Adaptive Sliding Mode Control for manipulator

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Motivation

Robotic manipulators are chosen for their versatility in performing repetitive, precise, and complex tasks across various industries. Motivations for their selection include increased efficiency, improved quality, and enhanced safety in manufacturing processes. With advancements in technology, robotic manipulators offer greater flexibility to adapt to changing production needs, contributing to reduced downtime and increased productivity. Additionally, their ability to handle hazardous or ergonomic challenging tasks can improve workplace conditions and reduce the risk of injuries. Furthermore, robotic manipulators enable companies to stay competitive by streamlining operations, reducing costs, and meeting stringent quality standards. Overall, the motivation for choosing robotic manipulators lies in their capacity to revolutionize industrial processes, drive innovation, and elevate overall performance and profitability.

Manipulator Dynamics

here $q = [\theta_1 \theta_2]^T \dot{q} = [\dot{\theta_1} \dot{\theta_2}]^T$ Mass Matrix M is given by -

$$M = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix} \tag{1}$$

$m_{11} =$
$\left(I_{c1} + m_1 r_1^2\right) + \left(I_{c2} + m_2\left(l_1^2 + r_2^2 + 2 l_1 r_2 \cos\theta_2\right)\right) + m_p\left(l_1^2 + l_2^2 + 2 l_1 l_2 \cos\theta_2\right)$

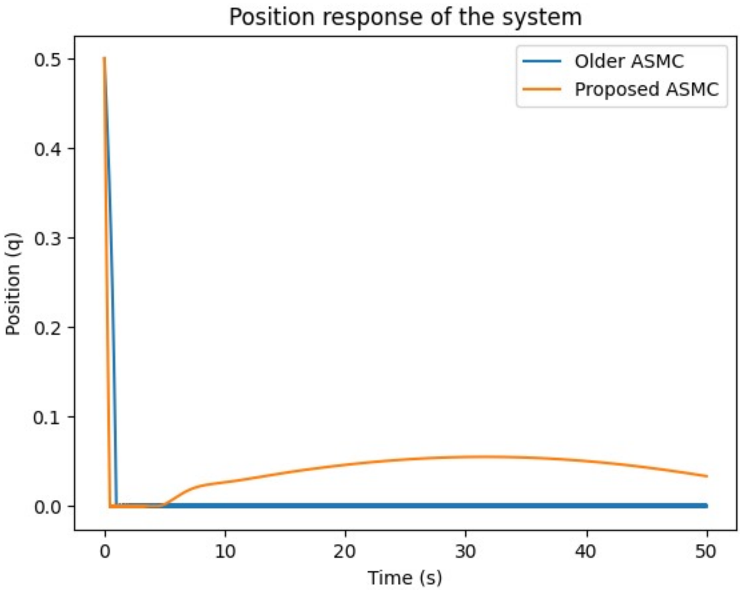
$$m_{12} = I_{c2} + m_2\left(r_2^2 + l_1 r_2 \cos\theta_2\right) + m_p\left(l_2^2 + l_1 l_2 \cos\theta_2\right) \tag{2}$$

$m22 = \left(I_{c2} + m_2 r_2^2\right) + m_p l_2^2$

THE Coriolis Matrix is given By

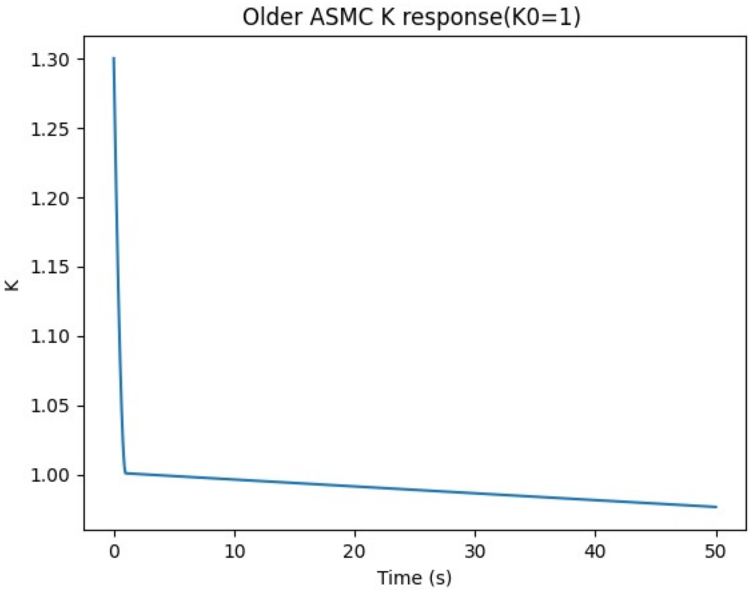
$$\text{C=-l}_1\left(m_2 r_2 + m_p l_2\right)\sin\theta_2 \begin{bmatrix} \dot{\theta_2} & \dot{\theta_1} + \dot{\theta_2} \\ \dot{\theta_1} & 0 \end{bmatrix} \tag{3}$$

Results

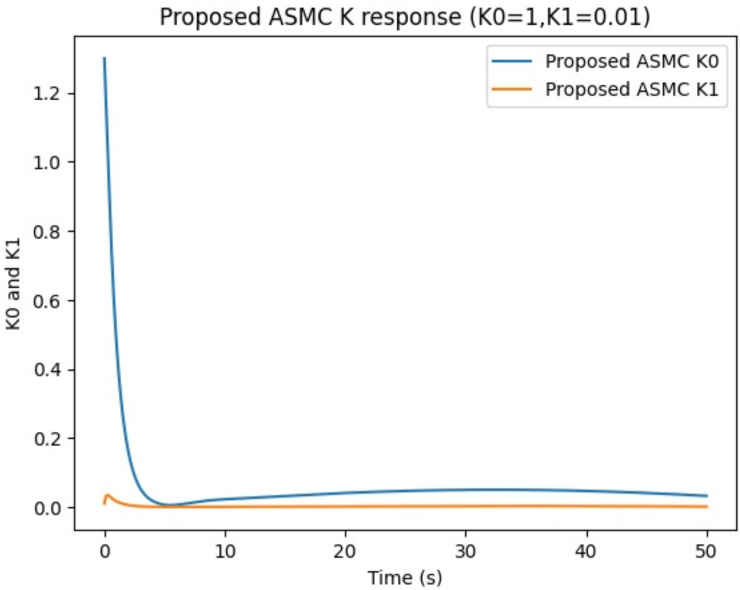


Position response of the system
Older ASMC
Proposed ASMC
0.5
0.4
0.3
0.2
0.1
0.0
Position (q)
0
10
20
30
40
50
Time (s)

Results

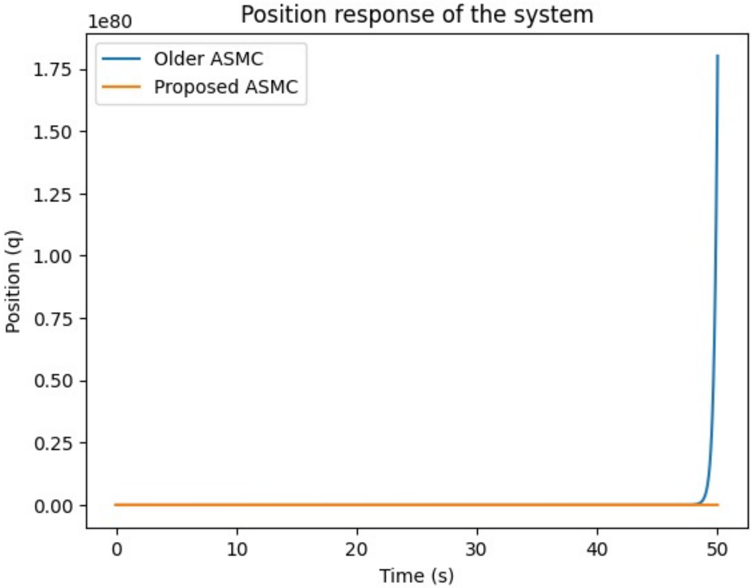

Older ASMC K response(K0=1)
1.30
1.25
1.20
1.15
1.10
1.05
1.00
K
0
10
20
30
40
50
Time (s)

Results

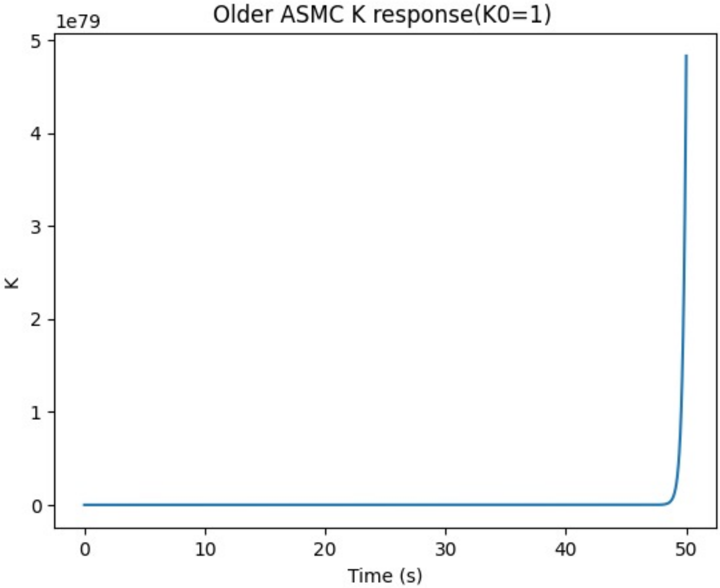


Proposed ASMC K response (K0=1,K1=0.01)
Proposed ASMC K0
Proposed ASMC K1
K0 and K1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
10
20
30
40
50
Time (s)

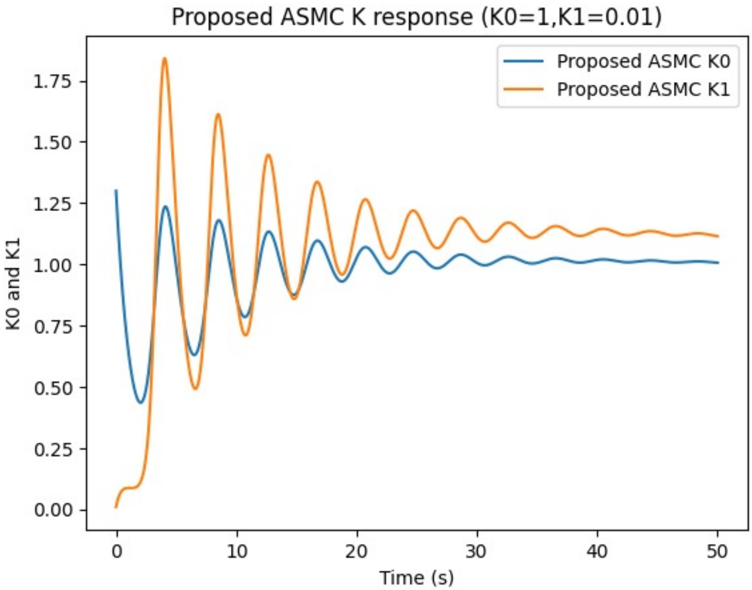
Results : When uncertainty is increased



Results



Results



Proposed ASMC K response (K0=1,K1=0.01)
Proposed ASMC K0
Proposed ASMC K1
K0 and K1
Time (s)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
0
10
20
30
40
50

Manipulator Contd.

the V Damping factor is given by

$$V = g\left(m_1 r_1 \sin\theta_1 + m_2\left(l_1 \sin\theta_1 + r_2 \sin\left(\theta_1 + \theta_2\right)\right)\right.$$

$+ \mathrm{m}_p\left(l_1 \sin\theta_1 + l_2 \sin\left(\theta_1 + \theta_2\right)\right)$ (4)

THE Gravity Matrix G is Given BY

$$\underline{\boldsymbol{G}} = g\begin{bmatrix} \left(m_1 r_1 + \left(m_2 + m_p\right) l_1\right)\cos\theta_1 + \left(m_p l_2 + m_2 r_2\right)\cos\left(\theta_1 + \theta_2\right) \\ \left(m_2 r_2 + m_p l_2\right)\cos\left(\theta_1 + \theta_2\right) \end{bmatrix} \tag{5}$$

$$M(q(t))\ddot{q}(t) + C(q(t), \dot{q}(t))\dot{q}(t) + G(q(t)) + F\dot{q}(t) + d(t) = \tau(t) \tag{6}$$

Controller

General Equation :

$$M(q(t))\ddot{q}(t) + C(q(t),\dot{q}(t))\dot{q}(t) + G(q(t)) + F\dot{q}(t) + d(t) = \tau(t) \quad (7)$$

Sliding Equation :

$$s(t) = \dot{e}(\mathrm{t}) + \lambda e(t), Assume, \xi = \begin{bmatrix} e^T & \dot{e}^T \end{bmatrix}^T \quad (8)$$

We can Write

$$M\dot{s} = M\left(\ddot{q} - \ddot{q^d} + \lambda\dot{e}\right) = \tau - Cs + \varphi \quad (9)$$

Where

$$\begin{aligned} \|\boldsymbol{\varphi}\| \leq \bar{c}\|\dot{\mathbf{q}}\|^2 + \bar{g} + \bar{f}\|\dot{\mathbf{q}}\| + \bar{d} + \bar{m}\left(\left\|\ddot{\mathbf{q}}^d\right\| + \|\boldsymbol{\lambda}\|\|\dot{\mathbf{e}}\|\right) \\ +\bar{c}\|\mathbf{q}\|(\|\dot{\mathbf{e}}\| + \|\boldsymbol{\lambda}\|\|\mathbf{q}\|) \end{aligned} \quad (10)$$

Convert the Above equation to the Below form

$$\|\varphi\| \leq \mathrm{K}_0^* + \mathrm{K}_1^*\|\xi\| + \mathrm{K}_2^*\|\xi\|^2 \quad (11)$$

Controller

the Control Input $\tau(t) isgivenby$

$$
\begin{aligned}
\boldsymbol{\tau}(t) &= -\mathbf{\Lambda s}(t) - \rho(t)\,\mathrm{sgn}(\mathbf{s}(t)) \\
Where, & \\
\rho(t) &= \hat{K}_0(t) + \hat{K}_1(t)\|\boldsymbol{\xi}(t)\| + \hat{K}_2(t)\|\boldsymbol{\xi}(t)\|^2
\end{aligned}
\tag{12}
$$

And $\dot{\hat{K}}_i(t)$ is given by the following Equation

$$
\begin{gathered}
\dot{\hat{K}}_i(t) = \|\mathbf{s}(t)\|\|\boldsymbol{\xi}(t)\|^i - \alpha_i\hat{K}_i(t) \\
\text{with } \hat{K}_i(0) > 0, \alpha_i > 0
\end{gathered}
\tag{13}
$$

conclusion

Have success fully implemented the Adaptive Sliding Mode Control(ASMC) for the Scalar system mention in the Research paper and Generated the Position and K plots with respect to time for both the proposed model as well as the Adaptive Law mentioned in the paper compared both control Laws using the plots generated .

THANK YOU