Shreyas Prabhakar
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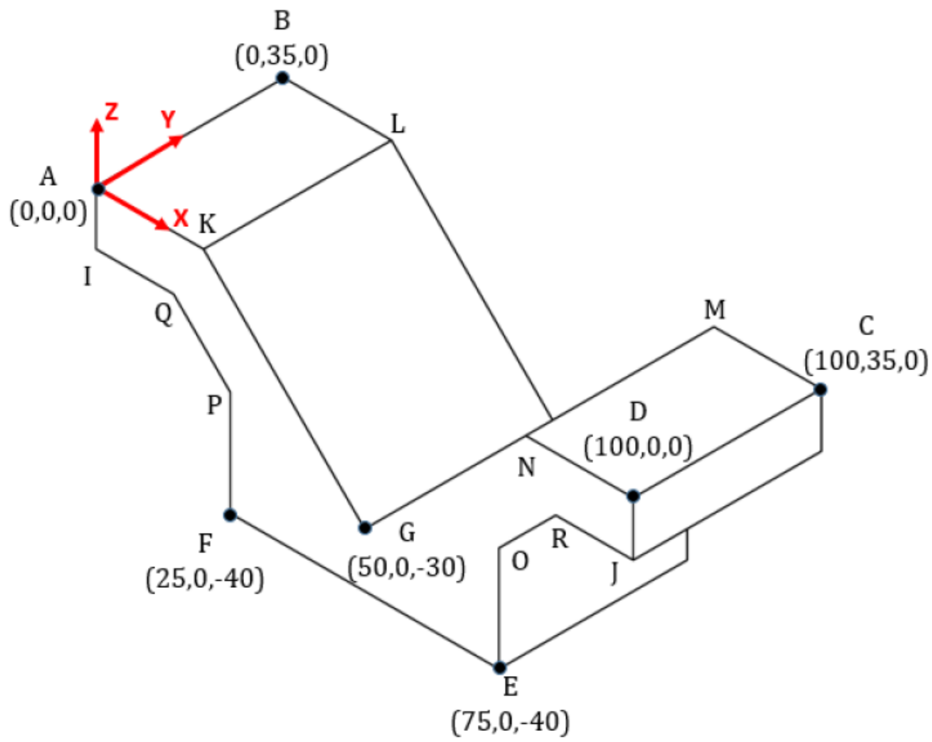
AUE 8930: AUTONOMOUS DRIVING TECHNOLOGIES

HOMEWORK 2

Problem

Given two images of a mold: “left.jpg” and “right.jpg” from two cameras, and the coordinates (X, Y, Z) of some corners of the mold in world frame as below:



Units of Co-ordinates in mm
Fig.1 Mold in world frame

(1) Use least square approach to find the 11 parameters for the left camera.

For the left camera, we have the equation –

$$u_l = (b_{11} - b_{31}u_l)X + (b_{12} - b_{32}u_l)Y + (b_{13} - b_{33}u_l)Z + b_{14}$$
$$v_l = (b_{21} - b_{31}v_l)X + (b_{22} - b_{32}v_l)Y + (b_{23} - b_{33}v_l)Z + b_{24}$$

This can be written as,

$$u_l = b_{11}X + b_{12}Y + b_{13}Z + b_{14} + b_{21}0 + b_{22}0 + b_{23}0 + b_{24}0 - b_{31}u_lX - b_{32}u_lY - b_{33}u_lZ$$
$$v_l = b_{11}0 + b_{12}0 + b_{13}0 + b_{14}0 + b_{21}X + b_{22}Y + b_{23}Z + b_{24} - b_{31}v_lX - b_{32}v_lY - b_{33}v_lZ$$

In matrix form, we can write this as,

$$\begin{bmatrix} X, Y, Z, 1,0,0,0,0, -u_l X, -u_l Y, -u_l Z \\ 0,0,0,0, X, Y, Z, 1, -v_l X, -v_l Y, -v_l Z \\ \vdots \end{bmatrix} \begin{bmatrix} b_{11} \\ b_{12} \\ b_{13} \\ b_{14} \\ b_{21} \\ b_{22} \\ b_{23} \\ b_{24} \\ b_{31} \\ b_{32} \\ b_{33} \end{bmatrix} = \begin{bmatrix} u_l \\ v_l \\ \vdots \end{bmatrix}$$

Which can be written in the form $Ax = B$

Where $A = \begin{bmatrix} X, Y, Z, 1,0,0,0,0, -u_l X, -u_l Y, -u_l Z \\ 0,0,0,0, X, Y, Z, 1, -v_l X, -v_l Y, -v_l Z \\ \vdots \end{bmatrix}$

$B = \begin{bmatrix} u_l \\ v_l \\ \vdots \end{bmatrix}$ and

$x = [b_{11}, b_{12}, b_{13}, b_{14}, b_{21}, b_{22}, b_{23}, b_{24}, b_{31}, b_{32}, b_{33}]^T$

From the above equations it can be seen that, for every point used for calibration, we get 2 rows for the matrices A and B. Therefore, for the 7 set of points given we get 14x11 matrix for A and 1x11 matrix for B.

We can find x using (in MATLAB),

$$x = pinv(A) * B$$

The 7 points in world co-ordinates (X,Y,Z) are given as shown in Fig.1. The image coordinates (u_l,v_l) are found out manually by zooming in on the image and using the Data Cursor tool in the figure window in MATLAB.

The 7 points used are –

Data Point	World Coordinates (X,Y,Z)	Image Coordinates (u_l,v_l)
A	(0,0,0)	(2544,2423)
B	(0,35,0)	(2563,2350)
C	(100,35,0)	(3060,2375)
D	(100,0,0)	(3064,2456)
E	(75,0,-40)	(2937,2637)
F	(25,0,-40)	(2675,2617)
G	(50,0,-30)	(2808,2587)

Using the data points in the above equation, and solving for x, we get the 11 parameters for the left camera as

b_{11}	**4.1201**
b_{12}	**4.0249**
b_{13}	**-0.8497**
b_{14}	**2.5440e+03**
b_{21}	**0.5577**
b_{22}	**1.0311**
b_{23}	**5.2596**
b_{24}	**2.4245e+03**
b_{31}	**-3.5458e-04**
b_{32}	**0.0014**
b_{33}	**-2.3549e-04**

(2) Use least square approach to find the 11 parameters for the right camera.

Using a similar approach to question 1, we find the 11 parameters for the right camera. For the right camera, we have the equation –

$$u_r = (c_{11} - c_{31}u_r)X + (c_{12} - c_{32}u_r)Y + (c_{13} - c_{33}u_r)Z + c_{14}$$
$$v_r = (c_{21} - c_{31}v_r)X + (c_{22} - c_{32}v_r)Y + (c_{23} - c_{33}v_r)Z + c_{24}$$

This can be written as,

$$u_r = c_{11}X + c_{12}Y + c_{13}Z + c_{14} + c_{21}0 + c_{22}0 + c_{23}0 + c_{24}0 - c_{31}u_rX - c_{32}u_rY - c_{33}u_rZ$$
$$v_r = c_{11}0 + c_{12}0 + c_{13}0 + c_{14}0 + c_{21}X + c_{22}Y + c_{23}Z + c_{24} - c_{31}v_rX - c_{32}v_rY - c_{33}v_rZ$$

In matrix form, we can write this as,

$$\begin{bmatrix} X, Y, Z, 1,0,0,0,0, -u_rX, -u_rY, -u_rZ \\ 0,0,0,0, X, Y, Z, 1, -v_rX, -v_rY, -v_rZ \\ \vdots \end{bmatrix} \begin{bmatrix} c_{11} \\ c_{12} \\ c_{13} \\ c_{14} \\ c_{21} \\ c_{22} \\ c_{23} \\ c_{24} \\ c_{31} \\ c_{32} \\ c_{33} \end{bmatrix} = \begin{bmatrix} u_r \\ v_r \\ \vdots \end{bmatrix}$$

Which can be written as $Ax = B$

Where $A = \begin{bmatrix} X, Y, Z, 1,0,0,0,0, -u_rX, -u_rY, -u_rZ \\ 0,0,0,0, X, Y, Z, 1, -v_rX, -v_rY, -v_rZ \\ \vdots \end{bmatrix}$

$B = \begin{bmatrix} u_r \\ v_r \\ \vdots \end{bmatrix}$ and

$x = [c_{11}, c_{12}, c_{13}, c_{14}, c_{21}, c_{22}, c_{23}, c_{24}, c_{31}, c_{32}, c_{33}]^T$

From the above equations it can be seen that, for every point used for calibration, we get 2 rows for the matrices A and B. Therefore, for the 7 set of points given we get 14x11 matrix for A and 1x11 matrix for B.

We can find x using (in MATLAB),

$$x = pinv(A) * B$$

The 7 points in world co-ordinates (X,Y,Z) are given as shown in Fig.1. The image coordinates(u_r,v_r) are found out manually by zooming in on the image and using the Data Cursor tool in the figure window in MATLAB.

The 7 points used are –

Data Point	World Coordinates (X,Y,Z)	Image Coordinates (u_r,v_r)
A	(0,0,0)	(517,3477)
B	(0,35,0)	(680,3352)
C	(100,35,0)	(1240,3584)
D	(100,0,0)	(1094,3744)
E	(75,0,-40)	(939,3931)
F	(25,0,-40)	(652,3789)
G	(50,0,-30)	(794,3795)

Using the data points in the above equation, and solving for x, we get the 11 parameters for the left camera as

c_{11}	**4.1201**
c_{12}	**4.0249**
c_{13}	**-0.8497**
c_{14}	**2.5440e+03**
c_{21}	**0.5577**
c_{22}	**1.0311**
c_{23}	**5.2596**
c_{24}	**2.4245e+03**
c_{31}	**-3.5458e-04**
c_{32}	**0.0014**
c_{33}	**-2.3549e-04**

(3) Calculate the coordinates (X, Y, Z) of other marked corners of the mold based on the two images.

The relationship between the image coordinates (u_l,v_l), (u_r,v_r) of the left and right image and the camera parameters b and c for the left camera and the right camera respectively is given by the 4 equations –

For Left Camera –

$$u_l = (b_{11} - b_{31}u_l)X + (b_{12} - b_{32}u_l)Y + (b_{13} - b_{33}u_l)Z + b_{14}$$
$$v_l = (b_{21} - b_{31}v_l)X + (b_{22} - b_{32}v_l)Y + (b_{23} - b_{33}v_l)Z + b_{24}$$

For Right Camera –

$$u_r = (c_{11} - c_{31}u_r)X + (c_{12} - c_{32}u_r)Y + (c_{13} - c_{33}u_r)Z + c_{14}$$
$$v_r = (c_{21} - c_{31}v_r)X + (c_{22} - c_{32}v_r)Y + (c_{23} - c_{33}v_r)Z + c_{24}$$

The values for (X,Y,Z) can be solved using the least square method from the above 4 equations as –

$$\begin{bmatrix} b_{11} - b_{31}u_l & b_{12} - b_{32}u_l & b_{13} - b_{33}u_l \\ b_{21} - b_{31}v_l & b_{22} - b_{32}v_l & b_{23} - b_{33}v_l \\ c_{11} - c_{31}u_r & c_{12} - c_{32}u_r & c_{13} - c_{33}u_r \\ c_{21} - c_{31}v_r & c_{22} - c_{32}v_r & c_{23} - c_{33}v_r \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} u_l - b_{14} \\ v_l - b_{24} \\ u_r - c_{14} \\ v_r - c_{24} \end{bmatrix}$$

Where,

b and c are the camera parameters for the left and the right camera calculated in question 1 and 2 respectively.

$$b = [b_{11}, b_{12}, b_{13}, b_{14}, b_{21}, b_{22}, b_{23}, b_{24}, b_{31}, b_{32}, b_{33}]^T$$
$$c = [c_{11}, c_{12}, c_{13}, c_{14}, c_{21}, c_{22}, c_{23}, c_{24}, c_{31}, c_{32}, c_{33}]^T$$

The above equation is of the form as $Ax = B$

Where $A = \begin{bmatrix} b_{11} - b_{31}u_l & b_{12} - b_{32}u_l & b_{13} - b_{33}u_l \\ b_{21} - b_{31}v_l & b_{22} - b_{32}v_l & b_{23} - b_{33}v_l \\ c_{11} - c_{31}u_r & c_{12} - c_{32}u_r & c_{13} - c_{33}u_r \\ c_{21} - c_{31}v_r & c_{22} - c_{32}v_r & c_{23} - c_{33}v_r \end{bmatrix}$

$B = \begin{bmatrix} u_l - b_{14} \\ v_l - b_{24} \\ u_r - c_{14} \\ v_r - c_{24} \end{bmatrix}$ and

$x = [X, Y, Z]^T$

We can find x using (in MATLAB),

$$x = pinv(A) * B$$

Using the above procedure, we can find the world coordinates (X,Y,Z) using the image coordinates (u_l,v_l), (u_r,v_r) of the left and right image and the camera parameters b and c of the left camera and the right camera respectively.

The image coordinates (u_l,v_l), (u_r,v_r) of the left and right image of the 10 edge points of the mold for which the world coordinates are to be calculated, are found out manually by zooming in on the image and using the Data Cursor tool in the figure window in MATLAB.

The data point (edges of mold) are –

Data points of Mold	Image Coordinates Left Image (u_l,v_l)	Image Coordinates Left Image (u_r,v_r)
I	(2545,2469)	(513,3550)
J	(3065,2499)	(1099,3811)
K	(2643,2353)	(613,3528)
L	(2565,2355)	(783,3402)
M	(2959,2369)	(1125,3536)
N	(2960,2451)	(972,3693)
O	(2938,2545)	(933,3806)
P	(2677,2531)	(652,3675)
Q	(2616,2472)	(586,3574)
R	(2992,2494)	(995,3767)

Using the procedure of least squares mentioned above, the world coordinates of the data points I through R of the mold are found to be –

Data points of Mold	World Coordinates (X,Y,Z)
I	**(0.3768,-0.7999,-10.2950)**
J	**(100.2666,0.3491,-9.8353)**
K	**(25.2605,-8.3888,12.2033)**
L	**(0.4917,56.3242,-17.5452)**
M	**(80.4131,35.7880,-0.3724)**
N	**(80.6386,-0.1751,-0.5536)**
O	**(75.6147,-1.9473,-18.9938)**
P	**(25.4740,-0.1932,-21.1461)**
Q	**(14.0835,-0.6058,-9.2797)**
R	**(86.2877,-2.8101,-7.5166)**

(4) Calculate the dimensions of the bar (length, width, height) beside the mold.

The procedure to find the edge points of the bar is similar to question 3.
The relationship between the image coordinates (u_l,v_l), (u_r,v_r) of the left and right image and the camera parameters b and c for the left camera and the right camera respectively is given by the 4 equations –

Left Camera –

$$u_l = (b_{11} - b_{31}u_l)X + (b_{12} - b_{32}u_l)Y + (b_{13} - b_{33}u_l)Z + b_{14}$$

$$v_l = (b_{21} - b_{31}v_l)X + (b_{22} - b_{32}v_l)Y + (b_{23} - b_{33}v_l)Z + b_{24}$$

Right Camera –

$$u_r = (c_{11} - c_{31}u_r)X + (c_{12} - c_{32}u_r)Y + (c_{13} - c_{33}u_r)Z + c_{14}$$
$$v_r = (c_{21} - c_{31}v_r)X + (c_{22} - c_{32}v_r)Y + (c_{23} - c_{33}v_r)Z + c_{24}$$

The values for (X,Y,Z) can be solved using the least square method from the above 4 equations as –

$$\begin{bmatrix} b_{11} - b_{31}u_l & b_{12} - b_{32}u_l & b_{13} - b_{33}u_l \\ b_{21} - b_{31}v_l & b_{22} - b_{32}v_l & b_{23} - b_{33}v_l \\ c_{11} - c_{31}u_r & c_{12} - c_{32}u_r & c_{13} - c_{33}u_r \\ c_{21} - c_{31}v_r & c_{22} - c_{32}v_r & c_{23} - c_{33}v_r \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} u_l - b_{14} \\ v_l - b_{24} \\ u_r - c_{14} \\ v_r - c_{24} \end{bmatrix}$$

Where,

b and c are the camera parameters for the left and the right camera calculated in question 1 and 2 respectively.

$$b = [b_{11}, b_{12}, b_{13}, b_{14}, b_{21}, b_{22}, b_{23}, b_{24}, b_{31}, b_{32}, b_{33}]^T$$
$$c = [c_{11}, c_{12}, c_{13}, c_{14}, c_{21}, c_{22}, c_{23}, c_{24}, c_{31}, c_{32}, c_{33}]^T$$

The above equation is of the form as $Ax = B$

Where $A = \begin{bmatrix} b_{11} - b_{31}u_l & b_{12} - b_{32}u_l & b_{13} - b_{33}u_l \\ b_{21} - b_{31}v_l & b_{22} - b_{32}v_l & b_{23} - b_{33}v_l \\ c_{11} - c_{31}u_r & c_{12} - c_{32}u_r & c_{13} - c_{33}u_r \\ c_{21} - c_{31}v_r & c_{22} - c_{32}v_r & c_{23} - c_{33}v_r \end{bmatrix}$

$B = \begin{bmatrix} u_l - b_{14} \\ v_l - b_{24} \\ u_r - c_{14} \\ v_r - c_{24} \end{bmatrix}$ and

$x = [X, Y, Z]^T$

We can find x using (in MATLAB),

$$x = pinv(A) * B$$

Using the above procedure, we can find the world coordinates (X,Y,Z) using the image coordinates (u_l,v_l), (u_r,v_r) of the left and right image and the camera parameters b and c of the left camera and the right camera respectively.

The image coordinates (u_l,v_l), (u_r,v_r) of the left and right image of the edge points of the bar (shown in Fig 2) for which the world coordinates are to be calculated, are found out manually by zooming in on the image and using the Data Cursor tool in the figure window in MATLAB.

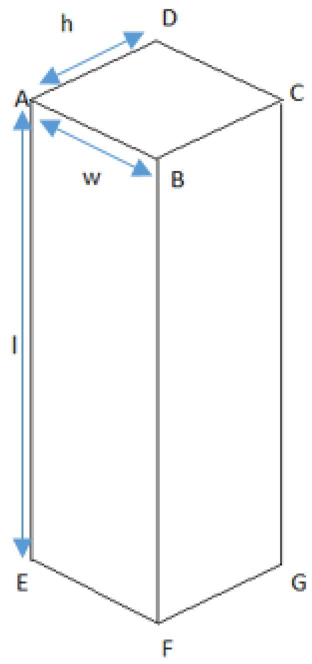


Fig. 2 Bar

Edge points of Bar	Image Coordinates Left Image (u_l,v_l)	Image Coordinates Left Image (u_r,v_r)
A	(3253,1708)	(1969,2615)
B	(3313,1730)	(2002,2678)
C	(3384,1716)	(2131,2673)
D	(3322,1693)	(2094,2615)
E	(3259,2286)	(1916,3409)
F	(3318,2318)	(1948,3489)
G	(3387,2298)	(2067,3484)

Using the procedure of least squares mentioned above, the world coordinates of the data points I through R of the bar are found to be –

Edge points of Bar	World Coordinates (X,Y,Z)
A	(148.7379,185.0139,103.3957)
B	(160.6773,166.8328,102.0877)
C	(177.5301,181.9910,101.6481)
D	(165.6015,200.4160,102.5439)
E	(148.3083,178.5289,-40.8624)
F	(145.0736,202.9285,-68.2798)
G	(176.9804,173.1222,-40.6700)

The dimensions are calculated using the Euclidian distance given by,

$$d = \sqrt{((X_2 - X_1)^2 (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2)}$$

Edges of Bar	World Coordinates (X,Y,Z)
AB	21.7902
BC	22.6712
CD	21.9676
AD	22.8546
AE	144.4044
BF	174.8469
CG	142.5952

From Fig. 2, we see that,
Length, l = AE = CG
Width, w = AB = CD and
Height, h = AD = BC

But due to numerical errors and human error (While finding the data points manually), I have considered the averages of the 2 parallel sides as the length, width and height.

Therefore,
Length, l = (AE+CG)/2 = (144.4044+142.5952)/2 = **143.4998 mm**
Width, w = (AB+CD)/2 = (21.7902+21.9676)/2 = **21.8789 mm**
Height, h = (AD+BC)/2 = (22.8546+22.6712)/2 = **22.7629 mm**

(5) Calculate the heights of the two students?

The procedure to find the height of students is similar to finding the dimensions of the bar in question 4.
The relationship between the image coordinates (u_l,v_l), (u_r,v_r) of the left and right image and the camera parameters b and c for the left camera and the right camera respectively is given by the 4 equations –
Left Camera –

$$u_l = (b_{11} - b_{31}u_l)X + (b_{12} - b_{32}u_l)Y + (b_{13} - b_{33}u_l)Z + b_{14}$$
$$v_l = (b_{21} - b_{31}v_l)X + (b_{22} - b_{32}v_l)Y + (b_{23} - b_{33}v_l)Z + b_{24}$$

Right Camera –

$$u_r = (c_{11} - c_{31}u_r)X + (c_{12} - c_{32}u_r)Y + (c_{13} - c_{33}u_r)Z + c_{14}$$
$$v_r = (c_{21} - c_{31}v_r)X + (c_{22} - c_{32}v_r)Y + (c_{23} - c_{33}v_r)Z + c_{24}$$

The values for (X,Y,Z) can be solved using the least square method from the above 4 equations as –

$$\begin{bmatrix} b_{11} - b_{31}u_l & b_{12} - b_{32}u_l & b_{13} - b_{33}u_l \\ b_{21} - b_{31}v_l & b_{22} - b_{32}v_l & b_{23} - b_{33}v_l \\ c_{11} - c_{31}u_r & c_{12} - c_{32}u_r & c_{13} - c_{33}u_r \\ c_{21} - c_{31}v_r & c_{22} - c_{32}v_r & c_{23} - c_{33}v_r \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} u_l - b_{14} \\ v_l - b_{24} \\ u_r - c_{14} \\ v_r - c_{24} \end{bmatrix}$$

Where,

b and c are the camera parameters for the left and the right camera calculated in question 1 and 2 respectively.

$b = [b_{11}, b_{12}, b_{13}, b_{14}, b_{21}, b_{22}, b_{23}, b_{24}, b_{31}, b_{32}, b_{33}]^T$

$c = [c_{11}, c_{12}, c_{13}, c_{14}, c_{21}, c_{22}, c_{23}, c_{24}, c_{31}, c_{32}, c_{33}]^T$

The above equation is of the form as $Ax = B$

Where $A = \begin{bmatrix} b_{11} - b_{31}u_l & b_{12} - b_{32}u_l & b_{13} - b_{33}u_l \\ b_{21} - b_{31}v_l & b_{22} - b_{32}v_l & b_{23} - b_{33}v_l \\ c_{11} - c_{31}u_r & c_{12} - c_{32}u_r & c_{13} - c_{33}u_r \\ c_{21} - c_{31}v_r & c_{22} - c_{32}v_r & c_{23} - c_{33}v_r \end{bmatrix}$

$B = \begin{bmatrix} u_l - b_{14} \\ v_l - b_{24} \\ u_r - c_{14} \\ v_r - c_{24} \end{bmatrix}$ and

$x = [X, Y, Z]^T$

We can find x using (in MATLAB),

$$x = pinv(A) * B$$

Using the above procedure, we can find the world coordinates (X,Y,Z) using the image coordinates (u_l,v_l), (u_r,v_r) of the left and right image and the camera parameters b and c of the left camera and the right camera respectively.

The image coordinates (u_l,v_l), (u_r,v_r) of the left and right image of the top and bottom points of the students for which the world coordinates are to be calculated, are found out manually by zooming in on the image and using the Data Cursor tool in the figure window in MATLAB.

Data Points	Image Coordinates Left Image (u_l,v_l)	Image Coordinates Left Image (u_r,v_r)
Top point of male	(671,224)	(508,129)
Bottom point of male	(1140,2102)	(790,2319)
Top point of female	(2001,302)	(2014,389)
Bottom point of female	(2117,1973)	(1846,2379)

Using the procedure of least squares mentioned above, the world coordinates of the data points I through R of the bar are found to be –

Data Points	World Coordinates (X,Y,Z)
Top point of male	(-623.0077,583.1127,674.1946)
Bottom point of male	(1.0e+03*-1.1187, 1.0e+03*-1.3825,-423.4345)
Top point of female	(-89.7049,619.9677,572.1553)
Bottom point of female	(-626.4809, 1.0e+03*2.1480,-575.0603)

The dimensions are calculated using the Euclidian distance given by,

$$d = \sqrt{((X_2 - X_1)^2 (Y_2 - Y_1)^2 + (Z_2 - Z_1)^2)}$$

To find the height of the male student –

X1 = Top point of male

X2 = Bottom point of male

Height of Male student is found to be,

Height of male, h_{male} = 1.4455e+03 = 56.7 inch = **4ft 9 in (approx.)**

To find the height of the female student –

X1 = Top point of female

X2 = Bottom point of female

Height of Female student is found to be,

Height of female, h_{female} = 1.9847e+03 mm = 78.1389 inch = **6 ft 6 in (approx.)**

For some reason the female student is way taller than the male student. But, in reality this is not true. This may be because of the human error (when manually finding the data points in the left and right image when calculating the parameters and when calculating the heights of the students in the scene. It can also be due to some computational errors and approximations.

APPENDIX –

MATLAB Code –

Hw2.m

```
close all
clear all

left = imread('Left.jpg');
right = imread('Right.jpg');

figure(1);imshow(left);
figure(2);imshow(right);
```

```
%%
%Data

%For question 1 and 2 - Calculating the parameters of
camera

worldMoldXYZ{1,1} = [0,0,0];
worldMoldXYZ{1,2} = [0,35,0];
worldMoldXYZ{1,3} = [100,35,0];
worldMoldXYZ{1,4} = [100,0,0];
worldMoldXYZ{1,5} = [75,0,-40];
worldMoldXYZ{1,6} = [25,0,-40];
worldMoldXYZ{1,7} = [50,0,-30];

leftMoldUV{1,1} = [2544, 2423];
leftMoldUV{1,2} = [2563, 2350];
leftMoldUV{1,3} = [3060, 2375];
leftMoldUV{1,4} = [3064, 2456];
leftMoldUV{1,5} = [2937, 2637];
leftMoldUV{1,6} = [2678, 2617];
leftMoldUV{1,7} = [2808, 2587];

rightMoldUV{1,1} = [512, 3477];
rightMoldUV{1,2} = [680, 3352];
rightMoldUV{1,3} = [1240, 3584];
rightMoldUV{1,4} = [1094, 3744];
rightMoldUV{1,5} = [939, 3931];
rightMoldUV{1,6} = [652, 3789];
rightMoldUV{1,7} = [794, 3795];

%For Question 3 - Finding world coordinates of vertices
of mold

leftMoldNewUV{1,1} = [2545, 2469];
leftMoldNewUV{1,2} = [3065, 2499];
leftMoldNewUV{1,3} = [2643, 2353];
leftMoldNewUV{1,4} = [2565, 2355];
leftMoldNewUV{1,5} = [2959, 2369];
leftMoldNewUV{1,6} = [2960, 2451];
leftMoldNewUV{1,7} = [2938, 2545];
leftMoldNewUV{1,8} = [2677, 2531];
leftMoldNewUV{1,9} = [2616, 2472];
leftMoldNewUV{1,10} = [2992, 2494];

rightMoldNewUV{1,1} = [513, 3550];
rightMoldNewUV{1,2} = [1099, 3811];
rightMoldNewUV{1,3} = [613, 3528];
```

```
rightMoldNewUV{1,4} = [783, 3402];
rightMoldNewUV{1,5} = [1125, 3536];
rightMoldNewUV{1,6} = [972, 3693];
rightMoldNewUV{1,7} = [933, 3806];
rightMoldNewUV{1,8} = [652, 3675];
rightMoldNewUV{1,9} = [586, 3574];
rightMoldNewUV{1,10} = [995, 3767];

%For question 4 - Finding the dimensions of the bar

leftBarUV{1,1} = [3253, 1708];
leftBarUV{1,2} = [3313, 1730];
leftBarUV{1,3} = [3384, 1716];
leftBarUV{1,4} = [3322, 1693];
leftBarUV{1,5} = [3259, 2286];
leftBarUV{1,6} = [3218, 2318];
leftBarUV{1,7} = [3387, 2298];

rightBarUV{1,1} = [1969, 2615];
rightBarUV{1,2} = [2002, 2678];
rightBarUV{1,3} = [2131, 2673];
rightBarUV{1,4} = [2094, 2615];
rightBarUV{1,5} = [1916, 3409];
rightBarUV{1,6} = [1948, 3489];
rightBarUV{1,7} = [2067, 3484];

%Question 5 - Finding the height of students

leftMaleUV{1,1} = [671, 224];
leftMaleUV{1,2} = [1140, 2102];
rightMaleUV{1,1} = [508, 129];
rightMaleUV{1,2} = [790, 2319];

leftFemaleUV{1,1} = [2001, 302];
leftFemaleUV{1,2} = [2117, 1973];
rightFemaleUV{1,1} = [2014, 389];
rightFemaleUV{1,2} = [1846, 2379];

%%
%Questions 1 and 2

b = param(worldMoldXYZ,leftMoldUV);
c = param(worldMoldXYZ,rightMoldUV);

%%
%Question 3 - To find world coordinates of other vertices
of Mold
```

```
for i = 1: size(rightMoldNewUV,2)
    worldMoldNewXYZ{1,i} = worldCoord(leftMoldNewUV{1,i},
b, rightMoldNewUV{1,i}, c);
end

%%
%Question 4 - Find the dimesions of the bar - w, h, l

for i = 1: size(rightBarUV,2)
    worldBarXYZ{1,i} = worldCoord(leftBarUV{1,i}, b,
rightBarUV{1,i}, c);
end

AB = sqrt(sum((worldBarXYZ{1,1} - worldBarXYZ{1,2}).^2));
BC = sqrt(sum((worldBarXYZ{1,2} - worldBarXYZ{1,3}).^2));
CD = sqrt(sum((worldBarXYZ{1,3} - worldBarXYZ{1,4}).^2));
AD = sqrt(sum((worldBarXYZ{1,1} - worldBarXYZ{1,4}).^2));
AE = sqrt(sum((worldBarXYZ{1,1} - worldBarXYZ{1,5}).^2));
BF = sqrt(sum((worldBarXYZ{1,2} - worldBarXYZ{1,6}).^2));
CG = sqrt(sum((worldBarXYZ{1,3} - worldBarXYZ{1,7}).^2));

%%
%Question 5 - Find the height of the two students

for i = 1: size(leftMaleUV,2)
    worldMaleXYZ{1,i} = worldCoord(leftMaleUV{1,i}, b,
rightMaleUV{1,i}, c);
end
heightMale = sqrt(sum((worldMaleXYZ{1,1} -
worldMaleXYZ{1,2}).^2));

for i = 1: size(leftFemaleUV,2)
    worldFemaleXYZ{1,i} = worldCoord(leftFemaleUV{1,i},
b, rightFemaleUV{1,i}, c);
end
heightFemale = sqrt(sum((worldFemaleXYZ{1,1} -
worldFemaleXYZ{1,2}).^2));

%in inches
heightMale = heightMale / 25.4;
heightFemale = heightFemale / 25.4;
```

param.m –

```
function x = param(worldXYZ,imageUV)

for i = 1 : size(worldXYZ,2)
```

```
    A((i*2)-1,:) = [worldXYZ{1,i}, 1, 0, 0, 0, 0, -
(worldXYZ{1,i}*imageUV{1,i}(1))];
    A((i*2),:) = [0, 0, 0, 0, worldXYZ{1,i}, 1, -
(worldXYZ{1,i}*imageUV{1,i}(2))];
    B((i*2)-1,:) = imageUV{1,i}(1);
    B((i*2),:) = imageUV{1,i}(2);
end
x = pinv(A)*B;

end
```

worldCoord.m –

```
function x = worldCoord(leftUV, b, rightUV, c)

A = [b(1)-(b(9)*leftUV(1)), b(2)-(b(10)*leftUV(1)), b(3)-
(b(11)*leftUV(1));
    b(5)-(b(9)*leftUV(2)), b(6)-(b(10)*leftUV(2)), b(7)-
(b(11)*leftUV(2));
    c(1)-(c(9)*rightUV(1)), c(2)-(c(10)*rightUV(1)),
c(3)-(c(11)*rightUV(1));
    c(5)-(c(9)*rightUV(2)), c(6)-(c(10)*rightUV(2)),
c(7)-(c(11)*rightUV(2));
    ];
B = [leftUV(1) - b(4);
    leftUV(2) - b(8);
    rightUV(1) - c(4);
    rightUV(2) - c(8)
    ];
x = pinv(A)*B;

end
```