

where θ is the angle between the laser emission and camera sighting. This is related to changes in height by sin θ.

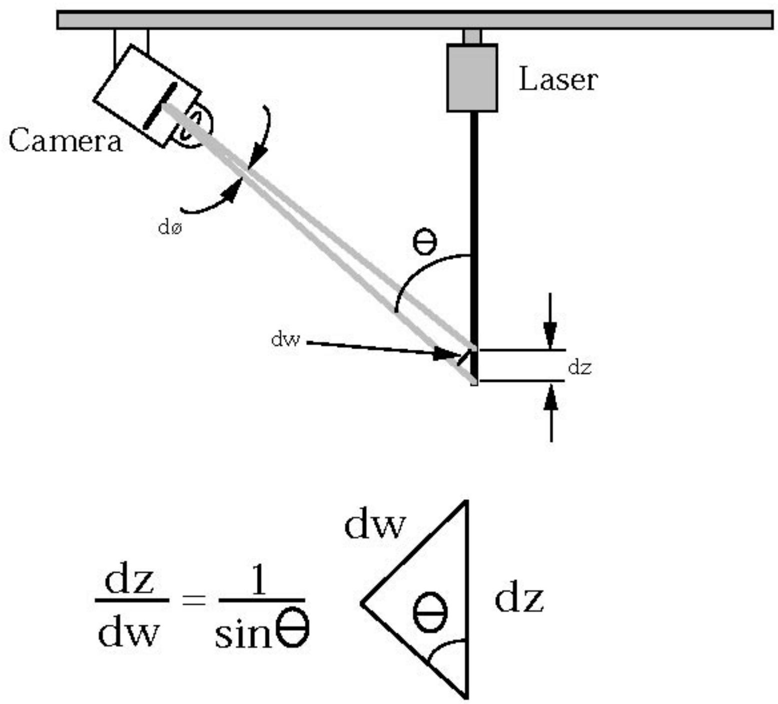


Figure 5.5 Sensitivity Analysis of Profile Scanner

In Fixed-Plane Structure Light sensors this sensitivity factor varies in a continuous fashion across the laser plane because θ varies somewhat across the laser profile (with motion in and out of the paper in the figure below). As the sensitivity improves, the degree of shadowing increases. The ranging geometry for our 3D Profile scanner was chosen to somewhat favor sensitivity versus shadowing. Freedom to increase shadowing was deemed acceptable because mostly convex objects with relatively slow rates of curvature were targeted for use with our project.

5.4 PROBLEMS AND CHALLENGES

During the whole process of design and implementation of this project, we faced a lot of problems. Few challenges could not be catered completely and were major reasons for the sensitivity of our results in terms of accuracy. We have tackled with all of these problems in a compromising manner to achieve our goal of 3D depth extraction. And ultimately we succeeded in making 3D profile scanner with acceptable results. Few of the problems are mentioned here.

5.4.1 LINE SOURCE

Our project was mainly relying on scanning of the object by laser line source. This type of light source is not very common. Despite our search from two organizations, i.e. Pakistan Atomic Energy Commission (PAEC) and KRL, we could not get any help. Neither are line source generators available in the open market. Hence we resolved towards local built cylindrical lens. The analysis of this lens is given in chapter 3. The thickness of laser was 3mm at the center, hence maximum inaccuracy of 3mm.

5.4.2 OPTICAL FILTERS

Had we had the optical filters, we would have reduced the noises in the images, consequently resulting in shorter algorithms. While using optical filters we also had to use laser of that particular frequency. Optical filters were available with PAC but in the pass band of IR, but that too were refused to us. Due to this reason we had to choose different algorithms, to remove noises. As in our case the noise not in the proximity of actual-image-line will cause drastic errors. And in doing so, the software takes about 170 second to scan 80 mm length of the platform.

5.4.3 HARDWARE DESIGN

To design any thing for the very first time is not an easy task. Because whenever such designs are implemented, always there is some draw back in the first design and you have to redesign for improvement. Specially when it comes to hardware, we have no prior experience. In our initial design all the components were working fine but when we started grabbing the images, the camera started vibrating due to movement of conveyer belt. So we had to redesign our rigid bone structure. Finally a rigid structure of wooden box was selected. Similarly to reduce the noises from stray light, the wooden box was painted black and rubber sealing was pasted at the openings.

5.4.4 SCARCITY OF LITERATURE ON THIS WORK

Despite the longevity of research in Structured Light sensing, a limited amount of published works focus on fundamental design and calibration issues. There is very little work available on the structured light range sensing.

5.5 RECOMMENDATIONS FOR IMPROVEMENTS

This project was very new in its kind and we succeeded to accomplish our defined goals. Since we have experienced through all the design and implementation process of this project, so we are in a position to give further recommendations to improve it. Few of them are listed below:

- The real time image processing can be implemented using VLSI.

- Image recognition was not our initial goal but we have tried it. We have limited ourselves to the 2D region recognition, but actual application extends to 3D object recognition.

- Having multiple camera views can reduce blind arcs due to lines hidden outside the line of sight of camera.

- Accuracy can be increased by having good line source

- Removing noises by using optical filter and high power laser can increase speed.

5.6 APPLICATIONS OF 3D DEPTH EXTRACTOR

Such devices can be used in a large variety of application including machine vision, medical diagnosis etc. Typical applications include

- Animation, Gaming
- 3D Movies
- Virtual Reality
- Reverse Engineering
- Non-Contact Inspection
- Museums, Archeologists, Insurance (the acquisition of Cultural Heritage artifacts)
- Machine vision
- Robot guidance and controls
- Object orientation

5.7 CONCLUDING REMARKS

Across the diverse spectrum of Machine Vision applications, the main objective is often the same, to extract useful information from image inputs. For tasks requiring 3D information, Machine Vision techniques may be grouped into passive or active approaches. Active approaches, such as Structured Light, use specialized illumination sources to overcome the ambiguities associated with passive methods. Despite the longevity of research in Structured Light sensing, a limited amount of published works focus on fundamental design and calibration issues. This document has included an introduction to the ranging process, discussions of design tradeoff, calibration methods, and performance benchmarks. Structured Light ranging has some particularly interesting advantages that allow sensors to be customized for the specific requirements of an application. This project is a Structured Light sensor that has been designed to scan moving objects. It uses a plane of laser light that is mounted in a fixed geometry. The laser illuminates scenes, allowing vertical profiles of range data to be acquired. Range sensors can be used to form the foundations of larger end-to-end Machine Vision systems.