Hochschule Bremen
City University of Applied Sciences

HSB

Advanced Topics of Laser Techniques (ATL)

MSc in Electronics engineering

Faculty Electrical Engineering & Computer Sciences, HSB

A Project on:

LASER TRIANGULATION

Submitted To:

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Abstract:

Laser Triangulation is a technology refers to the optical distance measurement. It is used for non-contact measurements and to measure small targets as spot size of laser beam is very small. This project fully carried out in simulation and the main purpose of the project is to implement the distance measurement method of the Nguyen and Blackburn paper. A program in Python also developed which automatically calculates the simulated data to find the Range/ Distance of the object from the camera. The manual measurements are also done to compare the results with simulated data.

ACKNOWLEDGEMENT

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1. Introduction:

Human has stereoscopic vision which enable us to visualize a sense of three-dimensional shape formed by visual inputs. Two eyes enable us to perceive depth, in addition to width and height. So, to extrapolate a 3-dimensional vision using the two different 2-D images passed from eyes to brains is a natural technique but using cameras to generate an image for gaining required information such as distance is challenging. There are several technique for non-contact distance measurement, one of the most popular technique used for non-contact distance measurements is Laser Triangulation. [1]

Triangulation means distance measurement by angle calculation. In measurement technology, a Sensor projects a laser spot onto the Measurement object . The reflected light falls incident onto a receiving element at a certain angle depending on the distance.

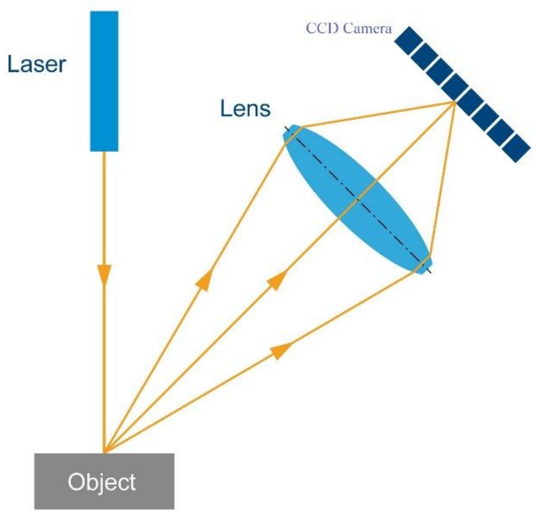

Figure 1-1 Laser triangulation for Distance measurement[2].

A machine-vision technique is used in Laser triangulation for 3 dimensional measurements. In this, Laser light is pointed towards the object and CCD camera placed in such way so that the backscattered light from the object can be captured by the camera through a focusing lens. The CCD camera can detect the signal and create a image. As this project carried out only in simulation, a lens and an image plane consider as the camera.

2. Theoretical Background

Triangulation is the process to determine the location of a point by forming triangles to it from known points. It involves only angle measurements, rather than measuring distances to the point directly. I the figure, *PI, P2* and *P3* represent reference point camera, laser source and the target point.

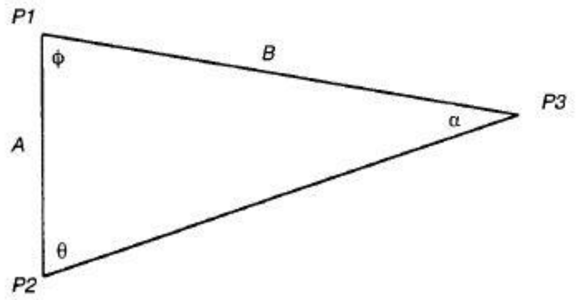

Figure 2-1: Configuration for triangulation ranging.

Theoretically, the baseline distance between source and sensor as well as sensor and source angles are used to determine distance via triangulation. Configuration for triangulation ranging shows in figure 2-1. The range *B* can be determined by the value of the baseline separation *A* and the angles α and **θ** using the law of sines:

$$B = A\frac{sin\theta}{\sin a}$$

But the baseline separation and angles are difficult to Measure accurately. Hoa G. Nguyen Michael R. Blackburn demonstrated a technique for obtaining range information via laser triangulation without knowing the value of A and the angles in the paper “A Simple Method for Range Finding via Laser Triangulation” published in 1995. The same method is used in the simulation of this project. [3]

3. Methodology:

The setup for Nguyen and Blackburn approach for triangulation shows in figure 3-1.

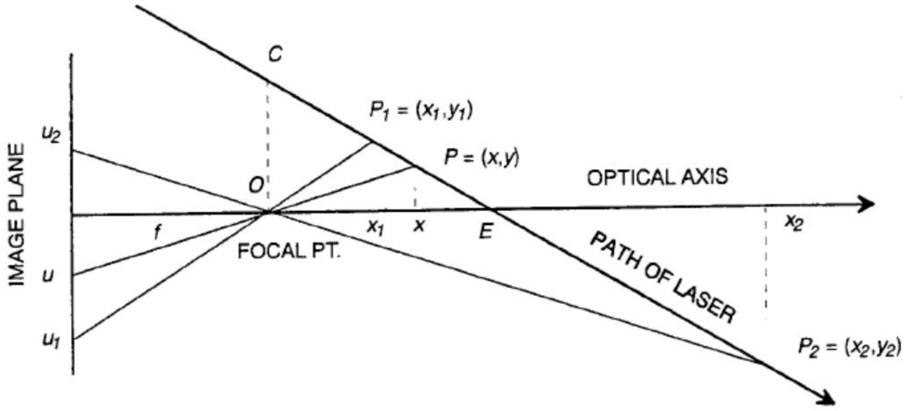

Figure 3-1: Nguyen & Blackburn Principle: Setup for Laser and Camera

In this setup,the camera position is represented by image plane; the laser is exactly above the camera. The point of interest is represented as P and CE is the path of the laser and at point E, it intersects the optical axis.The point **u** is the vertical projection of point **P** on the camera. X_1 and X_2 are the vertical projection of point P_1 and P_2 on optical axis which are two points used in the calibration to find the range of the object. Here, u_1 and u_2 are also the projections of P_1, P_2 on Image Plane.

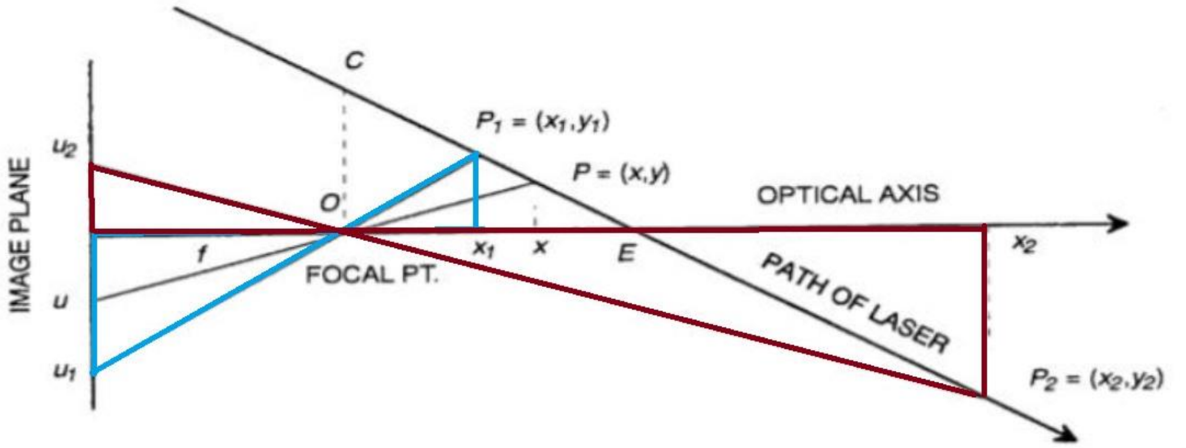

Figure 3-2: Similar Triangle

To find out the value of x, the following equations can be written from the similar triangles shown in the highlighted part of figure 3-2.

$$\frac{y_1}{x_1} = \frac{u_1}{f} \text{ and } \frac{y_2}{x_2} = \frac{u_2}{f} \qquad (1)$$

The slope *(m)* of the laser path and the y-intercept (c, the height of point C) are:

$$m = \frac{y_2 - y_1}{x_2 - x_1} \text{ and } c = y_2 - mx_2 \qquad (2)$$

Substituting equation 2 into equation 3 to eliminate v; and *y2*, we have:

$$m = \frac{u^2 x^2 - u_1 x_1}{f(x_2 - x_1)} \text{ and } c = \frac{u_2 x_2}{f} - mx_2 \qquad (3)$$

Now solving for x and y,

$$y = \frac{ux}{f} \qquad (4)$$

The laser beam path from the figure is given by

$$y = mx + c \qquad (5)$$

After solving equations 4 and 5 and simplifyin using equation 3, we get

$$x = \frac{N}{ud - k} \qquad (6)$$

After calibration process we get,

$$\left.\begin{aligned} d &= x_2 - x_1 \\ k &= u_2 x_2 - u_1 x_1 \\ N &= (u_1 - u_2) x_1 x_2 \end{aligned}\right\} \qquad (7)$$

Using these equations in python we canget the distance X of object from the camera with help of those calibrated projection points u_1 and u_2.[3]

4. OpticStudio Software:

OpticStudio is a productof Zemax company which is commonly used optical design program for Microsoft Windows. OpticStudio's user interface includes some tools and wizards which enable efficient simulation and design of any optical system. It is used for the design and analysis of both imaging and illumination systems. It works by ray tracing—modelling the propagation of rays through an optical system. [4]

5. Measurement Approach:

The following septs mentioned in figure5-1 are followed to measure the distance by triangulation. First of all, need to design a simulation setup in Zemax software, the Ray tracing and data collection. A python program will be written which can calculate the centroid the tracing beam spot on the Image plane and also to calculate the desired Distance according to the Nguyen and Blackburn's method.

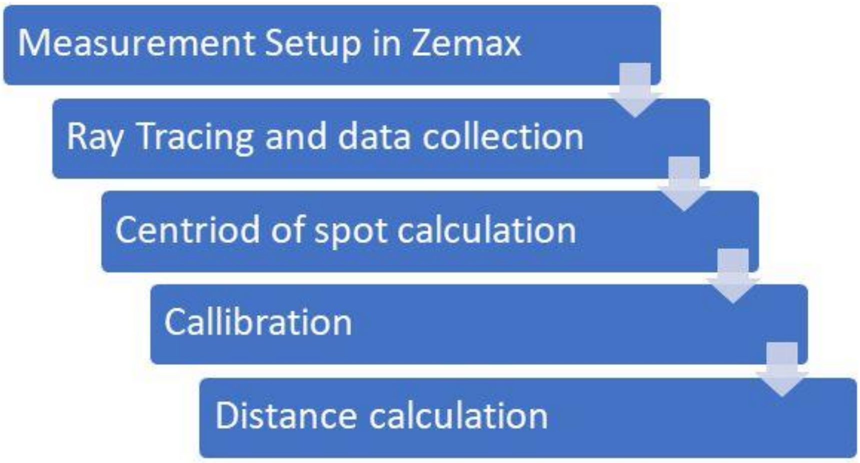

Figure 5-1: Measurement Approach

5.1 Simulation Setup:

The measurement setup includes following components:

1. Laser Source

2. Object Under test

3. Focusing Lens

4. Image Plane

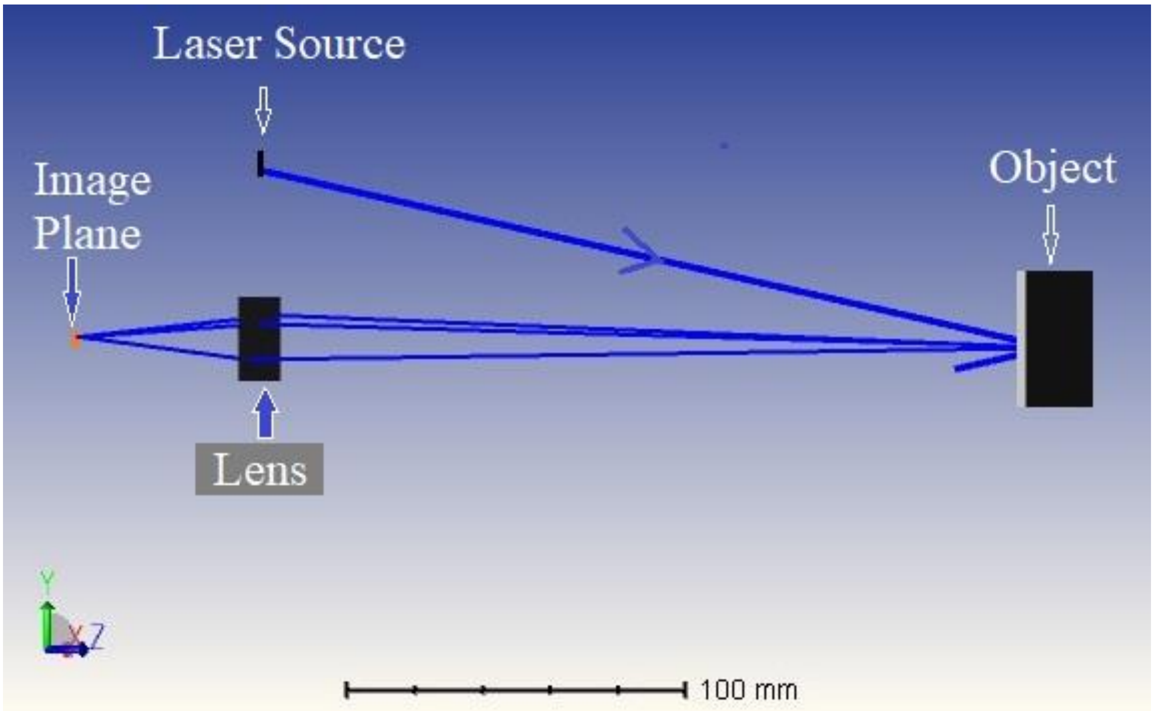

Figure 5-2: Measurement Setup

In the OpticStudio software, the measurement setup (shown in figure 5-2) is created which consists of Gaussian Laser source, Object under test, Lens and Image plane. The Lens and the Image plane together represent the CCD camera mentioned in the Nguyen and Blackburn's method for Range finding using Laser Triangulation. In this setup,the laser beam is focused on the object under test and this laser beam is scattered back towards image plane through Lens. The object under test is basically placed on the same axis as that of Focusing lens and Image plane.

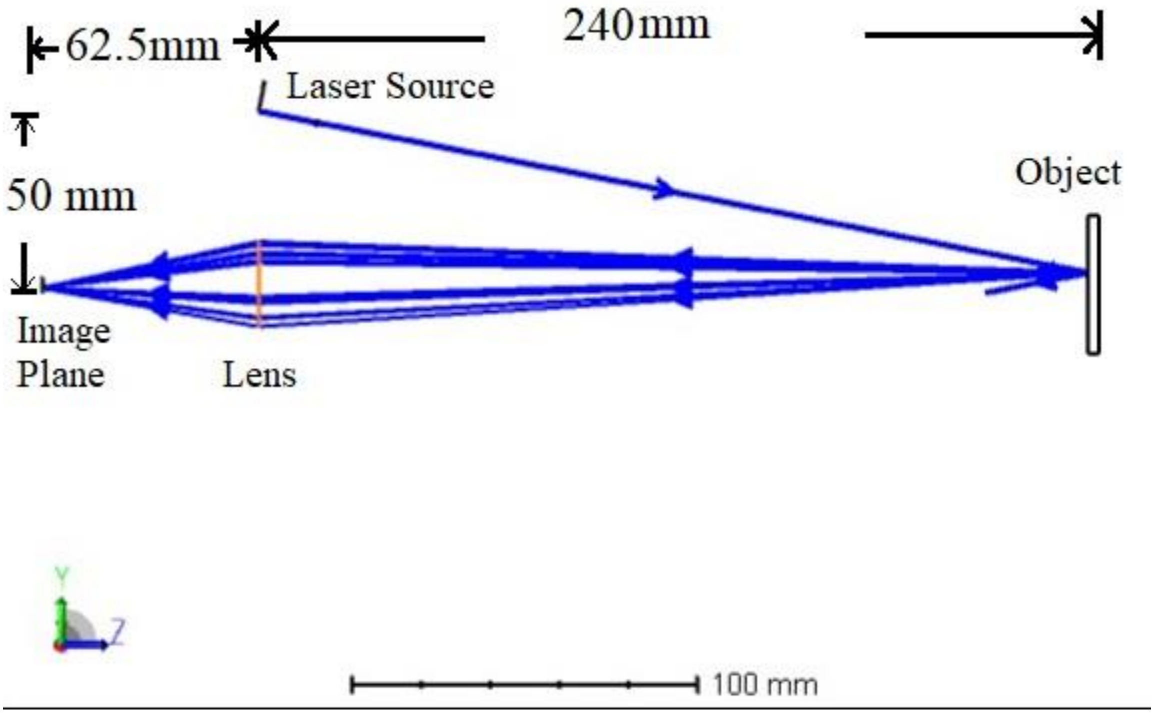

Figure 5-3: Distances among the Components

Figure 5-3 shows the distances among the components of the Laser triangulation setup on Zemax. The initial position of the Object under test is consider as the reference point (0,0,0) for Laser Source and the Lens but the position of the lens consider as the reference point of Image plane. Gaussian source type laser is used with beam size 0.5 and power 1 watt. Object Under test is a rectangular Volume with size (40x40) mm, which material type is Mirror. Lens is a Paraxial type with size (25x25) mm and Image Plane is a Detector rectangle which material is Absorb type with size (5x5) mm. The positions of the components are mentioned in the Table 1.

Table 1 Positions of the Components

Device Name	**Type**	**Position(X, Y, Z)**	**Tilt (X, Y, Z)**	**Size (X half width*Y half width)**
Laser Source	Source Gaussian	0, 50, -240	11, 0, 0	(Beam Size 0.5)
Object Under test	Rectangular Volume	0, 0, 0	0, 0, 0	20*20
Lens	Paraxial Lens	0, 0, -240	0, 0, 0	12.5*12.5
Image Plane	Detector Rectangle	0, 0, -62.5	0, 0, 0	2.5*2.5

5.2 Ray Tracing and Centroid Calculation:

The scattered rays from Object under test are captured on Image Plane through the lens by ray tracing. Figure 5-4 to 5-7 show the laser beam spot on the image plane at different z positions. It can be clearly observed that with the change of Object position's to negative direction the beam spot moves negative direction of Y axis (downward) and with the change of Object position's to positive direction the beam spot moves positive direction of Y axis (upwards). The centroid of the spot need to be calculated for corresponding position of Object by the data of laser beam spot in 'txt' file by python programing.[appendix]

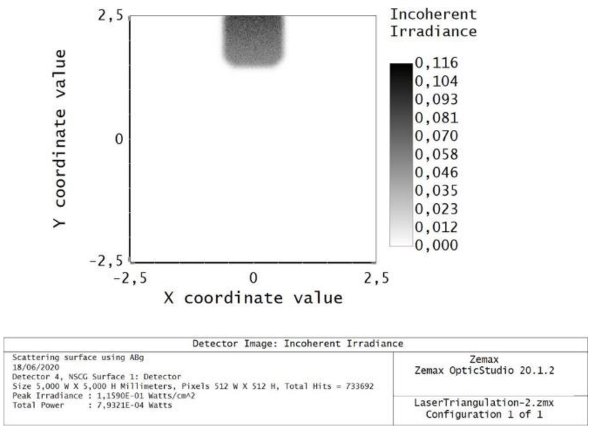

Figure 5-4: Z position 70

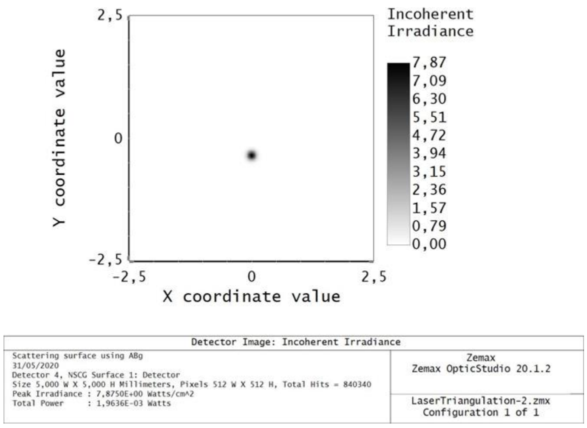

Figure 5-5: Z position 10

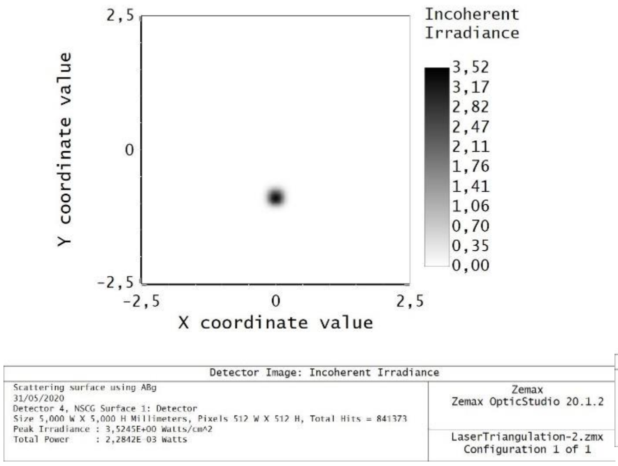

Figure 5-6: Z position 0

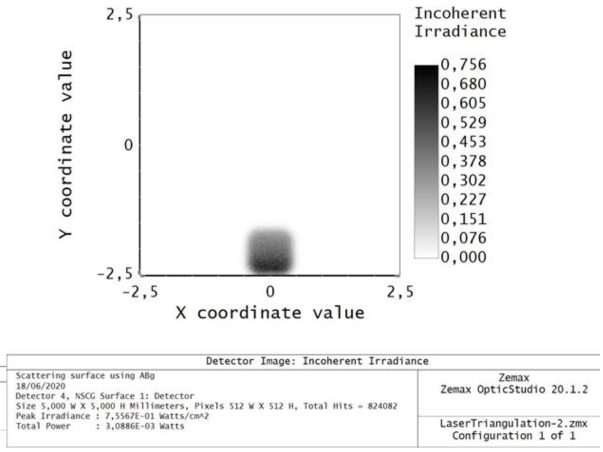

Figure 5-7: Z position -20

5.3 Calibration:

In Nguyen's Theory, the calibration equation comes from the idea of similar triangle theory (equation 7).
Since Nguyen's Theory seems to work only for two dimensions, In 3D, there is a slight change in the coordinate system.
Here, Z→X, Y→U
Therefore, the coordinate system in Simulator is shown in Figure 5-8.

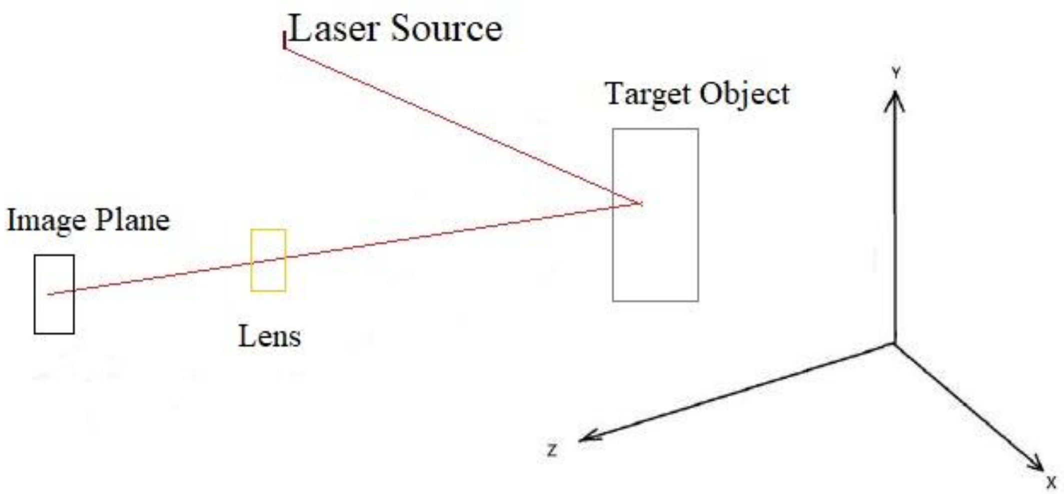

Figure 5-8: Coordinate system in Simulation

The same distance of the object calculated by using several calibration positions to find better calibration positions X1 and X2. The system is Calibrated using two z-positions within the measurement range. Several distance measurement of same object position are done (shown in table 2) using different calibration points of z-positions and comparing the deviation, X1 = 235 & X2 = 255 are selected to calibrate the system. Less deviation in measurement found using these two calibration points.

Table 2: Calibration Data.

Position of Object for Calibration		Object Under Test (at X=0)		
X1	X2	X_S (mm)	X_{th}(mm)	Deviation
-5	5	239.98203377650017	240	-0.017966
-5	**15**	**240.00270611582175**	**240**	**0.002706**
-5	20	240.00577659036753	240	0.005777
-5	30	240.02953827019743	240	0.029538

Calibration data:
X1 = 235 mm, U1 = -1.1622807017543857 mm.
X2 = 255 mm, U1 = -0.0927734375 mm.

6. Results:

The Measured data are shown in the Table 3. The Object under test is moved along the Z axis and the laser beam spot on the image plane recorded. The centroid of the beam spot calculated by python program then using the calibration equation 7 and range finding equation 6, the distance is calculated. The theoretical distance, X_{th} = Object position - (-240) and the measurement error is also calculated by $X_S - X_{th}$.

Table 3: Measured data

Object position(Z)	Centroid of Beam spot (X,Y)	X_{th} (mm)	X_S (mm)	Error (mm)
-25	-0.0048828125, -2.2314453125	215	218.33825701624815	3.338257
-20	-0.009765625, -2.1142578125	220	220.07196029776674	0.071960
-15	-0.0048828125, -1.7919921875	225	224.9847792998478	-0.015221
-10	-0.009765625, -1.484375	230	229.88335925349924	-0.116641
-5	-0.0048828125, -1.1767578125	235	240.00270611582175	0.0
0	-0.0048828125, -0.888671875	240	240.00270611582175	0.002706
5	-0.0048828125, -0.6103515625	245	245.04236507644134	0.042365
10	-0.0048828125, -0.3466796875	250	250.01597444089458	0.015974
15	-0.0048828125, -0.0927734375	255	255.0	0.0
20	-0.0048828125, 0.1513671875	260	259.98338870431894	-0.016611
30	0.0 0.60546875,	270	269.7901034272967	-0.209896
40	-0.0048828125, 1.0302734375	280	279.65839815009457	-0.341602
50	-0.009765625, 1.416015625	290	289.26614481409	-0.733855
60	-0.0048828125, 1.7724609375	300	298.75028070963396	-1.249719
70	-0.0048828125, 2.01171875	310	305.47301951779565	-4.526980
80	-0.009765625, 2.119140625	320	308.59081419624215	-11.409186

90	-0.0146484375, 2.2314453125	330	311.91910902696367	-18.080891
100	-0.0048828125 2.32421875	340	314.7232079488999	-25.276792

7. Evaluation and Analysis:

Comparison of theoretical distance and simulated distance shown in figure 7-1. The theoretical distance and the measured distance are almost same from 220 mm till 300 mm but above 310 mm the measured distances decrease comparing to theoretical distances.

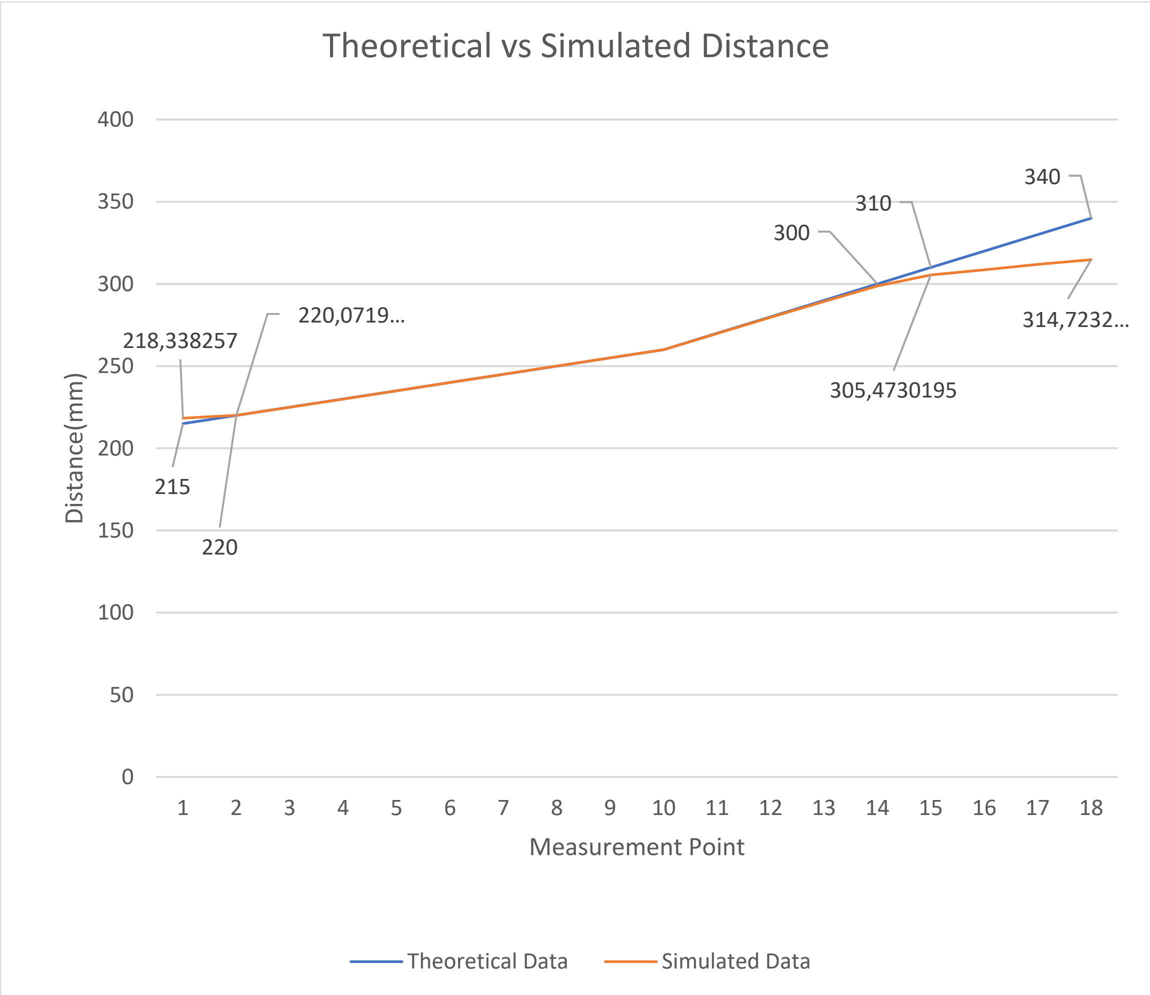

Figure 7-1: Theoretical vs Simulated Distance

To find out the deviation, measured Error vs theoretical distance shown in figure 7-2. It is clearly observed that below 220 mm and above 300 mm the deviation increases rapidly. So the measurement rang of this Laser Triangulation setup can be consider 220 mm – 300 mm. Error = Xs – Xth.

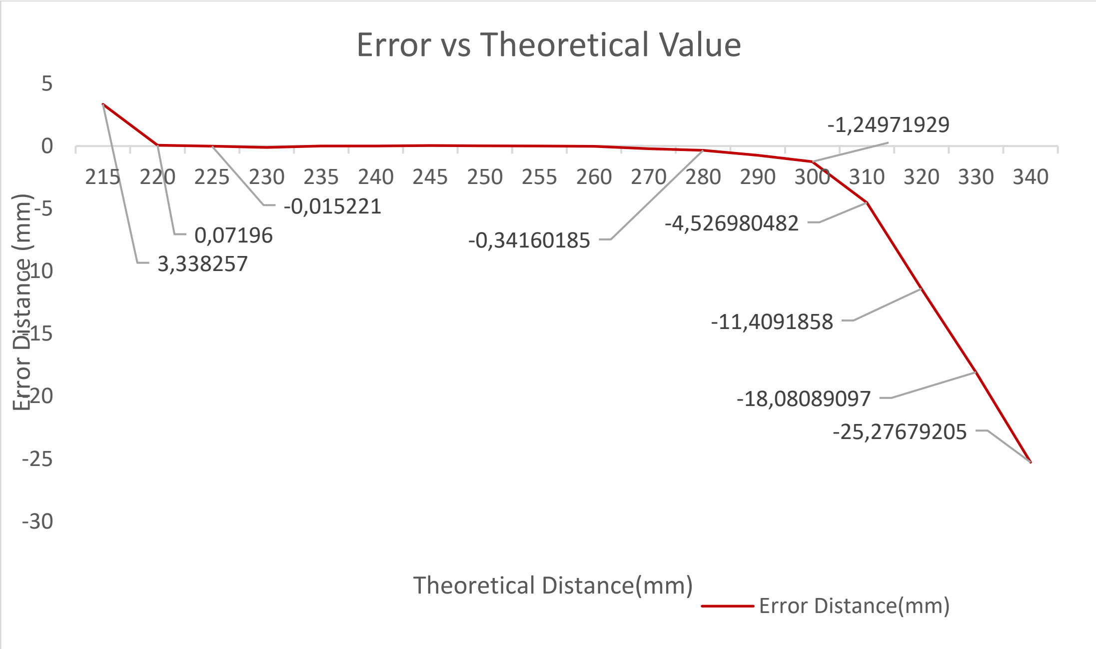

Figure 7-2: Error vs Theoretical Distance

8. Discussion:

The project objectives have been achieved successfully. Normally mirror should not be used as an Object to test to get scattered light through the lens but in this simulation other material except Mirror did not work perfectly. The data of Laser beam spot on image plane recorded in Zemax in 'jpg' and 'txt' file. Firstly, the Centroid of the spots were calculated by image processing in python with the 'jpg' file but the measured value was not satisfactory. Then the spot data in 'txt' files are used to calculate the centroid of the spots. It's also observed that the deviation was higher when the scattered laser beam through the lens was out of focus on the image plane. Furthermore the NGUYEN and Blackburn's theory has a limitation that it's only valid in 2D system but the simulation environment is 3D. So there might have some deflection for calibration.

9. References:

[1] https://www.micro-epsilon.com/service/glossar/Laser-Triang2]ulation.html?. Last access 26.07.2020

[2] https://www.baslerweb.com/en/vision-campus/camera-technology/3d-technology/ last access 01.07.2020

[3] 200Hoa G. Nguyen, Michael R. Blackburn, A simple approach for Range Finding via Laser Triangulation, Jan. 1995.

[4] https://www.zemax.com/products/opticstudio, last access 25.07.

10. Appendix:

```
"""

Created on Sun Jun 14 18:05:11 2020

@author: Firoj

"""

import numpy as np

import re

from PIL import Image

def utf16_decimals(char):

    char =re.sub('[,+]','',char)

    char =re.sub('[E]','e',char)

    return int(float(char))

file=open(r'F:\MScEE\ATLaser\project\result_F\text_z0.txt', encoding='utf-16-le')

lines=file.readlines()

pxl=np.zeros((512, 512))#creat empty 2D array

lenth = (len(lines))

row = 0

for l in lines[24:lenth]:#first row data print, 23-24 ...

    line=(l.split())

    for i in range(1,513):

        encoded_char = utf16_decimals(line[i])

        pxl[row, i-1] = encoded_char

    row +=1

data = pxl.astype(np.float64) / pxl.max() # normalize

data = 255 - 255 *data # 'now scale by 255

r1 = 0

c1 = 0

center1 = []

center2 = []

for row in data:
```

```
    for col in row:
        v = np.mean(col)
        if(v <= 120):
            #print(col)
            #print("r1:", r1, "c1", c1)
            center1.append(r1)
            center2.append(c1)
        c1+=1
    r1 += 1
    c1 = 0
print(len(center1), len(center2))
xx1 = np.min(center1)
xx2 = np.max(center1)
yy1 = np.min(center2)
yy2 = np.max(center2)
print("row: " ,np.mean([xx1, xx2]))
print("col: " ,np.mean([yy1, yy2]))
#transfer matrix linear
X = (5/512)*np.mean([yy1, yy2]) - 2.5


Y = (-5/512)*np.mean([xx1, xx2]) + 2.5
print("final X and Y: ", X, Y)
#%%Distance Calculation

x1=235
x2=245
u= -0.888671875 # object at position z 0
u1=-1.1767578125
u2=-0.6103515625

d=x2-x1
k=u2*x2-u1*x1
n=(u1-u2)*x1*x2
x_1=n/(u*d-k)
print(x_1)
print(x_1 - 240) # error according theoretical distance 240
```