Task 1a

$$m\ddot{y} = f - mg$$

We can rewrite the left side and get

$$m\ddot{y} = \frac{d}{dt}(m\dot{y}) = \frac{d}{dt}\frac{\partial}{\partial \dot{y}}\left(\frac{1}{2}m\dot{y}^2\right) = \frac{d}{dt}\frac{\partial K}{\partial \dot{y}}$$

since $K = \frac{1}{2}m\dot{y}^2$

The right side can be

$$f - mg = f - \frac{\partial}{\partial y}(mgy) = f - \frac{\partial P}{\partial y}$$

since $P = mgy$

We get:

$$\frac{d}{dt}\frac{\partial K}{\partial \dot{y}} = f - \frac{\partial P}{\partial y}$$

Lets the define $L = K - P$ where L is the Lagrangian

We can then rewrite

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{y}} - \frac{\partial L}{\partial y} = f$$

Since we then want to use generalized coordinates, we write it as

$$\frac{d}{dt}\frac{\partial L}{\partial \dot{q}_i} - \frac{\partial L}{\partial q_i} = \tau_i$$

Task 1b I start of by finding v_1, ω_1, v_2 and ω_2

$$J_v = \begin{bmatrix} -s_1(L_2c_2 + L_3c_{23}) & -c_1(L_2s_2 + L_3s_{23}) & -c_1(L_3s_{23}) \\ c_1(L_2c_2 + L_3c_{23}) & -s_1(L_2s_2 + L_3s_{23}) & -s_1(L_3s_{23}) \\ 0 & (L_2c_2 + L_3c_{23}) & L_3c_{23} \end{bmatrix}$$

$$J_\omega = \begin{bmatrix} 0 & s_1 & s_1 \\ 0 & -c_1 & -c_1 \\ 1 & 0 & 0 \end{bmatrix}$$

$$J_{v_1} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad J_{\omega_1} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix} \quad I_1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \frac{m_1 r_1^2}{2} \end{bmatrix}$$

$$\dot{q} = \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix}$$

$$v_1 = J_{v_1}(q) \cdot \dot{q} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \quad \omega_1 = J_{\omega_1}(q) \cdot \dot{q} = \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 \end{bmatrix}$$

$$J_{v_2} = \begin{bmatrix} -s_1L_2c_2 & -c_1L_2s_2 & 0 \\ c_1L_2c_2 & -s_1L_2s_2 & 0 \\ 0 & L_2c_2 & 0 \end{bmatrix} \quad J_{\omega_2} = \begin{bmatrix} 0 & s_1 & 0 \\ 0 & -c_1 & 0 \\ 1 & 0 & 0 \end{bmatrix} \quad I_2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$v_2 = J_{v_2}(q) \cdot \dot{q} = \begin{bmatrix} -L_2c_2s_1\dot{q}_1 - L_2c_1s_2\dot{q}_2 \\ L_2c_2c_1\dot{q}_1 - L_2s_1s_2\dot{q}_2 \\ L_2c_2\dot{q}_2 \end{bmatrix}$$

$$\omega_2 = J_{\omega_2}(q) \cdot \dot{q} = \begin{bmatrix} s_1\dot{q}_2 \\ -c_1\dot{q}_2 \\ \dot{q}_1 \end{bmatrix}$$

$$K_1 = \frac{1}{2} m_1 v_1^T v_1 + \frac{1}{2} \omega_1^T I_1 \omega_1$$

gives us:

$$K_1 = \frac{1}{2} m_1 \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}^T \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} + \frac{1}{2} \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 \end{bmatrix}^T \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \frac{m_1 r_1^2}{2} \end{bmatrix} \begin{bmatrix} 0 \\ 0 \\ \dot{q}_1 \end{bmatrix} = \frac{m_1 \dot{q}_1^2 r_1^2}{4}$$

The same equation can be written for K_2

$$K_2 = \frac{1}{2} m_2 v_2^T v_2 + \frac{1}{2} \omega_2^T I_2 \omega_2$$

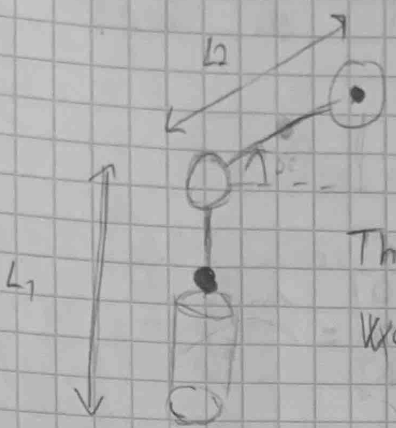
Which gives us:

$$K_2 = m_2 \frac{((-L_2 c_2 s_1 \dot{q}_1 - L_2 c_1 s_2)^2 + (L_2 c_2 c_1 \dot{q}_1 - L_2 s_1 s_2 \dot{q}_2)^2 + L_2^2 c_2^2 \dot{q}_2^2)}{2}$$

If we simplify this we get

$$K_2 = \frac{1}{2} m_2 (L_2^2 \dot{q}_1^2 c_2^2 + L_2^2 \dot{q}_2^2)$$

Task 1b



This is a simplyfied two-link robot, where the weight is uniform

● - center of mass

$P_1 = m_1 g \frac{L_1}{2}$ $\quad$ $P_2 = m_2 g(L_1 + s_2 (L_2))$

To lastly get the lagrangian, we need to subtract the potensial energy from the kinetic energy

$\mathcal{L} = K - P$

$\mathcal{L}\ (K_1 + K_2) - (P_1 + P_2)$

$$\mathcal{L} = \left(\frac{\dot{q}_1^2 m_1 c_1^2}{4} + \frac{m_2 L_2^2 \dot{q}_1^2 c_2^2 + m_2 L_2^2 \dot{q}_2^2}{2}\right) - \left(\frac{m_1 g L_1}{2} + m_2 g L_1 + m_2 g s_2 L_2\right)$$

Task 1c

$$\tau_1 = \frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{q}_1} - \frac{\partial \mathcal{L}}{\partial q_1}$$

$$\mathcal{L} = \frac{m_2\left((L_2 c_2 \dot{q}_1 s_1 + L_2 c_1 \dot{q}_2 s_2)^2 + (L_2 \dot{q}_2 s_1 s_2 - L_2 c_1 c_2 \dot{q}_1)^2 + L_2^2 c_2^2 \dot{q}_1^2\right) \cdot L_1 g m_1}{2}$$

$$+ \frac{m_1 \dot{q}_1^2 r_1^2}{4} - g m_2 \left(L_1 + \frac{(L_2 s_2)}{2}\right)$$

When finding the first part of the torque, all parts whitout $\dot{q}_1$ will disappear in the partial derivativ and we get:

$$\frac{m_2\left((L_2 c_2 \dot{q}_1 s_1 + L_2 c_1 \dot{q}_2 s_2)^2 + (L_2 \dot{q}_2 s_1 s_2 - L_2 c_1 c_2 \dot{q}_1)^2\right.}{2} \quad \frac{+ m_1 \dot{q}_1^2 r_1^2}{4}$$

$$\frac{\partial \mathcal{L}}{\partial \dot{q}_1} = L_2^2 c_2^2 m_2 \dot{q}_1 (c_1^2 + s_1^2) + \frac{m_1 r_1}{4}$$

We can then expand this, and remove the last part since it is not relevant for the derivativ in regards to time

$$\rightarrow \frac{d}{dt} \; L_2^2 c_2^2 m_2 \dot{q}_1 c_1^2 + L_2^2 c_2^2 m_2 \dot{q}_1 s_1^2$$

Task 1c

$$\frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{q}_1} - \frac{\partial \mathcal{L}}{\partial q_1} = \tau_1$$

$$\mathcal{L} = \frac{\dot{q}_1^2 m_1 r_1^2}{4} + \frac{m_2 L_2^2 \dot{q}_1^2 c_2^2 + m_2 L_2^2 \dot{q}_2^2}{2} - \cancel{\frac{m_1 g L_1}{2}} - \cancel{m_2 g L_1} - m_2 g s_2 L_2$$

When calculating $\frac{\partial \mathcal{L}}{\partial \dot{q}_1}$ we can exclude the parts without $\dot{q}_1$

$$\frac{\partial \mathcal{L}}{\partial \dot{q}_1} = \frac{\dot{q}_1 m_1 r_1^2}{2} + m_2 L_2^2 \dot{q}_1 c_2^2$$

$$\frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{q}_1} = \frac{\ddot{q}_1 m_1 r_1^2}{2} + m_2 L_2^2(\ddot{q}_1 c_2^2 - 2\dot{q}_1 \dot{q}_2 c_2 s_2)$$

$u = m_2 L_2^2 \qquad u' = 0$

$v = \dot{q}_1 c_2^2 \qquad v' = \ddot{q}_1 c_2^2 - 2\dot{q}_1 \dot{q}_2 c_2 s_2$

$u = \dot{q}_1 \qquad u' = \ddot{q}_1$

$v = c_2^2 \qquad v' = -2 c_2 s_2 \dot{q}_2$

When calculating $\frac{\partial \mathcal{L}}{\partial q_1}$ we can see from the Lagrangian that we don't have any c_1, s_1 or q_1, hence $\frac{\partial \mathcal{L}}{\partial q_1} = 0$

$$\tau_1 = \frac{\ddot{q}_1 m_1 r_1^2}{2} + m_2 L_2^2 \ddot{q}_1 c_2^2 - 2 m_2 L_2^2 \dot{q}_1 \dot{q}_2 c_2 s_2$$

Task 1c

$$\frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{q}_2} - \frac{\partial \mathcal{L}}{\partial q_2} = \tau_2$$

$$\mathcal{L} = \cancel{\frac{\dot{q}_1^2 m_1 r_1^2}{4}} + \frac{m_2 L_2^2 \dot{q}_1^2 c_2^2}{2} + \frac{m_2 L_2^2 \dot{q}_2^2}{2} - \left(\cancel{\frac{m_1 g L_1}{2}} + m_2 g s_2 L_2 + \cancel{m_2 g L_1}\right)$$

again we remove the parts without $\dot{q}_2$ and we get

$$\frac{\partial \mathcal{L}}{\partial \dot{q}_2} = m_2 L_2^2 \dot{q}_2$$

$$\frac{d}{dt}\frac{\partial \mathcal{L}}{\partial \dot{q}_2} = m_2 L_2^2 \ddot{q}_2$$

$\boxed{\frac{m_2 L_2^2 \dot{q}_1^2 c_2^2}{2} - m_2 g s_2 L_2}$ is what we use to find $\frac{\partial \mathcal{L}}{\partial q_2}$

$$\frac{\partial \mathcal{L}}{\partial q_2} = -m_2 L_2^2 \dot{q}_1^2 c_2 s_2 - m_2 g L_2 c_2$$

$$\tau_2 = m_2 L_2^2 \ddot{q}_2 + m_2 L_2^2 \dot{q}_1^2 c_2 s_2 + m_2 L_2 g c_2$$

Task 1c

$$\tau = \begin{bmatrix} \frac{\ddot{q}_1 m_1 r_1^2}{2} + m_2 L_2^2 \ddot{q}_1 c_2^2 - 2 m_2 L_2^2 \dot{q}_1 \dot{q}_2 c_2 s_2 \\ m_2 L_2^2 \ddot{q}_2 + m_2 L_2^2 \dot{q}_1^2 c_2 s_2 + m_2 L_2 g c_2 \end{bmatrix}$$

$$\tau = \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} = \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & D_{22} \end{bmatrix} \begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \end{bmatrix} + \begin{bmatrix} C_{11} & C_{12} \\ C_{21} & C_{22} \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \end{bmatrix}$$

$D_{11} = \frac{m_1 r_1^2}{2} + m_2 L_2^2 c_2^2$ $\qquad$ $C_{11} = -2 m_2 L_2^2 \dot{q}_2 c_2 s_2$

$D_{12} = 0$ $\qquad$ $C_{12} = 0$

$D_{21} = 0$ $\qquad$ $C_{21} = m_2 L_2^2 \dot{q}_1 c_2 s_2$

$D_{22} = m_2 L_2^2$ $\qquad$ $C_{22} = 0$

$g_1 = 0$

$g_2 = m_2 L_2 c_2$

$$\tau = \begin{bmatrix} \tau_1 \\ \tau_2 \end{bmatrix} = \begin{bmatrix} \frac{m_1 r_1^2}{2} + m_2 L_2^2 c_2^2 & 0 \\ 0 & m_2 L_2^2 \end{bmatrix} \begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \end{bmatrix} + \begin{bmatrix} -2 m_2 L_2^2 \dot{q}_2 c_2 s_2 & 0 \\ m_2 L_2^2 \dot{q}_1 c_2 s_2 & 0 \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \end{bmatrix} + \begin{bmatrix} 0 \\ m_2 L_2 c_2 \end{bmatrix}$$

Task 2c)

$$D(q)\ddot{q} + C(q,\dot{q})\dot{q} + g(q) = \tau$$

$$\tau = \begin{bmatrix} D_{11} & D_{12} & \cdots & D_{1n} \\ D_{21} & D_{22} & \cdots & D_{2n} \\ \vdots & \vdots & & \\ D_{n1} & D_{n2} & & D_{nn} \end{bmatrix} \begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \\ \vdots \\ \ddot{q}_n \end{bmatrix} + \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1n} \\ C_{21} & C_{22} & \cdots & C_{2n} \\ \vdots & \vdots & & \\ C_{n1} & C_{n2} & & C_{nn} \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \vdots \\ \dot{q}_n \end{bmatrix} + \begin{bmatrix} g_1 \\ g_2 \\ \vdots \\ g_n \end{bmatrix}$$

$$\sum_{j=1}^{n} d_{kj}(q)\ddot{q}_j + \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ijk}(q)\dot{q}_i\dot{q}_j + g_k(q) = \tau_k, \quad k = 1, \dots, n$$

From equation 6.62 in the pdf textbook we can see that $C(q,\dot{q})$ can be written as $\sum_{i=1}^{n} c_{ijk}(q)\dot{q}_i$, then we're only left with a $\dot{q}$ in the middle part which we need to sum.

The $g_k(q)$ is the same as $g(q)$

Since the D-matrix always will be diagonal, then d_{kj} will be the diagonal of the D. Then the sum of $d_{kj}(q) \cdot \ddot{q}_j$ will be $D(q) \cdot \ddot{q}$

D is inertia
C is centrifugal
g is gravity

```
syms I1x I1y I1z I2x I2y I2z I3x I3y I3z th1 th2 th3 qdx qdy qdz L1 L2 L3 qddx qddy qddz g
m1 = 0.3833;
m2 = 0.2724;
m3 = 0.1406;
s1 = sin(th1);
s2 = sin(th2);
s3 = sin(th3);
c1 = cos(th1);
c2 = cos(th2);
c3 = cos(th3);
g = [0;0;-9.81];
g = transpose(g);
s23 = sin(th2*th3);
c23 = cos(th2*th3);
```

Task 2a

Here I just use the formula given in the exercise

```
%%task 2a
rc1 = [0;0;L1/2];
rc2 = [cos(th2)*L2/2; 0 ;L1+sin(th2)*L2/2];
rc3 = [cos(th2)*L2+sin(th3)*L3/2; 0; L1+sin(th2)*L2+cos(th3)*L3/2];

P1 = m1*g*rc1;
P2 = m2*g*rc2;
P3 = m3*g*rc3;


P = P1+P2+P3;

vpa(P, 4);
```

```
P =

- 5.932*L1 - 0.6896*L3*cos(th3) - 2.715*L2*sin(th2)
```

2b)

Here again, I use the formula given in the exercise and the Jv and Jw matrices from task 1b

The first pictures are just declaring matrices and variables

```
%%task 2b
qdott = [qdx
         qdy
         qdz];
I1 = [I1x 0 0
      0 I1y 0
      0 0 I1z];
I2 = [I2x 0 0
      0 I2y 0
      0 0 I2z];
I3 = [I3x 0 0
      0 I3y 0
      0 0 I3z];

A1 = [1 0 0
      0 1 0
      0 0 1];
%A2 and A3 are z-rotations
A2 = [cos(th2) -sin(th2) 0
      sin(th2) cos(th2) 0
      0 0 1];
A3 = [cos(th3) -sin(th3) 0
      sin(th3) cos(th3) 0
      0 0 1];
R01 = A1;
R02 = R01*A2;
R03 = R02*A3;
```

```
%These parts of the jacobian are directly copied from task 1b
Jv3 = [-s1*(L2*c2+L3*c23) -c1*(L2*s2+L3*s23) -c1*(L3*s23)
      c1*(L2*c2+L3*c23) -s1*(L2*s2+L3*s23) -s1*(L3*s23)
      0 (L2*c2+L3*c23) L3*c23];

Jv1 = [ 0 0 0
        0 0 0
        0 0 0];
Jv2 = [-s1*L2*c2 -c1*L2*s2 0
       c1*L2*c2 -s1*L2*s2 0
       0 L2*c2 0];

%These parts of the jacobian are directly copied from task 1b
Jw1 = [0 0 0
       0 0 0
       1 0 0];

Jw2 = [0 s1 0
       0 -c1 0
       1 0 0];

Jw3 = [0 s1 s1
       0 -c1 -c1
      1 0 0];
```

```
%Here I calculate the kinetic energy as described in eq 14
k1 =  m1*transpose(Jv1)*Jv1 + transpose(Jw1)*R01*I1*transpose(R01)*Jw1;
k2 =  m2*transpose(Jv2)*Jv2 + transpose(Jw2)*R02*I2*transpose(R02)*Jw2;
k3 =  m3*transpose(Jv3)*Jv3 + transpose(Jw3)*R03*I3*transpose(R03)*Jw3;
K = 1/2*transpose(qdott)*(k1+k2+k3)*qdott;
```

K=

```
qdy*((qdz*(cos(th1)*(I3x*(cos(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) - sin(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)))*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) +
I3y*(cos(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) + sin(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)))*(cos(th2)*cos(th3) - sin(th2)*sin(th3))) -
sin(th1)*(I3x*(cos(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) - sin(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)))*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) -
I3y*(cos(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) + sin(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)))*(cos(th2)*sin(th3) + cos(th3)*sin(th2))) +
(703*L3*cos(th2*th3)*(L3*cos(th2*th3) + L2*cos(th2)))/5000 + (703*L3*sin(th2*th3)*sin(th1)^2*(L3*sin(th2*th3) + L2*sin(th2)))/5000 +
(703*L3*sin(th2*th3)*cos(th1)^2*(L3*sin(th2*th3) + L2*sin(th2)))/5000))/2 + (qdy*((681*L2^2*cos(th2)^2)/2500 + (703*cos(th1)^2*(L3*sin(th2*th3) +
L2*sin(th2))^2)/5000 + cos(th1)*(I3x*(cos(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) - sin(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)))*(cos(th2)*sin(th3) +
cos(th3)*sin(th2)) + I3y*(cos(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) + sin(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)))*(cos(th2)*cos(th3) - sin(th2)*sin(th3))) +
(703*sin(th1)^2*(L3*sin(th2*th3) + L2*sin(th2))^2)/5000 - sin(th1)*(I3x*(cos(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) - sin(th1)*(cos(th2)*cos(th3) -
sin(th2)*sin(th3)))*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) - I3y*(cos(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) + sin(th1)*(cos(th2)*sin(th3) +
cos(th3)*sin(th2)))*(cos(th2)*sin(th3) + cos(th3)*sin(th2))) + (L3*cos(th2*th3) + L2*cos(th2))*((703*L3*cos(th2*th3))/5000 + (703*L2*cos(th2))/5000) +
cos(th1)*(I2y*cos(th2)*(cos(th1)*cos(th2) + sin(th1)*sin(th2)) + I2x*sin(th2)*(cos(th1)*sin(th2) - cos(th2)*sin(th1))) - sin(th1)*(I2x*cos(th2)*(cos(th1)*sin(th2) -
cos(th2)*sin(th1)) - I2y*sin(th2)*(cos(th1)*cos(th2) + sin(th1)*sin(th2))) + (681*L2^2*cos(th1)^2*sin(th2)^2)/2500 + (681*L2^2*sin(th1)^2*sin(th2)^2)/2500))/2) +
qdz*((qdy*(cos(th1)*(I3x*(cos(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) - sin(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)))*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) +
I3y*(cos(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) + sin(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)))*(cos(th2)*cos(th3) - sin(th2)*sin(th3))) -
sin(th1)*(I3x*(cos(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) - sin(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)))*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) -
I3y*(cos(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) + sin(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)))*(cos(th2)*sin(th3) + cos(th3)*sin(th2))) + L3*cos(th2*th3)*
((703*L3*cos(th2*th3))/5000 + (703*L2*cos(th2))/5000) + (703*L3*sin(th2*th3)*sin(th1)^2*(L3*sin(th2*th3) + L2*sin(th2)))/5000 + (703*L3*sin(th2*th3)*cos(th1)^2*
(L3*sin(th2*th3) + L2*sin(th2)))/5000))/2 + (qdz*((703*L3^2*cos(th2*th3)^2)/5000 + cos(th1)*(I3x*(cos(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) - sin(th1)*(cos(th2)*
cos(th3) - sin(th2)*sin(th3)))*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) + I3y*(cos(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) + sin(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)))
*(cos(th2)*cos(th3) - sin(th2)*sin(th3))) - sin(th1)*(I3x*(cos(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)) - sin(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)))*(cos(th2)*
cos(th3) - sin(th2)*sin(th3)) - I3y*(cos(th1)*(cos(th2)*cos(th3) - sin(th2)*sin(th3)) + sin(th1)*(cos(th2)*sin(th3) + cos(th3)*sin(th2)))*(cos(th2)*sin(th3) + cos(th3)*sin(th2)))
+ (703*L3^2*sin(th2*th3)^2*cos(th1)^2)/5000 + (703*L3^2*sin(th2*th3)^2*sin(th1)^2)/5000))/2) + (qdx^2*(I1z + I2z + I3z + (703*cos(th1)^2*(L3*cos(th2*th3) +
L2*cos(th2))^2)/5000 + (703*sin(th1)^2*(L3*cos(th2*th3) + L2*cos(th2))^2)/5000 + (681*L2^2*cos(th1)^2*cos(th2)^2)/2500 + (681*L2^2*cos(th2)^2*sin(th1)^2)/2500))/2
```

Task 2d

Calculating D

```
%% Task 2d


%From equation 15 in the assignment, we can se that D must be equal to the
%sum of k1,k2,k3
D = k1+k2+k3;
```

Calculating g

```
%From the lecture slides for dynamics, page 41 we get the an equation for g
%The P is from task 2a
P = - 5.932*L1 - 0.6896*L3*cos(th3) - 2.715*L2*sin(th2);
g1 = diff(P, th1);
g2 = diff(P, th2);
g3 = diff(P, th3);
g = [g1
    g2
    g3];
```

Calculating C

```
%The C-matrix formula is also taken from page 41 in the slides for dynamics
q_vector = [th1
            th2
            th3];

C = sym(zeros(3,3));
for k=1:3
    for j=1:3
        for i=1:3
            pt1 = diff(D(k,j), q_vector(i));
            pt2 = diff(D(k,i), q_vector(j));
            pt3 = diff(D(i,j), q_vector(k));
            C(k,j) = C(k,j) + 1/2*(pt1+pt2-pt3);
        end
    end
end
```

The answers here are simply too big to display, and therefore might be wrong. But when only using symbols for the calculations it’s near impossible to do effective debugging.

2e

```
%% Task 2e
%Lastly we will calculate tau from eq 16 in the task
qdottdott = [qddx
          qddy
          qddz];

t = D*qdottdott + C*qdott + g;
```

The same goes for 2e, which is simply too big to be displayed.