Challenge Deliverable 1
Answer form

4DB00 Dynamics and Control of mechanical systems
2019-2020

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Be aware of the TU/e Code of Scientific conduct. See: https://www.tue.nl/en/our-university/about-the-university/organization/integrity/scientific-integrity/.

Question a):

Express the x-position of the load in terms of x_1, φ_1, φ_2, F_A and the system parameters.

$$x_{load} = x_1 cos(\varphi_1) + L_2 sin(\varphi_2 - \frac{1}{2}\pi) = x_1 cos(\varphi_1) - L_2 cos(\varphi_2)$$

Question b):

Express the kinetic energy T in terms of x_1, φ_1, φ_2, F_A and the system parameters. Please transform any product between vectors into a scalar expression and simplify your answer as much as possible.

$$T^{Jib} = \frac{1}{6} m_1 (L_1)^2 \dot{\varphi}_1^2$$

$$T^{Hoist} = \frac{1}{2} m_2 \dot{x}_1^2 + \frac{1}{2} m_2 x_1^2 \dot{\varphi}_1^2$$

$$T^{Load} = \frac{1}{2} m_3 \dot{x}_1^2 + \frac{1}{2} m_3 x_1^2 \dot{\varphi}_1^2 + \frac{1}{2} m_3 L_2^2 \dot{\varphi}_2^2 + m_3 \dot{x}_1 \, L_2 \dot{\varphi}_2 \left(cos(\varphi_1)\sin(\varphi_2) - \cos(\varphi_2)\sin(\varphi_1)\right) - m_3 x_1 L_2 \dot{\varphi}_1 \, \dot{\varphi}_2 \left(sin(\varphi_1) sin(\varphi_2) + cos(\varphi_1) cos(\varphi_2)\right)$$

$$T = \frac{1}{2} \dot{x}_1^2 (m_2 + m_3) + \frac{1}{2} x_1^2 \dot{\varphi}_1^2 (m_2 + m_3) + \frac{1}{2} m_3 L_2^2 \dot{\varphi}_2^2 + m_3 \dot{x}_1 \, L_2 \dot{\varphi}_2 \left(cos(\varphi_1)\sin(\varphi_2) - \cos(\varphi_2)\sin(\varphi_1)\right) - m_3 x_1 L_2 \dot{\varphi}_1 \, \dot{\varphi}_2 \left(sin(\varphi_1) sin(\varphi_2) + cos(\varphi_1) cos(\varphi_2)\right) + \frac{1}{6} m_1 (L_1)^2 \dot{\varphi}_1^2$$

Question c):

Express the potential energy V in terms of x_1, φ_1, φ_2, F_A and the system parameters. Please transform any product between vectors into a scalar expression and simplify your answer as much as possible.

$$V_{Gravitational}^{CraneBase} = \frac{1}{2} m_0 g L_0$$

$$V_{Gravitational}^{Jib} = m_1 g \left(L_0 + \frac{1}{2} L_1 sin(\varphi_1) \right)$$

$$V_{Gravitational}^{Hoist} = m_2 g \left(L_0 + x_1 sin(\varphi_1) \right)$$

$$V_{Gravitational}^{Load} = m_3 g \left(L_0 + x_1 sin(\varphi_1) - L_2 sin(\varphi_2) \right)$$

$$V_{Elastic} = \frac{1}{2} k_h \left(x_1 - \frac{1}{2} L_1 \right)^2$$

$$V = \frac{1}{2} k_h \left(x_1 - \frac{1}{2} L_1 \right)^2 + \frac{1}{2} m_0 g L_0 + m_1 g \left(L_0 + \frac{1}{2} L_1 sin(\varphi_1) \right) + m_2 g \left(L_0 + x_1 sin(\varphi_1) \right) + m_3 g \left(L_0 + x_1 sin(\varphi_1) - L_2 sin(\varphi_2) \right)$$

Question d):

Express the generalized forces $\underline{Q}^{nc}$ that follow from the non-conservative forces acting on the load and the hoist block in terms of x_1, φ_1, φ_2, F_A and the system parameters. Please transform any product between vectors into a scalar expression and simplify your answer as much as possible.

$$\underline{Q}^{nc} = F_A - d_h \dot{x}_1 - d_w L_2^2 \dot{\varphi}_2$$

Question e):

Compute the equations of motion by utilizing the "NonlinearEOM" request and by providing symbolic expressions for T, V and $\underline{Q}^{nc}$ to the DOMS toolbox. You may copy and paste the derived expression(s) from Matlab into this document.

```
- x1*(m2 + m3)*dphi1^2 + L2*m3*cos(phi1 - phi2)*dphi2^2 - FA +
dh*dx1 - (kh*(L1 - 2*x1))/2 + ddx1*(m2 + m3) + g*m2*sin(phi1) +
g*m3*sin(phi1) - L2*ddphi2*m3*sin(phi1 - phi2)
 -L2*(- m3*x1*sin(phi1 - phi2)*dphi1^2 + 2*dx1*m3*cos(phi1 -
phi2)*dphi1 + g*m3*cos(phi2) + ddx1*m3*sin(phi1 - phi2) -
L2*dW*dphi2 - L2*ddphi2*m3 + ddphi1*m3*x1*cos(phi1 - phi2))
```

Question f):

Generate a time trajectory for the equations of motion that are computed in question e, by utilizing the “Sim_Nonlinear” request within the DOMS toolbox. Use the simulation conditions as described in the deliverable and add the requested plots here.

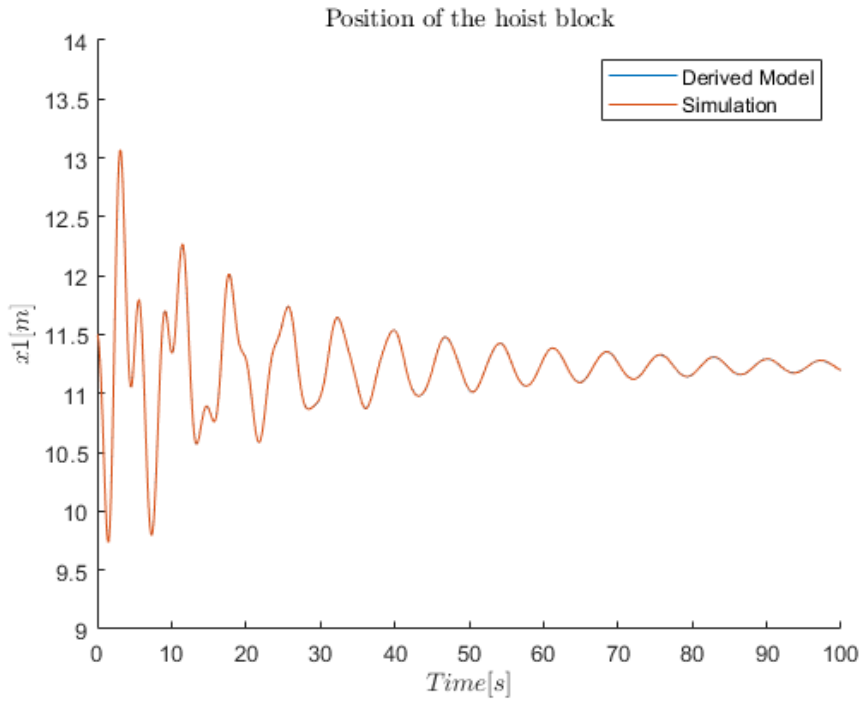

Figure 1: Position of the hoist block

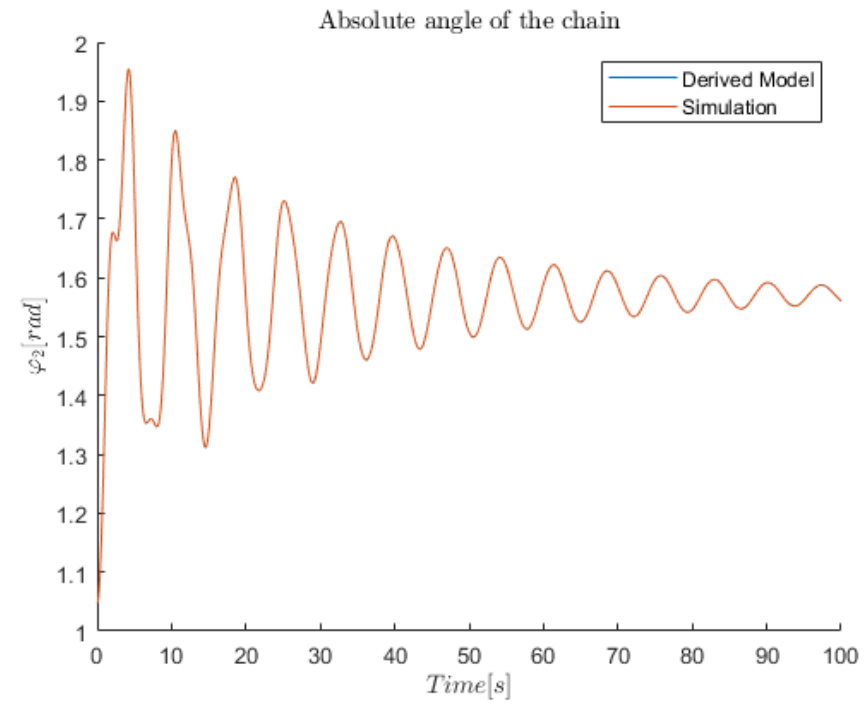

Figure 2: Absolute angle of the chain

Question g):

Simulate a time trajectory for the “virtual test setup” by utilizing the “Sim_Setup” request within the DOMS toolbox. Use the simulation conditions as described in the deliverable. Are there any differences between the time trajectories in questions f and g. If so, can you explain them?

As seen in the plots in Question f), the line of the *Derived Model* (Sim_Nonlinear) is not visible. After zooming in (see figure 3 and 4), both trajectories can be distinguished. The reason that the plots differ, is due to the non-smooth shape of the *Derived model* (Sim_Nonlinear) curve. This can be explained by the solver that is used to derive Sim_Nonlinear, which takes (relatively) not a lot of timesteps within the predefined time range, hence the graphical output is not smooth (mainly at the extrema).

Add the requested plots here.

The main plots are already shown at Question f)

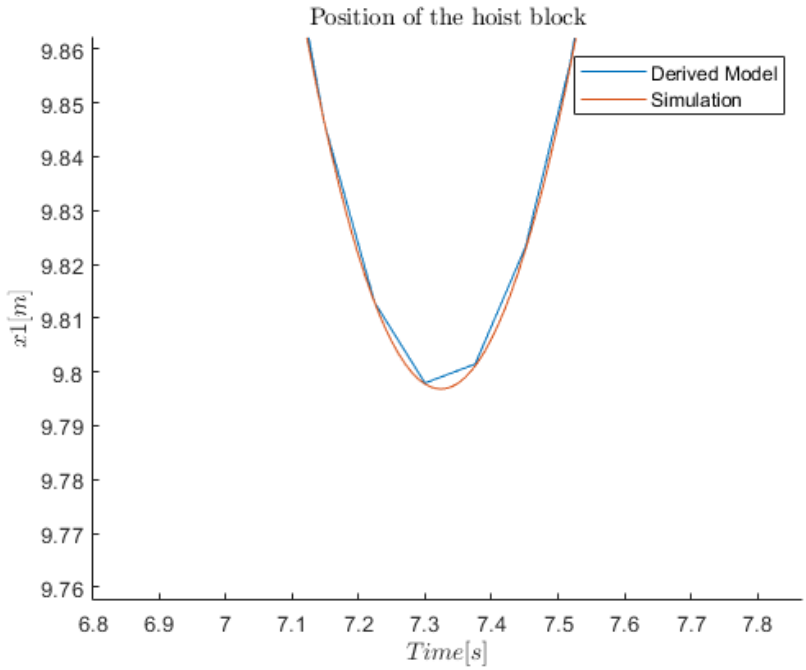

Figure 3: A zoomed in version of figure 1, to show that my equations satisfy the actual equations of the crane

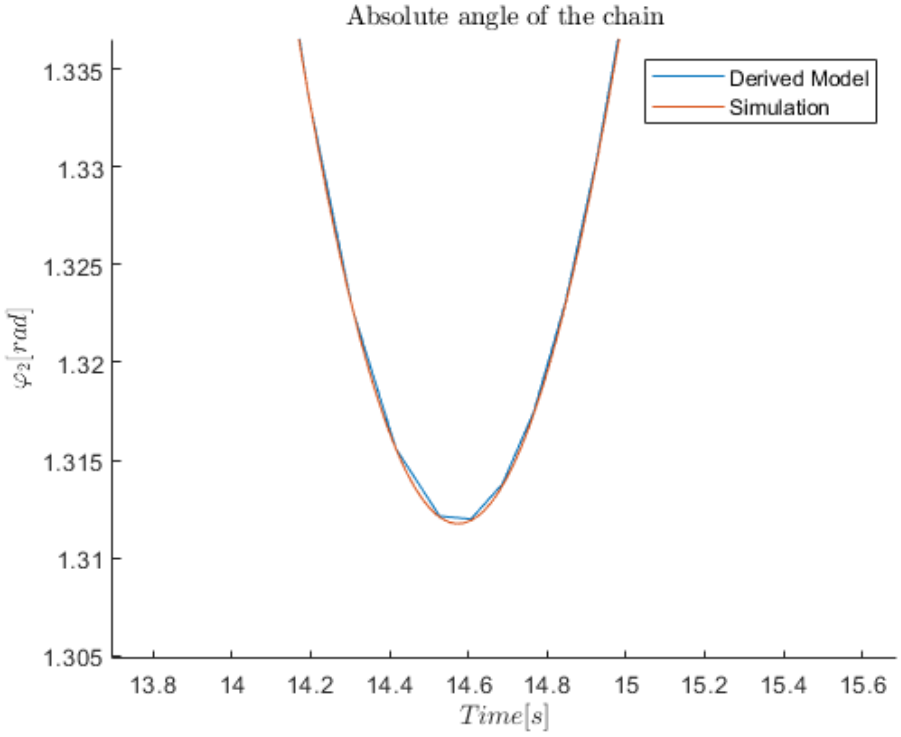

Figure 4: A zoomed in version of figure 2, to show that my equations satisfy the actual equations of the crane