
```

%Answer to Question 4
clc
clear all%clearing all previous outputs and variables

syms a d cos(theta) sin(theta) cos(alpha) sin(alpha) %Defining all the
variables through syms
r_z_theta=[cos(theta) -sin(theta) 0 0;sin(theta) cos(theta) 0 0;0 0 1];%defining rotation through theta around the z axis
trform_z_d=[1 0 0 0;0 1 0 0;0 0 1 d;0 0 0 1];%translation by d along
the z axis
trform_x_a=[1 0 0 a;0 1 0 0;0 0 1 0;0 0 0 1];%translation by a along
the x axis
r_x_alpha=[1 0 0 0;0 cos(alpha) -sin(alpha) 0;0 sin(alpha) cos(alpha)
0 0 0 1];%defining rotation through alpha around the x axis

H=r_z_theta*trform_z_d*trform_x_a*r_x_alpha %the combination of
rotation and transformation matrix as
%described in the problem

%below given are all the other combinations of the Homogeneous
matrices
H_1= r_z_theta*trform_z_d*trform_x_a*r_x_alpha
H_2= r_z_theta*trform_z_d*r_x_alpha*trform_x_a
H_3= r_z_theta*trform_x_a*trform_z_d*r_x_alpha
H_4= r_z_theta*trform_x_a*r_x_alpha*trform_z_d
H_5= r_z_theta*r_x_alpha*trform_z_d*trform_x_a
H_6=r_z_theta*r_x_alpha*trform_x_a*trform_z_d
H_7= trform_z_d*r_z_theta*trform_x_a*r_x_alpha
H_8= trform_z_d*r_z_theta*r_x_alpha*trform_x_a
H_9= trform_z_d*trform_x_a*r_z_theta*r_x_alpha
H_10= trform_z_d*trform_x_a*r_x_alpha*r_z_theta
H_11= trform_z_d*r_x_alpha*r_z_theta*trform_z_d
H_12= trform_z_d*r_x_alpha*trform_z_d*r_z_theta
H_13=trform_x_a*r_z_theta*trform_z_d*r_x_alpha
H_14=trform_x_a*r_z_theta*r_x_alpha*trform_z_d
H_15=trform_x_a*trform_z_d*r_z_theta*r_x_alpha
H_16=trform_x_a*trform_z_d*r_x_alpha*r_z_theta
H_17=trform_x_a*r_x_alpha*r_z_theta*trform_z_d
H_18=trform_x_a*r_x_alpha*trform_z_d*r_z_theta
H_19=r_x_alpha*r_z_theta*trform_z_d*trform_x_a
H_20=r_x_alpha*r_z_theta*trform_x_a*trform_z_d
H_21=r_x_alpha*trform_z_d*r_z_theta*trform_x_a
H_22=r_x_alpha*trform_z_d*trform_x_a*r_z_theta
H_23=r_x_alpha*trform_x_a*r_z_theta*trform_z_d
H_24=r_x_alpha*trform_x_a*trform_z_d*r_z_theta

% checking the equality between H and various other combinations
fprintf('Comparing H and H_1:
r_z_theta*trform_z_d*trform_x_a*r_x_alpha')
isequal(H,H_1)
fprintf('Comparing H and
H_2=r_z_theta*trform_z_d*r_x_alpha*trform_x_a')

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isequal(H,H_2)
fprintf('Comparing H and H_3=
  r_z_theta*trform_x_a*trform_z_d*r_x_alpha')
isequal(H,H_3)
fprintf('Comparing H and H_4=
  r_z_theta*trform_x_a*r_x_alpha*trform_z_d')
isequal(H,H_4)
fprintf('Comparing H and H_5=
  r_z_theta*r_x_alpha*trform_z_d*trform_x_a')
isequal(H,H_5)
fprintf('Comparing H and
  H_6=r_z_theta*r_x_alpha*trform_x_a*trform_z_d')
isequal(H,H_6)
fprintf('Comparing H and H_7=
  trform_z_d*r_z_theta*trform_x_a*r_x_alpha')
isequal(H,H_7)
fprintf('Comparing H and H_8=
  trform_z_d*r_z_theta*r_x_alpha*trform_x_a')
isequal(H,H_8)
fprintf('Comparing H and H_9=
  trform_z_d*trform_x_a*r_z_theta*r_x_alpha')
isequal(H,H_9)
fprintf('Comparing H and H_10=
  trform_z_d*trform_x_a*r_x_alpha*r_z_theta')
isequal(H,H_10)
fprintf('Comparing H and H_11=
  trform_z_d*r_x_alpha*r_z_theta*trform_z_d')
isequal(H,H_11)
fprintf('Comparing H and H_12=
  trform_z_d*r_x_alpha*trform_z_d*r_z_theta')
isequal(H,H_12)
fprintf('Comparing H and
  H_13=trform_x_a*r_z_theta*trform_z_d*r_x_alpha')
isequal(H,H_13)
fprintf('Comparing H and
  H_14=trform_x_a*r_z_theta*r_x_alpha*trform_z_d')
isequal(H,H_14)
fprintf('Comparing H and
  H_15=trform_x_a*trform_z_d*r_z_theta*r_x_alpha')
isequal(H,H_15)
fprintf('Comparing H and
  H_16=trform_x_a*trform_z_d*r_x_alpha*r_z_theta')
isequal(H,H_16)
fprintf('Comparing H and
  H_17=trform_x_a*r_x_alpha*r_z_theta*trform_z_d')
isequal(H,H_17)
fprintf('Comparing H and
  H_18=trform_x_a*r_x_alpha*trform_z_d*r_z_theta')
isequal(H,H_18)
fprintf('Comparing H and
  H_19=r_x_alpha*r_z_theta*trform_z_d*trform_x_a')
isequal(H,H_19)
fprintf('Comparing H and
  H_20=r_x_alpha*r_z_theta*trform_x_a*trform_z_d')

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isequal(H,H_20)
fprintf('Comparing H and
  H_21=r_x_alpha*trform_z_d*r_z_theta*trform_x_a')
isequal(H,H_21)
fprintf('Comparing H and
  H_22=r_x_alpha*trform_z_d*trform_x_a*r_z_theta')
isequal(H,H_22)
fprintf('Comparing H and
  H_23=r_x_alpha*trform_x_a*r_z_theta*trform_z_d')
isequal(H,H_23)
fprintf('Comparing H and
  H_24=r_x_alpha*trform_x_a*trform_z_d*r_z_theta')
isequal(H,H_24)

```

$H =$

```

[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta),
  a*cos(theta)]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta),
  a*sin(theta)]
[      0,          sin(alpha),          cos(alpha),
  d]
[      0,          0,          0,
  1]

```

$H_1 =$

```

[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta),
  a*cos(theta)]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta),
  a*sin(theta)]
[      0,          sin(alpha),          cos(alpha),
  d]
[      0,          0,          0,
  1]

```

$H_2 =$

```

[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta),
  a*cos(theta)]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta),
  a*sin(theta)]
[      0,          sin(alpha),          cos(alpha),
  d]
[      0,          0,          0,
  1]

```

$H_3 =$

```

[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta),
  a*cos(theta)]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta),
  a*sin(theta)]
[      0,          sin(alpha),          cos(alpha),
  d]
[      0,          0,          0,
  1]

```

H_4 =

```

[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta),
  a*cos(theta) + d*sin(alpha)*sin(theta)]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta),
  a*sin(theta) - d*sin(alpha)*cos(theta)]
[      0,          sin(alpha),          cos(alpha),
  d*cos(alpha)]
[      0,          0,          0,
  1]

```

H_5 =

```

[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta),
  a*cos(theta) + d*sin(alpha)*sin(theta)]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta),
  a*sin(theta) - d*sin(alpha)*cos(theta)]
[      0,          sin(alpha),          cos(alpha),
  d*cos(alpha)]
[      0,          0,          0,
  1]

```

H_6 =

```

[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta),
  a*cos(theta) + d*sin(alpha)*sin(theta)]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta),
  a*sin(theta) - d*sin(alpha)*cos(theta)]
[      0,          sin(alpha),          cos(alpha),
  d*cos(alpha)]
[      0,          0,          0,
  1]

```

H_7 =

```

[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta),
  a*cos(theta)]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta),
  a*sin(theta)]
[      0,          sin(alpha),          cos(alpha),
  d]

```

```

[      0,      0,      0,
 1]

```

```

H_8 =

```

```

[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta),
  a*cos(theta)]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta),
  a*sin(theta)]
[      0,      sin(alpha),      cos(alpha),
  d]
[      0,      0,      0,
 1]

```

```

H_9 =

```

```

[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta), a]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta), 0]
[      0,      sin(alpha),      cos(alpha), d]
[      0,      0,      0, 1]

```

```

H_10 =

```

```

[      cos(theta),      -sin(theta),      0, a]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha), 0]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta), cos(alpha), d]
[      0,      0,      0, 1]

```

```

H_11 =

```

```

[      cos(theta),      -sin(theta),      0,
 0]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha), -
d*sin(alpha)]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta), cos(alpha), d +
d*cos(alpha)]
[      0,      0,      0,
 1]

```

```

H_12 =

```

```

[      cos(theta),      -sin(theta),      0,
 0]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha), -
d*sin(alpha)]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta), cos(alpha), d +
d*cos(alpha)]
[      0,      0,      0,
 1]

```

$H_{13} =$

```
[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta), a]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta), 0]
[          0,          sin(alpha),          cos(alpha), d]
[          0,          0,          0, 1]
```

$H_{14} =$

```
[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta), a +
d*sin(alpha)*sin(theta)]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta), -
d*sin(alpha)*cos(theta)]
[          0,          sin(alpha),          cos(alpha),
d*cos(alpha)]
[          0,          0,          0,
1]
```

$H_{15} =$

```
[ cos(theta), -cos(alpha)*sin(theta), sin(alpha)*sin(theta), a]
[ sin(theta), cos(alpha)*cos(theta), -sin(alpha)*cos(theta), 0]
[          0,          sin(alpha),          cos(alpha), d]
[          0,          0,          0, 1]
```

$H_{16} =$

```
[          cos(theta),          -sin(theta),          0, a]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha), 0]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta), cos(alpha), d]
[          0,          0,          0, 1]
```

$H_{17} =$

```
[          cos(theta),          -sin(theta),          0,
a]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha), -
d*sin(alpha)]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta), cos(alpha),
d*cos(alpha)]
[          0,          0,          0,
1]
```

$H_{18} =$

```
[          cos(theta),          -sin(theta),          0,
a]
```

```

[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha), -
d*sin(alpha)]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta), cos(alpha),
d*cos(alpha)]
[                                0,                                0,                                0,
1]

```

H_19 =

```

[ cos(theta), -sin(theta), 0,
a*cos(theta)]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha),
a*cos(alpha)*sin(theta) - d*sin(alpha)]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta), cos(alpha),
d*cos(alpha) + a*sin(alpha)*sin(theta)]
[                                0,                                0,                                0,
1]

```

H_20 =

```

[ cos(theta), -sin(theta), 0,
a*cos(theta)]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha),
a*cos(alpha)*sin(theta) - d*sin(alpha)]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta), cos(alpha),
d*cos(alpha) + a*sin(alpha)*sin(theta)]
[                                0,                                0,                                0,
1]

```

H_21 =

```

[ cos(theta), -sin(theta), 0,
a*cos(theta)]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha),
a*cos(alpha)*sin(theta) - d*sin(alpha)]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta), cos(alpha),
d*cos(alpha) + a*sin(alpha)*sin(theta)]
[                                0,                                0,                                0,
1]

```

H_22 =

```

[ cos(theta), -sin(theta), 0,
a]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha), -
d*sin(alpha)]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta), cos(alpha),
d*cos(alpha)]
[                                0,                                0,                                0,
1]

```

$H_{23} =$

```
[      cos(theta),      -sin(theta),      0,
  a]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha), -
d*sin(alpha)]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta),  cos(alpha),
  d*cos(alpha)]
[      0,      0,      0,
  1]
```

$H_{24} =$

```
[      cos(theta),      -sin(theta),      0,
  a]
[ cos(alpha)*sin(theta), cos(alpha)*cos(theta), -sin(alpha), -
d*sin(alpha)]
[ sin(alpha)*sin(theta), sin(alpha)*cos(theta),  cos(alpha),
  d*cos(alpha)]
[      0,      0,      0,
  1]
```

Comparing H and H_1 : $r_z_theta*trform_z_d*trform_x_a*r_x_alpha$
ans =

logical

1

Comparing H and $H_2=r_z_theta*trform_z_d*r_x_alpha*trform_x_a$
ans =

logical

1

Comparing H and $H_3= r_z_theta*trform_x_a*trform_z_d*r_x_alpha$
ans =

logical

1

Comparing H and $H_4= r_z_theta*trform_x_a*r_x_alpha*trform_z_d$
ans =

logical

0

Comparing H and $H_5= r_z_theta*r_x_alpha*trform_z_d*trform_x_a$

ans =

logical

0

Comparing H and H_6= $r_z\theta r_x\alpha \text{trform}_x a \text{trform}_z d$

ans =

logical

0

Comparing H and H_7= $\text{trform}_z d r_z\theta \text{trform}_x a r_x\alpha$

ans =

logical

1

Comparing H and H_8= $\text{trform}_z d r_z\theta r_x\alpha \text{trform}_x a$

ans =

logical

1

Comparing H and H_9= $\text{trform}_z d \text{trform}_x a r_z\theta r_x\alpha$

ans =

logical

0

Comparing H and H_10= $\text{trform}_z d \text{trform}_x a r_x\alpha r_z\theta$

ans =

logical

0

Comparing H and H_11= $\text{trform}_z d r_x\alpha r_z\theta \text{trform}_z d$

ans =

logical

0

Comparing H and H_12= $\text{trform}_z d r_x\alpha \text{trform}_z d r_z\theta$

ans =

logical

0

Comparing H and $H_{13}=trform_x_a*r_z_theta*trform_z_d*r_x_alpha$
ans =

logical

0

Comparing H and $H_{14}=trform_x_a*r_z_theta*r_x_alpha*trform_z_d$
ans =

logical

0

Comparing H and $H_{15}=trform_x_a*trform_z_d*r_z_theta*r_x_alpha$
ans =

logical

0

Comparing H and $H_{16}=trform_x_a*trform_z_d*r_x_alpha*r_z_theta$
ans =

logical

0

Comparing H and $H_{17}=trform_x_a*r_x_alpha*r_z_theta*trform_z_d$
ans =

logical

0

Comparing H and $H_{18}=trform_x_a*r_x_alpha*trform_z_d*r_z_theta$
ans =

logical

0

Comparing H and $H_{19}=r_x_alpha*r_z_theta*trform_z_d*trform_x_a$
ans =

logical

0

Comparing H and $H_{20}=r_x_alpha*r_z_theta*trform_x_a*trform_z_d$
ans =

logical

0

Comparing H and $H_{21}=r_x_alpha*trform_z_d*r_z_theta*trform_x_a$
ans =

logical

0

Comparing H and $H_{22}=r_x_alpha*trform_z_d*trform_x_a*r_z_theta$
ans =

logical

0

Comparing H and $H_{23}=r_x_alpha*trform_x_a*r_z_theta*trform_z_d$
ans =

logical

0

Comparing H and $H_{24}=r_x_alpha*trform_x_a*trform_z_d*r_z_theta$
ans =

logical

0

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