Rhino

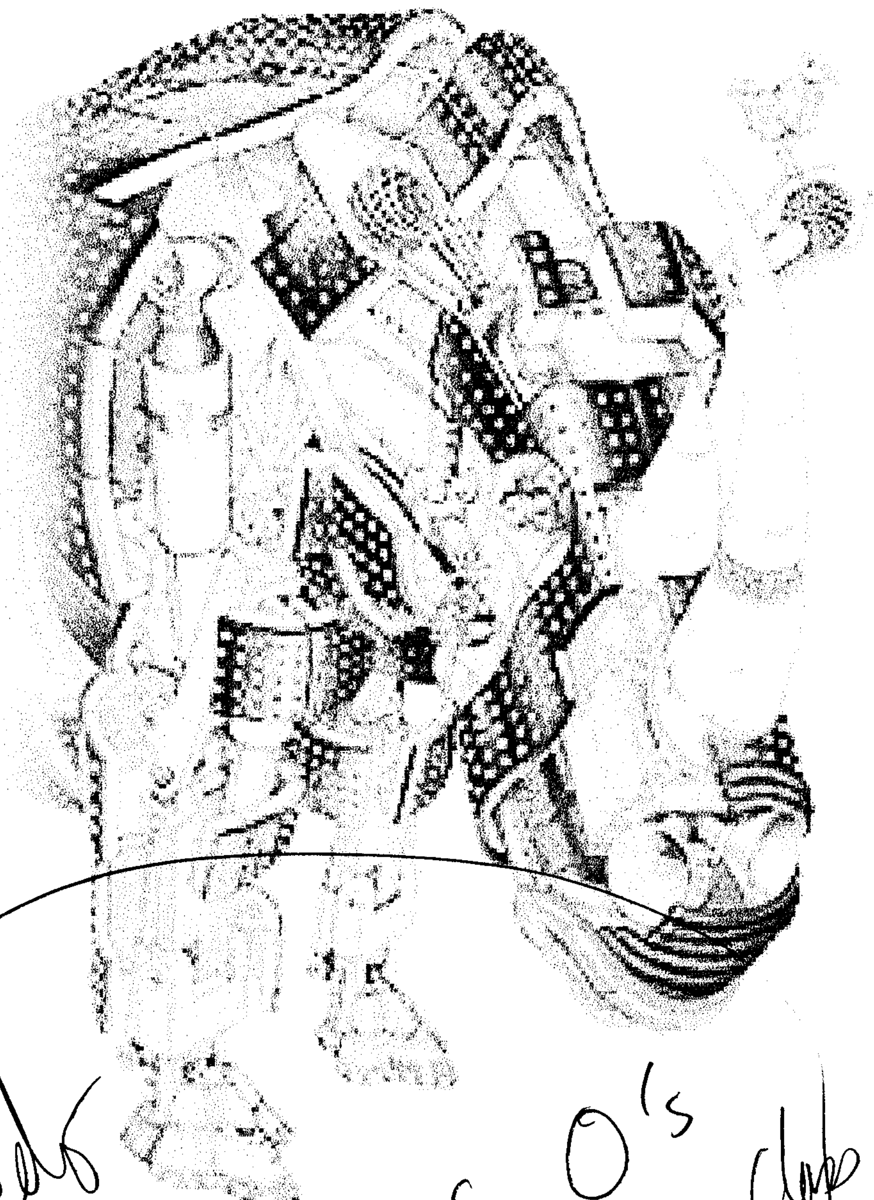
ASSIGNMENT NO-5 SUBMITTED BY FOZIA MERCHANT

A rhino's horn looks as if it is made of bone but actually is made of hairlike fibers stuck together with a type of natural resin-like glue.

Two metal horns on the robot simulate a real rhino's strong horns.

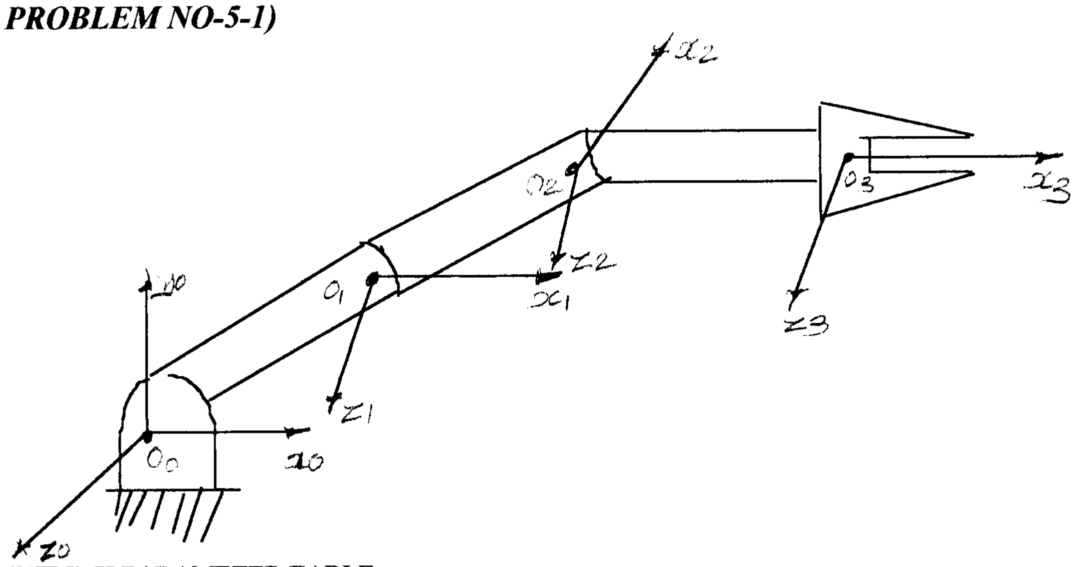
Flattened feet and broad, three-toed hooves distribute the rhino's massive weight over a large area.

Shock-absorbing pads and flared supports on the robot's feet help bear its weight.



Redo Using Z's O's as explained in class

PROBLEM NO-5-1)



THE D-H PARAMETER TABLE:

LINKS	ai	αi	di	θθ
1	a1	0	0	θ1
2	a2	0	0	θ2
3	a3	0	0	θ3

```
> restart;
```
PROBLEM 5-1) For a 3- link planar manipulator derive jacobian
```
> with(linalg):
Warning, new definition for norm
Warning, new definition for trace
> A1:=matrix(4,4,[cos(theta1),-sin(theta1),0,a1cos(theta1),sin(theta
  1),cos(theta1),0,a1sin(theta1),0,0,1,0,0,0,0,1]);
```
$$A1 := \begin{bmatrix} \cos(\theta 1) & -\sin(\theta 1) & 0 & a1\cos(\theta 1) \\ \sin(\theta 1) & \cos(\theta 1) & 0 & a1\sin(\theta 1) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$
```
> A2:=matrix(4,4,[cos(theta2),-sin(theta2),0,a2cos(theta2),sin(theta
  2),cos(theta2),0,a2sin(theta2),0,0,1,0,0,0,0,1]);
```
$$A2 := \begin{bmatrix} \cos(\theta 2) & -\sin(\theta 2) & 0 & a2\cos(\theta 2) \\ \sin(\theta 2) & \cos(\theta 2) & 0 & a2\sin(\theta 2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$
```
> A3:=matrix(4,4,[cos(theta3),-sin(theta3),0,a3cos(theta3),sin(theta
  3),cos(theta3),0,a3sin(theta3),0,0,1,0,0,0,0,1]);
```
$$A3 := \begin{bmatrix} \cos(\theta 3) & -\sin(\theta 3) & 0 & a3\cos(\theta 3) \\ \sin(\theta 3) & \cos(\theta 3) & 0 & a3\sin(\theta 3) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$
```
> T3:=matrix(4,4,[nx,ox,ax,px,ny,oy,ay,py,nz,oz,az,pz,0,0,0,1]);
```
$$T3 := \begin{bmatrix} nx & ox & ax & px \\ ny & oy & ay & py \\ nz & oz & az & pz \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where T3=A1*(A2*A3);
```
> To1:=multiply(A2,A3);
```
$To1 :=$

$[\cos(\theta 2)\cos(\theta 3) - \sin(\theta 2)\sin(\theta 3), -\cos(\theta 2)\sin(\theta 3) - \sin(\theta 2)\cos(\theta 3), 0,$
$\cos(\theta 2)\, a3\cos(\theta 3) - \sin(\theta 2)\, a3\sin(\theta 3) + a2\cos(\theta 2)]$

$[\sin(\theta 2)\cos(\theta 3) + \cos(\theta 2)\sin(\theta 3), \cos(\theta 2)\cos(\theta 3) - \sin(\theta 2)\sin(\theta 3), 0,$
$\sin(\theta 2)\, a3\cos(\theta 3) + \cos(\theta 2)\, a3\sin(\theta 3) + a2\sin(\theta 2)]$

$[0, 0, 1, 0]$

$[0, 0, 0, 1]$
```
>
> T3:=multiply(A1,To1);
```
$T3 :=$

$[\cos(\theta 1)(\cos(\theta 2)\cos(\theta 3) - \sin(\theta 2)\sin(\theta 3)) - \sin(\theta 1)(\sin(\theta 2)\cos(\theta 3) + \cos(\theta 2)\sin(\theta 3)),$

$$T3 :=$$

$$\begin{aligned}
&[\cos(\theta 1)(\cos(\theta 2)\cos(\theta 3)-\sin(\theta 2)\sin(\theta 3))-\sin(\theta 1)(\sin(\theta 2)\cos(\theta 3)+\cos(\theta 2)\sin(\theta 3)),\\
&\cos(\theta 1)(-\cos(\theta 2)\sin(\theta 3)-\sin(\theta 2)\cos(\theta 3))-\sin(\theta 1)(\cos(\theta 2)\cos(\theta 3)-\sin(\theta 2)\sin(\theta 3)),\\
&0, \cos(\theta 1)(\cos(\theta 2)\,a3\cos(\theta 3)-\sin(\theta 2)\,a3\sin(\theta 3)+a2\cos(\theta 2))\\
&\ -\sin(\theta 1)(\sin(\theta 2)\,a3\cos(\theta 3)+\cos(\theta 2)\,a3\sin(\theta 3)+a2\sin(\theta 2))+a1\cos(\theta 1)]\\
&[\sin(\theta 1)(\cos(\theta 2)\cos(\theta 3)-\sin(\theta 2)\sin(\theta 3))+\cos(\theta 1)(\sin(\theta 2)\cos(\theta 3)+\cos(\theta 2)\sin(\theta 3)),\\
&\sin(\theta 1)(-\cos(\theta 2)\sin(\theta 3)-\sin(\theta 2)\cos(\theta 3))+\cos(\theta 1)(\cos(\theta 2)\cos(\theta 3)-\sin(\theta 2)\sin(\theta 3)),\\
&0, \sin(\theta 1)(\cos(\theta 2)\,a3\cos(\theta 3)-\sin(\theta 2)\,a3\sin(\theta 3)+a2\cos(\theta 2))\\
&\ +\cos(\theta 1)(\sin(\theta 2)\,a3\cos(\theta 3)+\cos(\theta 2)\,a3\sin(\theta 3)+a2\sin(\theta 2))+a1\sin(\theta 1)]\\
&[0, 0, 1, 0]\\
&[0, 0, 0, 1]
\end{aligned}$$

Now T3d1x =[-nx*py+ny*px] ie defining each subpart as a small matrix and then taking its determinant;

```
> T3d1x=matrix(2,2,[cos(theta1)*(cos(theta2)*cos(theta3)-sin(theta2)
  *sin(theta3))-sin(theta1)*(sin(theta2)*cos(theta3)+cos(theta2)*sin
  (theta3)),
  cos(theta1)*(cos(theta2)*a3cos(theta3)-sin(theta2)*a3sin(theta3)+a
  2cos(theta2))-sin(theta1)*(sin(theta2)*a3cos(theta3)+cos(theta2)*a
  3sin(theta3)+a2sin(theta2))+a1cos(theta1),
  sin(theta1)*(cos(theta2)*cos(theta3)-sin(theta2)*sin(theta3))+cos(
  theta1)*(sin(theta2)*cos(theta3)+cos(theta2)*sin(theta3)),
  sin(theta1)*(cos(theta2)*a3cos(theta3)-sin(theta2)*a3sin(theta3)+a
  2cos(theta2))+cos(theta1)*(sin(theta2)*a3cos(theta3)+cos(theta2)*a
  3sin(theta3)+a2sin(theta2))+a1sin(theta1)]);
>
```

$$T3d1x :=$$

$$\begin{aligned}
&[\cos(\theta 1)(\cos(\theta 2)\cos(\theta 3)-\sin(\theta 2)\sin(\theta 3))-\sin(\theta 1)(\sin(\theta 2)\cos(\theta 3)+\cos(\theta 2)\sin(\theta 3)),\\
&\cos(\theta 1)(\cos(\theta 2)\,a3\cos(\theta 3)-\sin(\theta 2)\,a3\sin(\theta 3)+a2\cos(\theta 2))\\
&\ -\sin(\theta 1)(\sin(\theta 2)\,a3\cos(\theta 3)+\cos(\theta 2)\,a3\sin(\theta 3)+a2\sin(\theta 2))+a1\cos(\theta 1)]\\
&[\sin(\theta 1)(\cos(\theta 2)\cos(\theta 3)-\sin(\theta 2)\sin(\theta 3))+\cos(\theta 1)(\sin(\theta 2)\cos(\theta 3)+\cos(\theta 2)\sin(\theta 3)),\\
&\sin(\theta 1)(\cos(\theta 2)\,a3\cos(\theta 3)-\sin(\theta 2)\,a3\sin(\theta 3)+a2\cos(\theta 2))\\
&\ +\cos(\theta 1)(\sin(\theta 2)\,a3\cos(\theta 3)+\cos(\theta 2)\,a3\sin(\theta 3)+a2\sin(\theta 2))+a1\sin(\theta 1)]
\end{aligned}$$

```
> det(T3d1x);
```

$$\begin{aligned}
&\cos(\theta 1)^2\cos(\theta 2)^2\cos(\theta 3)\,a3\sin(\theta 3)+\cos(\theta 1)^2\cos(\theta 2)\cos(\theta 3)\,a2\sin(\theta 2)\\
&\ -\cos(\theta 1)^2\sin(\theta 2)^2\sin(\theta 3)\,a3\cos(\theta 3)-\cos(\theta 1)^2\sin(\theta 2)\sin(\theta 3)\,a2\sin(\theta 2)\\
&\ +\sin(\theta 1)^2\sin(\theta 2)^2\cos(\theta 3)\,a3\sin(\theta 3)-\sin(\theta 1)^2\sin(\theta 2)\cos(\theta 3)\,a2\cos(\theta 2)\\
&\ -\sin(\theta 1)^2\cos(\theta 2)^2\sin(\theta 3)\,a3\cos(\theta 3)-\sin(\theta 1)^2\cos(\theta 2)\sin(\theta 3)\,a2\cos(\theta 2)\\
&\ +\cos(\theta 1)\cos(\theta 2)\cos(\theta 3)\,a1\sin(\theta 1)-\cos(\theta 1)\sin(\theta 2)\sin(\theta 3)\,a1\sin(\theta 1)\\
&\ -\sin(\theta 1)\sin(\theta 2)\cos(\theta 3)\,a1\sin(\theta 1)-\sin(\theta 1)\cos(\theta 2)\sin(\theta 3)\,a1\sin(\theta 1)
\end{aligned}$$

2)

```
> det(T3d1a);
```

$$
\begin{aligned}
&\cos(\theta 1)^2 \cos(\theta 2)^2 \cos(\theta 3)\,\mathrm{a3}\sin(\theta 3) + \cos(\theta 1)^2 \cos(\theta 2)\cos(\theta 3)\,\mathrm{a2}\sin(\theta 2)\\
&\quad - \cos(\theta 1)^2 \sin(\theta 2)^2 \sin(\theta 3)\,\mathrm{a3}\cos(\theta 3) - \cos(\theta 1)^2 \sin(\theta 2)\sin(\theta 3)\,\mathrm{a2}\sin(\theta 2)\\
&\quad + \sin(\theta 1)^2 \sin(\theta 2)^2 \cos(\theta 3)\,\mathrm{a3}\sin(\theta 3) - \sin(\theta 1)^2 \sin(\theta 2)\cos(\theta 3)\,\mathrm{a2}\cos(\theta 2)\\
&\quad - \sin(\theta 1)^2 \cos(\theta 2)^2 \sin(\theta 3)\,\mathrm{a3}\cos(\theta 3) - \sin(\theta 1)^2 \cos(\theta 2)\sin(\theta 3)\,\mathrm{a2}\cos(\theta 2)\\
&\quad + \cos(\theta 1)\cos(\theta 2)\cos(\theta 3)\,\mathrm{a1}\sin(\theta 1) - \cos(\theta 1)\sin(\theta 2)\sin(\theta 3)\,\mathrm{a1}\sin(\theta 1)\\
&\quad - \sin(\theta 1)\sin(\theta 2)\cos(\theta 3)\,\mathrm{a1}\sin(\theta 1) - \sin(\theta 1)\cos(\theta 2)\sin(\theta 3)\,\mathrm{a1}\sin(\theta 1)\\
&\quad - \cos(\theta 1)^2 \cos(\theta 2)^2\,\mathrm{a3}\cos(\theta 3)\sin(\theta 3) + \cos(\theta 1)^2 \sin(\theta 2)^2\,\mathrm{a3}\sin(\theta 3)\cos(\theta 3)\\
&\quad - \cos(\theta 1)^2\,\mathrm{a2}\cos(\theta 2)\sin(\theta 2)\cos(\theta 3) - \cos(\theta 1)^2\,\mathrm{a2}\cos(\theta 2)\cos(\theta 2)\sin(\theta 3)\\
&\quad - \sin(\theta 1)^2 \sin(\theta 2)^2\,\mathrm{a3}\cos(\theta 3)\sin(\theta 3) + \sin(\theta 1)^2 \cos(\theta 2)^2\,\mathrm{a3}\sin(\theta 3)\cos(\theta 3)\\
&\quad + \sin(\theta 1)^2\,\mathrm{a2}\sin(\theta 2)\cos(\theta 2)\cos(\theta 3) - \sin(\theta 1)^2\,\mathrm{a2}\sin(\theta 2)\sin(\theta 2)\sin(\theta 3)\\
&\quad - \mathrm{a1}\cos(\theta 1)\sin(\theta 1)\cos(\theta 2)\cos(\theta 3) + \mathrm{a1}\cos(\theta 1)\sin(\theta 1)\sin(\theta 2)\sin(\theta 3)\\
&\quad - \mathrm{a1}\cos(\theta 1)\cos(\theta 1)\sin(\theta 2)\cos(\theta 3) - \mathrm{a1}\cos(\theta 1)\cos(\theta 1)\cos(\theta 2)\sin(\theta 3)
\end{aligned}
$$

```
> T3d1b:=matrix(2,2,[cos(theta1)*(-cos(theta2)*sin(theta3)-sin(theta2
  )*cos(theta3))-sin(theta1)*(cos(theta2)*cos(theta3)-sin(theta2)*si
  n(theta3)),
  cos(theta1)*(cos(theta2)*a3cos(theta3)-sin(theta2)*a3sin(theta3)+a
  2cos(theta2))-sin(theta1)*(sin(theta2)*a3cos(theta3)+cos(theta2)*a
  3sin(theta3)+a2sin(theta2))+a1cos(theta1),
  sin(theta1)*(-cos(theta2)*sin(theta3)-sin(theta2)*cos(theta3))+cos
  (theta1)*(cos(theta2)*cos(theta3)-sin(theta2)*sin(theta3)),
  sin(theta1)*(cos(theta2)*a3cos(theta3)-sin(theta2)*a3sin(theta3)+a
  2cos(theta2))+cos(theta1)*(sin(theta2)*a3cos(theta3)+cos(theta2)*a
  3sin(theta3)+a2sin(theta2))+a1sin(theta1)]);
```

T3d1b :=

$$
\begin{aligned}
&[\cos(\theta 1)(-\cos(\theta 2)\sin(\theta 3) - \sin(\theta 2)\cos(\theta 3)) - \sin(\theta 1)(\cos(\theta 2)\cos(\theta 3) - \sin(\theta 2)\sin(\theta 3))\\
&\;, \cos(\theta 1)(\cos(\theta 2)\,\mathrm{a3}\cos(\theta 3) - \sin(\theta 2)\,\mathrm{a3}\sin(\theta 3) + \mathrm{a2}\cos(\theta 2))\\
&\quad - \sin(\theta 1)(\sin(\theta 2)\,\mathrm{a3}\cos(\theta 3) + \cos(\theta 2)\,\mathrm{a3}\sin(\theta 3) + \mathrm{a2}\sin(\theta 2)) + \mathrm{a1}\cos(\theta 1)]\\
&[\sin(\theta 1)(-\cos(\theta 2)\sin(\theta 3) - \sin(\theta 2)\cos(\theta 3)) + \cos(\theta 1)(\cos(\theta 2)\cos(\theta 3) - \sin(\theta 2)\sin(\theta 3))\\
&\;, \sin(\theta 1)(\cos(\theta 2)\,\mathrm{a3}\cos(\theta 3) - \sin(\theta 2)\,\mathrm{a3}\sin(\theta 3) + \mathrm{a2}\cos(\theta 2))\\
&\quad + \cos(\theta 1)(\sin(\theta 2)\,\mathrm{a3}\cos(\theta 3) + \cos(\theta 2)\,\mathrm{a3}\sin(\theta 3) + \mathrm{a2}\sin(\theta 2)) + \mathrm{a1}\sin(\theta 1)]
\end{aligned}
$$

```
> det(T3d1b)
```

$$
\begin{aligned}
&-\cos(\theta 1)^2 \cos(\theta 2)^2 \sin(\theta 3)\,\mathrm{a3}\sin(\theta 3) - \cos(\theta 1)^2 \cos(\theta 2)\sin(\theta 3)\,\mathrm{a2}\sin(\theta 2)\\
&\quad - \cos(\theta 1)^2 \sin(\theta 2)^2 \cos(\theta 3)\,\mathrm{a3}\cos(\theta 3) - \cos(\theta 1)^2 \sin(\theta 2)\cos(\theta 3)\,\mathrm{a2}\sin(\theta 2)\\
&\quad - \sin(\theta 1)^2 \cos(\theta 2)^2 \cos(\theta 3)\,\mathrm{a3}\cos(\theta 3) - \sin(\theta 1)^2 \cos(\theta 2)\cos(\theta 3)\,\mathrm{a2}\cos(\theta 2)\\
&\quad - \sin(\theta 1)^2 \sin(\theta 2)^2 \sin(\theta 3)\,\mathrm{a3}\sin(\theta 3) + \sin(\theta 1)^2 \sin(\theta 2)\sin(\theta 3)\,\mathrm{a2}\cos(\theta 2)\\
&\quad - \cos(\theta 1)\cos(\theta 2)\sin(\theta 3)\,\mathrm{a1}\sin(\theta 1) - \cos(\theta 1)\sin(\theta 2)\cos(\theta 3)\,\mathrm{a1}\sin(\theta 1)
\end{aligned}
$$

Solving the above & reducing it to much compact equation using Trigonometry, we obtain the above resultFOR THE FIRST COLUMN, NOW FOR THE SECOND COLUMN,

To1:=A2*A3

```
> Tol := matrix([[cos(theta2)*cos(theta3)-sin(theta2)*sin(theta3),
  -cos(theta2)*sin(theta3)-sin(theta2)*cos(theta3), 0,
  cos(theta2)*a3cos(theta3)-sin(theta2)*a3sin(theta3)+a2cos(theta2)]
  , [sin(theta2)*cos(theta3)+cos(theta2)*sin(theta3),
  cos(theta2)*cos(theta3)-sin(theta2)*sin(theta3), 0,
  sin(theta2)*a3cos(theta3)+cos(theta2)*a3sin(theta3)+a2sin(theta2)]
  , [0, 0, 1, 0], [0, 0, 0, 1]]);
```

Tol :=

$$
\begin{bmatrix}
\cos(\theta 2)\cos(\theta 3) - \sin(\theta 2)\sin(\theta 3) & -\cos(\theta 2)\sin(\theta 3) - \sin(\theta 2)\cos(\theta 3) & 0 & \cos(\theta 2)\,a3\cos(\theta 3) - \sin(\theta 2)\,a3\sin(\theta 3) + a2\cos(\theta 2) \\
\sin(\theta 2)\cos(\theta 3) + \cos(\theta 2)\sin(\theta 3) & \cos(\theta 2)\cos(\theta 3) - \sin(\theta 2)\sin(\theta 3) & 0 & \sin(\theta 2)\,a3\cos(\theta 3) + \cos(\theta 2)\,a3\sin(\theta 3) + a2\sin(\theta 2) \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
$$

```
> T6d2:=matrix(2,2,[cos(theta2)*cos(theta3)-sin(theta2)*sin(theta3),
  cos(theta2)*a3cos(theta3)-sin(theta2)*a3sin(theta3)+a2cos(theta2),
  sin(theta2)*cos(theta3)+cos(theta2)*sin(theta3),sin(theta2)*a3cos(
  theta3)+cos(theta2)*a3sin(theta3)+a2sin(theta2)]);
```

T6d2 :=

$$
\begin{bmatrix}
\cos(\theta 2)\cos(\theta 3) - \sin(\theta 2)\sin(\theta 3) & \cos(\theta 2)\,a3\cos(\theta 3) - \sin(\theta 2)\,a3\sin(\theta 3) + a2\cos(\theta 2) \\
\sin(\theta 2)\cos(\theta 3) + \cos(\theta 2)\sin(\theta 3) & \sin(\theta 2)\,a3\cos(\theta 3) + \cos(\theta 2)\,a3\sin(\theta 3) + a2\sin(\theta 2)
\end{bmatrix}
$$

```
> det(T6d2);
```

$$
\cos(\theta 2)^2\cos(\theta 3)\,a3\sin(\theta 3) + \cos(\theta 2)\cos(\theta 3)\,a2\sin(\theta 2) - \sin(\theta 2)^2\sin(\theta 3)\,a3\cos(\theta 3)
- \sin(\theta 2)\sin(\theta 3)\,a2\sin(\theta 2) - \cos(\theta 2)^2\,a3\cos(\theta 3)\sin(\theta 3) + \sin(\theta 2)^2\,a3\sin(\theta 3)\cos(\theta 3)
- a2\cos(\theta 2)\sin(\theta 2)\cos(\theta 3) - a2\cos(\theta 2)\cos(\theta 2)\sin(\theta 3)
$$

=a2s3

```
> T6d2:=matrix(2,2,[-cos(theta2)*sin(theta3)-sin(theta2)*cos(theta3)
  ,cos(theta2)*a3cos(theta3)-sin(theta2)*a3sin(theta3)+a2cos(theta2)
  ,cos(theta2)*cos(theta3)-sin(theta2)*sin(theta3),sin(theta2)*a3cos
  (theta3)+cos(theta2)*a3sin(theta3)+a2sin(theta2)]);
```

T6d2 :=

$$
\begin{bmatrix}
-\cos(\theta 2)\sin(\theta 3) - \sin(\theta 2)\cos(\theta 3) & \cos(\theta 2)\,a3\cos(\theta 3) - \sin(\theta 2)\,a3\sin(\theta 3) + a2\cos(\theta 2) \\
\cos(\theta 2)\cos(\theta 3) - \sin(\theta 2)\sin(\theta 3) & \sin(\theta 2)\,a3\cos(\theta 3) + \cos(\theta 2)\,a3\sin(\theta 3) + a2\sin(\theta 2)
\end{bmatrix}
$$

```
> det(T6d2);
```

$$
-\cos(\theta 2)^2\sin(\theta 3)\,a3\sin(\theta 3) - \cos(\theta 2)\sin(\theta 3)\,a2\sin(\theta 2) - \sin(\theta 2)^2\cos(\theta 3)\,a3\cos(\theta 3)
- \sin(\theta 2)\cos(\theta 3)\,a2\sin(\theta 2) - \cos(\theta 2)^2\,a3\cos(\theta 3)\cos(\theta 3) - \sin(\theta 2)^2\,a3\sin(\theta 3)\sin(\theta 3)
- a2\cos(\theta 2)\cos(\theta 2)\cos(\theta 3) + a2\cos(\theta 2)\sin(\theta 2)\sin(\theta 3)
$$

T3 3x:=0;
T3 3y:=0;
T3 3z:=1;
Therefore the 3rd column of jacobian becomes;

```
> T6c:=matrix(6,1,[0,a3,0,0,0,1]);
```

$$\frac{\partial\, T6c}{\partial \theta_3} := \begin{bmatrix} 0 \\ a3 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

Look page 36 in key

THEREFORE THE FINAL J=

```
> J:=matrix(6,3,[a1sin(theta23)+a2sin(theta3),a2sin(theta3),0,a1cos(
  theta23)+a2cos(theta3)+a3,a3+a2cos(theta3),a3,0,0,0,0,0,0,0,0,0,1,
  1,1]);
```

$$J := \begin{bmatrix} a1\sin(\theta 23) + a2\sin(\theta 3) & a2\sin(\theta 3) & 0 \\ a1\cos(\theta 23) + a2\cos(\theta 3) + a3 & a3 + a2\cos(\theta 3) & a3 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

Use the Z's & 0's to form Jacobian efficiently

PROBLEM 5-2)
LOOKING AT THE RIGHT SIDE AT THE D-H PARAMETER TABLE WE SEE;

```
> A1:=matrix(4,4,[cos(theta1),0,-sin(theta1),0,sin(theta1),0,-cos(th
  eta1),0,0,1,0,0,0,0,0,1]);
```

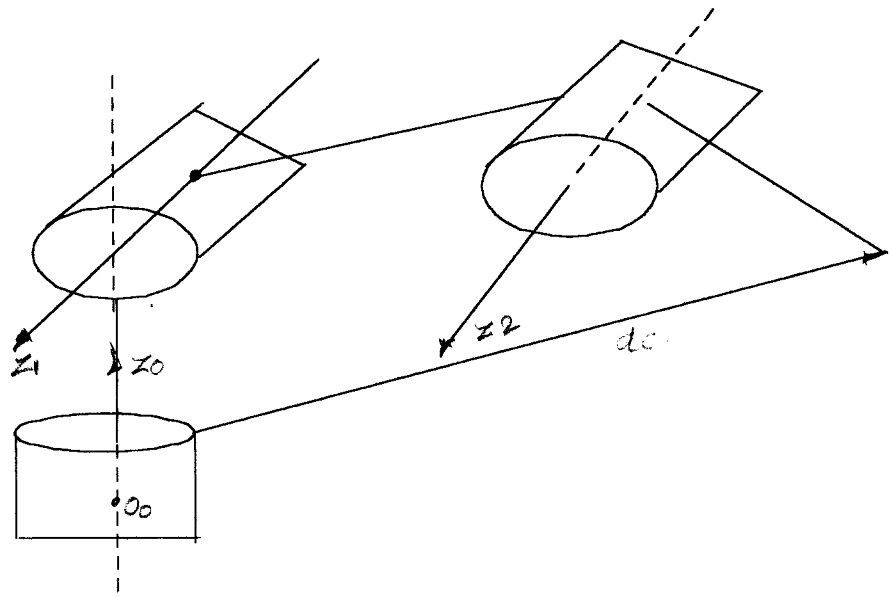
$$A1 := \begin{bmatrix} \cos(\theta 1) & 0 & -\sin(\theta 1) & 0 \\ \sin(\theta 1) & 0 & -\cos(\theta 1) & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

```
> A2:=matrix(4,4,[cos(theta2),-sin(theta2),0,a2cos(theta2),sin(theta
  2),-cos(theta2),0,a2sin(theta2),0,0,1,0,0,0,0,1]);
```

$$A2 := \begin{bmatrix} \cos(\theta 2) & -\sin(\theta 2) & 0 & a2\cos(\theta 2) \\ \sin(\theta 2) & -\cos(\theta 2) & 0 & a2\sin(\theta 2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

```
> A3:=matrix(4,4,[cos(theta3),-sin(theta3),0,a3cos(theta3),sin(theta
  3),-cos(theta3),0,a3sin(theta3),0,0,1,0,0,0,0,1]);
```

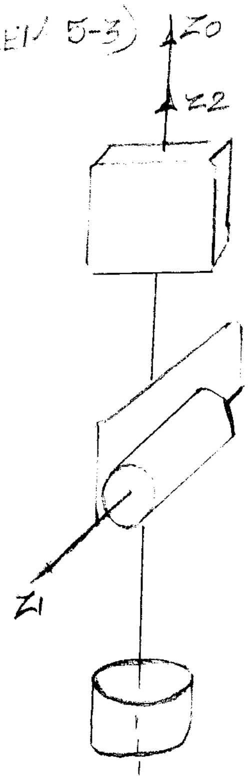
PROBLEM –5-2)



THE D-H PARAMETER TABLE:

LINKS	ai	αi	di	θθ
1	0	-90	0	θ1
2	a2	0	0	θ2
3	a3	0	0	θ3

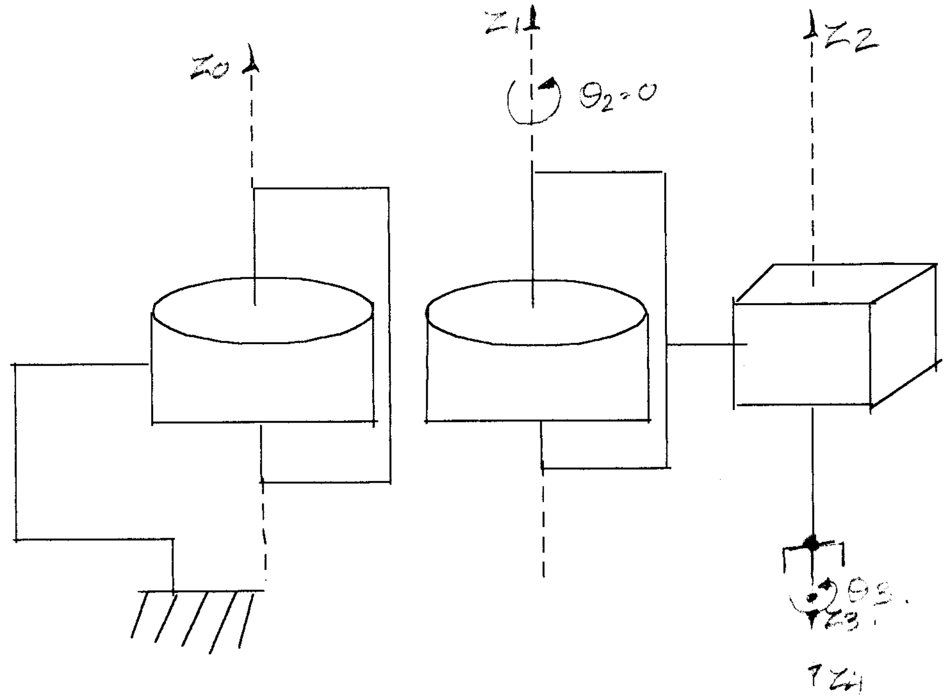
PROBLEM 5-3)



D-H PARAMETER TABLE.

LINKS	a_i	α_i	d_i	θ_i
1	0	-90	0	θ_1
2	0	-90	d_2	θ_2
3	0	0	d_3	0

PROBLEM 5-4)



THE D-H PARAMETER TABLE:

LINKS	ai	αi	di	θθ
1	a1	0	0	θ1
2	a2	180	0	θ2
3	0	0	d3	0
4	0		d4	θ4

```
cos(theta2)*a3cos(theta3)-sin(theta2)*a3sin(theta3)+a2cos(theta2),
-cos(theta2)*sin(theta3)+sin(theta2)*cos(theta3),sin(theta2)*a3cos
(theta3)-cos(theta2)*a3sin(theta3)+a2sin(theta2)]);
```

$$T3d2 := \begin{bmatrix} \cos(\theta 2)\cos(\theta 3) - \sin(\theta 2)\sin(\theta 3) & \cos(\theta 2)\,\mathrm{a3cos}(\theta 3) - \sin(\theta 2)\,\mathrm{a3sin}(\theta 3) + \mathrm{a2cos}(\theta 2) \\ -\cos(\theta 2)\sin(\theta 3) + \sin(\theta 2)\cos(\theta 3) & \sin(\theta 2)\,\mathrm{a3cos}(\theta 3) - \cos(\theta 2)\,\mathrm{a3sin}(\theta 3) + \mathrm{a2sin}(\theta 2) \end{bmatrix}$$

\>

Therefore by solving the above matrix we get the jacobian of the 2nd column as

```
> T3d2b:=matrix(6,1,[a2sin(theta3),a3+a2cos(theta3),0,0,0,1]);
```

$$\frac{\partial T3d2b}{\partial\theta_2} := \begin{bmatrix} \mathrm{a2sin}(\theta 3) \\ a3 + \mathrm{a2cos}(\theta 3) \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

SIMILARLY THE 3RD COLUMN OF THE JACOBIAN IS NOTHING BUT THE SAME AS MARIX (A3)

```
> T3d3c:=matrix(6,1,[0,0,0,0,0,1]);
```

$$\frac{\partial T3d3c}{\partial\theta_3} := \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

Also the PARTIAL DERIVITIVES OF THE LOWER 3 ROWS OF EACH COLUMN ARE NOTHING BUT THE nz ,oz,az of the EACH RESPECTIVE MATRIX; THEREFORE COMBINING THE ABOVE THE ENTIRE JACOBIAN IS;

```
> J:=matrix(6,3,[0,a2sin(theta3),0,0,a3+a2cos(theta3),0,a2cos(theta2
)+a3cos(theta23),0,0,-sin(theta23),0,0,-cos(theta23),0,0,0,1,1]);
```

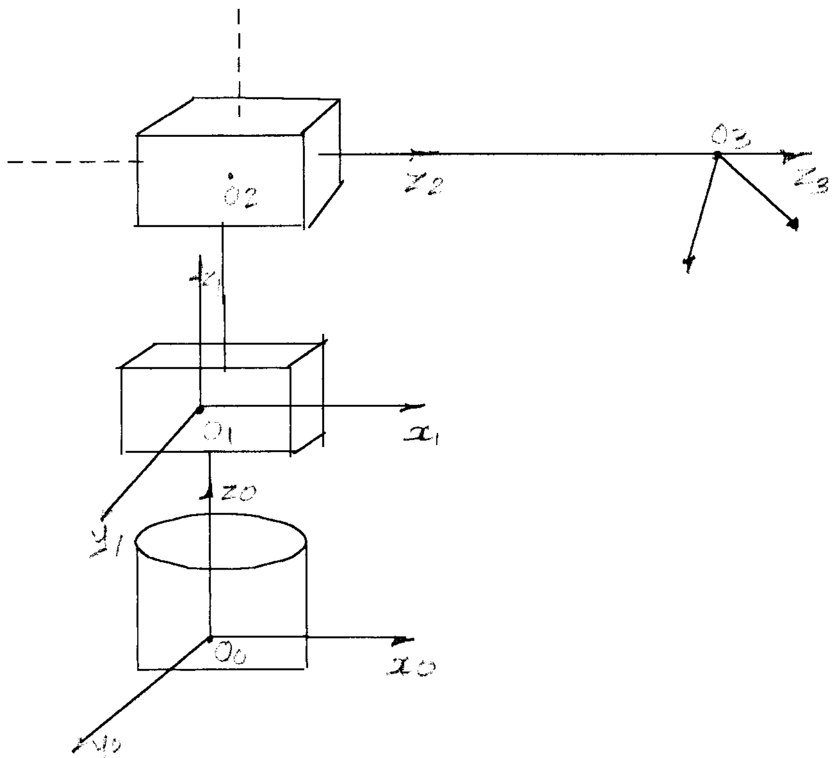
$$J := \begin{bmatrix} 0 & \mathrm{a2sin}(\theta 3) & 0 \\ 0 & a3 + \mathrm{a2cos}(\theta 3) & 0 \\ \mathrm{a2cos}(\theta 2) + \mathrm{a3cos}(\theta 23) & 0 & 0 \\ -\sin(\theta 23) & 0 & 0 \\ -\cos(\theta 23) & 0 & 0 \\ 0 & 1 & 1 \end{bmatrix}$$

PROBLEM 5-3)

NOTE : THE LAST JOINT IS PRISMATIC;

```
> A1:=matrix(4,4,[cos(theta1),0,-sin(theta1),0,sin(theta1),0,cos(the
ta1),0,0,-1,0,0,0,0,0,1]);
```

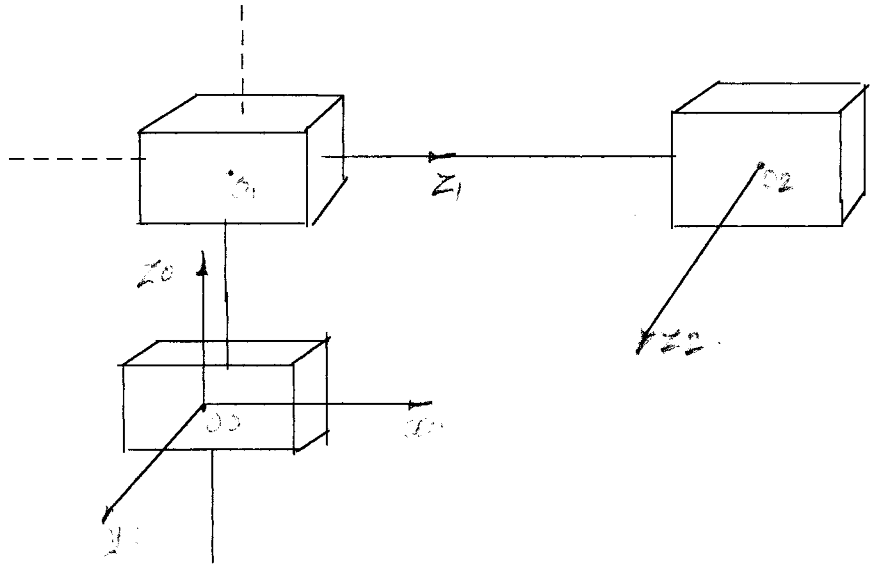
PROBLEM 5 –5)



THE D-H PARAMETER TABLE:

LINKS	ai	αi	di	θθ
1	0	0	d1	θ1
2	0	-90	d2	0
3	0	0	d3	0

PROBLEM 5-6)



THE D-H PARAMETER TABLE:

LINKS	ai	αi	di	θθ
1	0	-90	d1	θ1
2	0	90	d2	90
3	0	0	d3	90

`> T4:=multiply(A1,T01);`

$$T4 := \text{multiply}(A1, \text{multiply}(A3, A2))$$

now to find THE FIRST COLUMN OF THE JACOBIAN, FIND THE DETERMINANTS OF THE MATRIX T4;

Td1x= -nxpy+nypx = -d3

Td1y = -oxpy+oypx = 0

T d1z = -axpy+aypx = 0

ALSO TAKING THEIR PARTIAL DERIVITIVES;

(partial deri)x = 0

(partial deri)y = -1

(partial der)z = 0

`> T4a:=matrix(6,1,[-d3,0,0,0,-1,0]);`

$$\frac{\partial T4a}{\partial \theta_1} := \begin{bmatrix} -d3 \\ 0 \\ 0 \\ 0 \\ -1 \\ 0 \end{bmatrix}$$

SINCE THE OTHER 2 LINKS ARE PRISMATIC WE CAN DIRECTLY WRITE AS:

`> T4b:=matrix(6,1,[0,-1,0,0,0,0]);`

$$\frac{\partial T4b}{\partial \theta_2} := \begin{bmatrix} 0 \\ -1 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

`> T4c:=matrix(6,1,[0,0,1,0,0,0]);`

$$\frac{\partial T4c}{\partial \theta_3} := \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

COMBINING ALL AND WRITING THE FINAL JACOBIAN;

`> T4:=matrix(6,3,[-d3,0,0,0,-1,0,0,0,1,0,0,0,-1,0,0,0,0,0]);`

$$J \; \cancel{\frac{\partial T4}{\partial \theta_4}} := \begin{bmatrix} -d3 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

PROBLEM 5-6) THREE LINK CARTESIAN ROBOT;