EN3563 Robotics Laboratory Experiment 02
Answer Sheet

Index No: 220148G

1 Homogeneous Transformation Matrix H_1^0 for Task 3.4

The homogeneous transformation matrix H_1^0 represents the transformation from frame $\{0\}$ to frame $\{1\}$, where frame $\{1\}$ is rotated 90° about the z-axis and translated by vector $q^0 = [2, 1, 1]^T$.

$$H_1^0 = \begin{bmatrix} 0 & -1 & 0 & 2 \\ 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

2 MATLAB Code for Tasks 3.1 to 3.6

Listing 1: MATLAB Code for Tasks 3.1-3.6

```
clear; close all; clc;

% 3.1 - Visualize coordinate system {0}
figure; hold on; grid on; axis([0 4 0 4 0 3]); view(35,25);
trplot(eye(4),'frame','0','color','b');

% 3.2 - Obtain rotation matrix and translation vector
q0   = [2; 1; 1];              % translation vector t1_0
R1_0 = rotz(pi/2);             % 90 degrees about z-axis
t1_0 = q0;

% 3.3 - Visualize q0 using blue color
quiver3(0,0,0, q0(1),q0(2),q0(3), 0, 'Color','b');

% Create cube wireframe to show q0 vector endpoint
qx = q0(1); qy = q0(2); qz = q0(3);
C = [ 0  0  0;   qx 0  0;   qx qy 0;   0  qy 0;
      0  0  qz;   qx 0  qz;   qx qy qz;   0  qy qz ];
E = [1 2; 2 3; 3 4; 4 1;   5 6; 6 7; 7 8; 8 5;   1 5; 2 6; 3 7; 4 8];
for k = 1:size(E,1)
    i = E(k,1); j = E(k,2);
    plot3([C(i,1) C(j,1)], [C(i,2) C(j,2)], [C(i,3) C(j,3)], 'b--');
end

% 3.4 - Obtain homogeneous transformation matrix H1_0
H1_0 = rt2tr(R1_0, t1_0);            % homogeneous transform
trplot(H1_0,'frame','1','color','r');
disp('H1_0 ='); disp(H1_0);

% 3.5 - Find p0 and visualize using green color
p1 = [0.5; 0.8; 0.6];               % define p1 in frame {1}
```

```
p0 = h2e(H1_0 * e2h(p1));            % p0 = H1_0 * p1 (homogeneous)
quiver3(0,0,0, p0(1), p0(2), p0(3), 0, 'Color','g');

% 3.6 - Visualize p1 using red color
u = R1_0 * p1;                       % p1 expressed in {0}
quiver3(q0(1),q0(2),q0(3), u(1),u(2),u(3), 0, 'Color','r');
```

3 Final Output MATLAB Figure for Operations 3.1 to 3.6

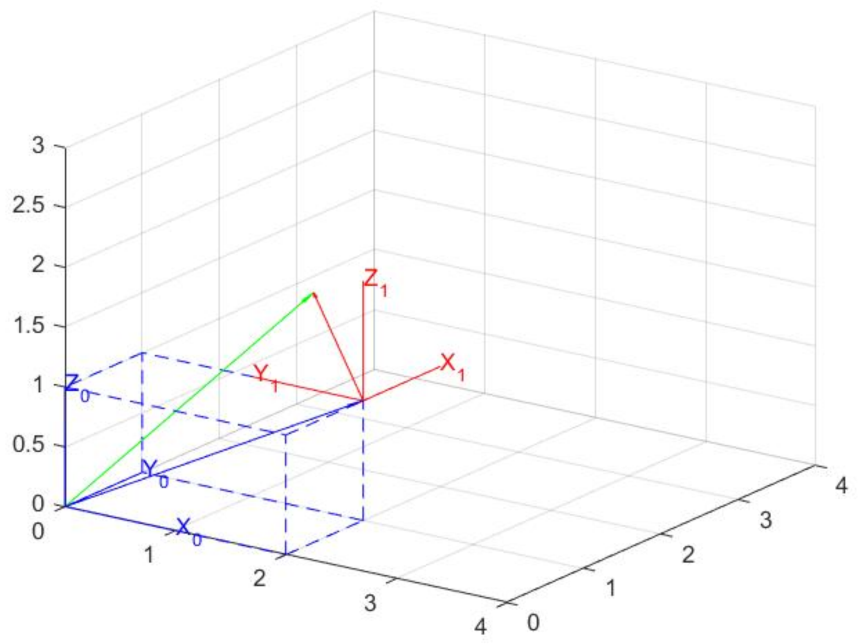

Figure 1: 3D visualization showing coordinate frames {0} (blue) and {1} (red), position vector q^0 (blue arrow), transformed point p^0 (green arrow), and point p^1 (red arrow) from frame {1}

4 Homogeneous Transformation Matrix H_0^1 for Task 3.8

The inverse homogeneous transformation matrix H_0^1 represents the transformation from frame {1} to frame {0}:

$$H_0^1 = (H_1^0)^{-1} = \begin{bmatrix} 0 & 1 & 0 & -1 \\ -1 & 0 & 0 & 2 \\ 0 & 0 & 1 & -1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

5 t_0^1 for Task 3.10

The translation vector t_0^1 extracted from the homogeneous transformation matrix H_0^1:

$$t_0^1 = \begin{bmatrix} -1.0000 \\ 2.0000 \\ -1.0000 \end{bmatrix}$$

6 MATLAB Code for Tasks 3.7 to 3.11

Listing 2: MATLAB Code for Tasks 3.7-3.11

```
% 3.7 - New figure to visualize coordinate system {1} and p1
figure; hold on; grid on; axis([-4 2 -1 3 -2 2]); view(35,25);
trplot(eye(4),'frame','1','color','r');
quiver3(0,0,0, p1(1),p1(2),p1(3), 0, 'Color','r');

% 3.8 - Obtain homogeneous transformation matrix H0_1
H0_1 = inv(H1_0);
disp('H0_1 ='); disp(H0_1);

% 3.9 - Visualize frame {0} with blue color
trplot(H0_1,'frame','0','color','b');

% 3.10 - Find t0_1 and visualize with blue color
[~, t0_1] = tr2rt(H0_1);
quiver3(0,0,0, t0_1(1), t0_1(2), t0_1(3), 0, 'Color','b');
fprintf('t0_1 = [%.4f %.4f %.4f]^T\n', t0_1);

% 3.11 - Visualize green arrow from tip of p1 to origin of frame {0}
d = t0_1 - p1;  % vector from p1 to origin of {0}
quiver3(p1(1), p1(2), p1(3), d(1), d(2), d(3), 0, 'Color','g');
```

7 Final Output MATLAB Figure for Operations 3.7 to 3.11

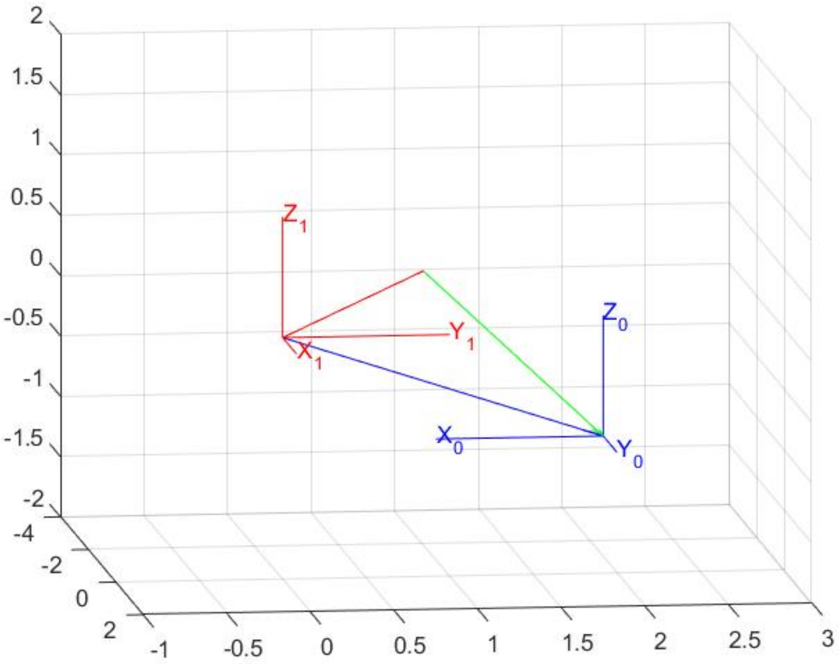

Figure 2: 3D visualization from frame {1} perspective showing coordinate frame {1} (red), point p^1 (red arrow), coordinate frame {0} (blue), translation vector t_0^1 (blue arrow), and green arrow from tip of p^1 to origin of frame {0}

8 Homogeneous Transformation Table

Requirement	MATLAB Script to Satisfy Requirement	Homogeneous Transformation Matrix Result
$o_0x_0y_0z_0$ to $o_1x_1y_1z_1$	`H1_0 = rt2tr(eye(3), [-0.5; 1.5; 1.0]);`	$\begin{bmatrix} 1 & 0 & 0 & -0.5 \\ 0 & 1 & 0 & 1.5 \\ 0 & 0 & 1 & 1.0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$
$o_0x_0y_0z_0$ to $o_2x_2y_2z_2$	`H2_0 = rt2tr(eye(3), [-0.5; 1.5; 1.1]);`	$\begin{bmatrix} 1 & 0 & 0 & -0.5 \\ 0 & 1 & 0 & 1.5 \\ 0 & 0 & 1 & 1.1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$
$o_0x_0y_0z_0$ to $o_3x_3y_3z_3$	`H3_0 = rt2tr(rotx(pi), [-0.5; 1.5; 3.0]);`	$\begin{bmatrix} 1 & 0 & 0 & -0.5 \\ 0 & -1 & 0 & 1.5 \\ 0 & 0 & -1 & 3.0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$

Table 1: Homogeneous transformation matrices for the 3D environment (Task 3.12)

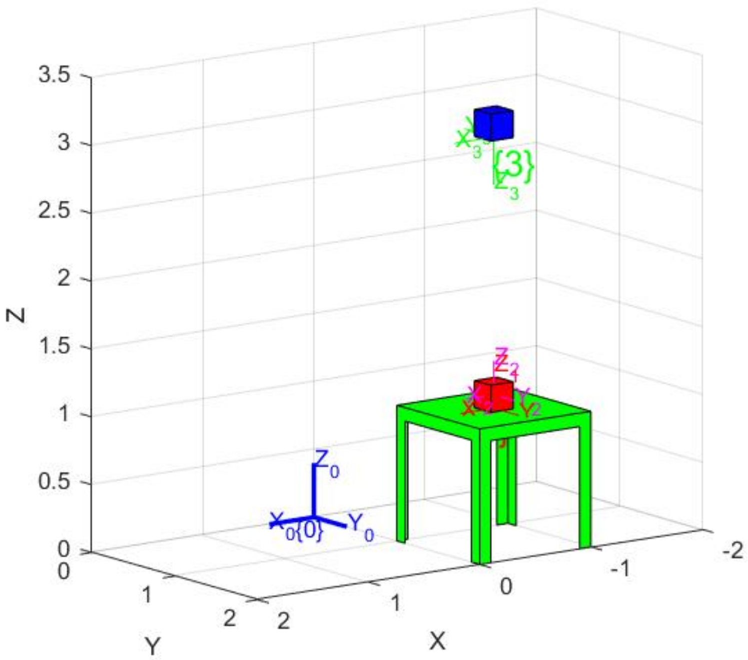

Figure 3: 3D environment for visual servoing showing table (green), box (red), camera (blue), and coordinate frames {0}, {1}, {2}, {3}