HOMEWORK 3

INTERACTIVE MEDICAL ROBOTICS
ROB-GY 6423

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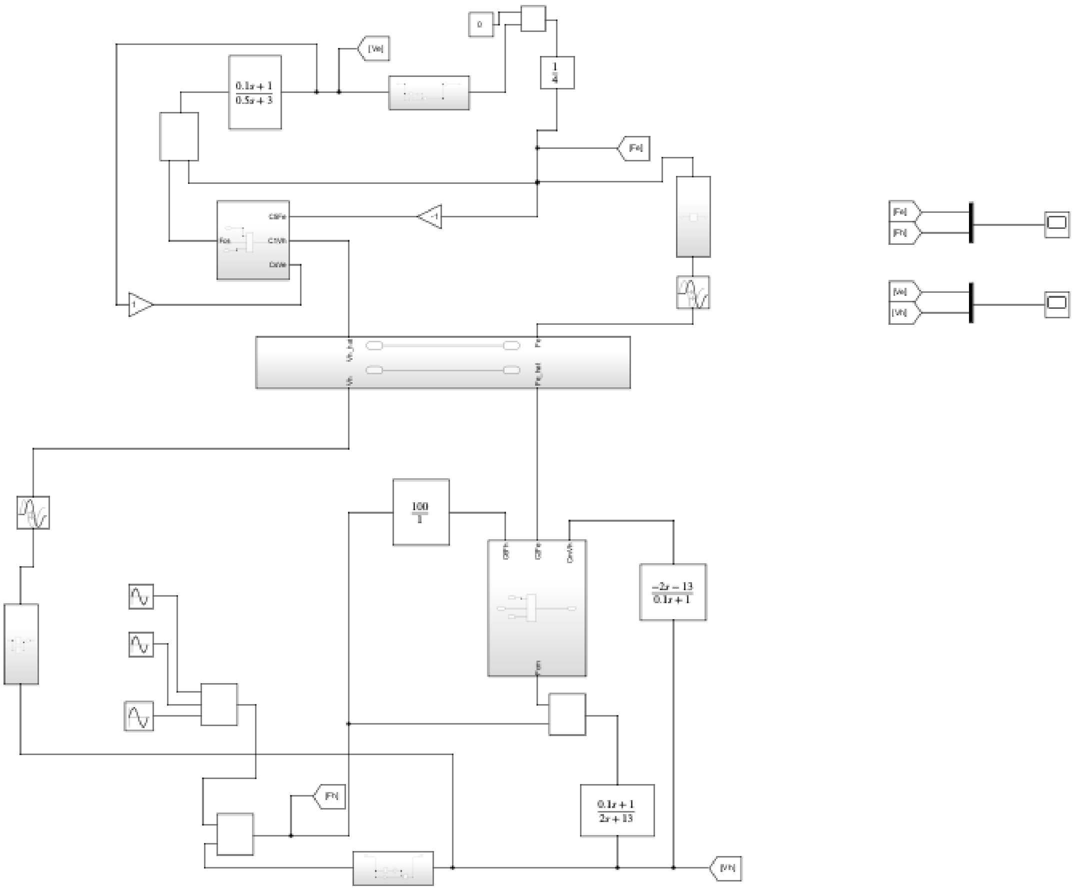
Question 1

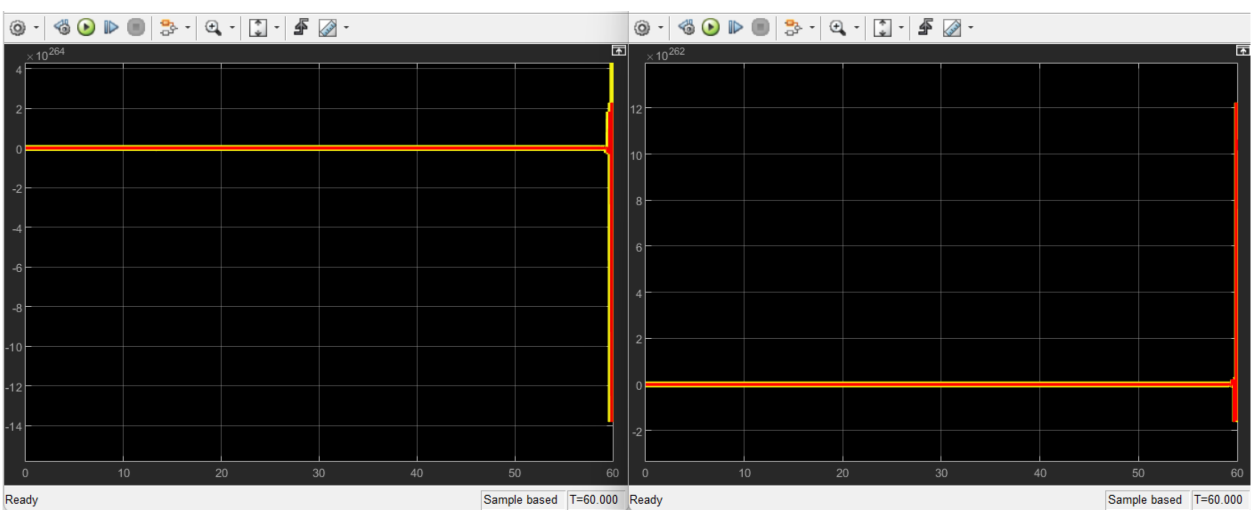
The paper presents the concept of tele-impedance as a method for remotely controlling a robotic arm in interaction with uncertain environments as an alternative to bilateral force-reflecting teleoperation control. This method addresses the limitations – allows human operator to control a robotic arm using force feedback. The system sends a compound reference to the slave robot including desired motion trajectory and impedance profile. The impedance profile is estimated from non-intrusive position and EMG measurements of the operator's arm. This approach avoids the need for force feedback devices on the master side. The proposed body-machine interface exploits a novel algorithm to decouple the estimates of force and stiffness of the human arm while performing the task. The endpoint position of the human arm is monitored by an optical tracking system used for closed loop position control of the robot's end-effector. It tackles the shortcomings of existing methods that might struggle when precise interaction with objects is crucial. Tele-impedance bridges the gap by incorporating human like stiffness control into robotic manipulation. The performance of the tele-impedance control is assessed by comparing results obtained with slave arm under constantly low or high stiffness. The effectiveness of the proposed method is evaluated in two experiments and also involves measuring forces and positions at the subject's wrist while they maintained different levels of arm stiffness. The stiffness was quantified by a mathematical model relating the measured forces to the positions. The model identified the stiffness along each direction of the arm's movement, and combines position control with stiffness information derived from the operator's arm muscles. The goal of the experiment is to effectively transfer a human operator's stiffness control to a robotic arm during teleoperation tasks.

The operator maintains different stiffness levels in their arm while researchers measure the corresponding forces and positions. This helps establish a relationship between the operator's muscle activity (EMG signals) and the resulting stiffness. Reference Levels of stiffness: Relaxed arm to establish a baseline stiffness level. Stiffened arm to define extreme. Three reference levels of stiffness between the two extremes. EMG to stiffness map identification was done while The subject maintained each reference stiffness level while their arm was perturbed by small random movements. The measured forces and positions were used to estimate the stiffness of the arm at that level using a mathematical model which assumed a linear relationship between applied force ad resulting displacement for each direction. The operator's arm stiffness is estimated in a calibration phase where they maintain different stiffness levels. During the actual task, EMG signals are used to estimate the operator's real-time stiffness. This estimated stiffness is then used to adjust the stiffness of the robotic arm, essentially mimicking the operator's arm stiffness to control the robotic arm. The accuracy of the stiffness estimation method was evaluated using – a peg-in-hole and a ball-catching task. The first experiment results showed that tele-impedance outperformed constant high or low stiffness control for the robot arm and allowed for better force control during peg insertion, this aims to evaluate the accuracy of the stiffness estimation. The second experiment offered an advantage by enabling the robot arm to adjust stiffness for a smoother catch and reduced bouncing. These aimed to see how well the model copes with situations where the arm interacts with an external object. In the peg-in-hole experiment the robot could adjust its stiffness to achieve a smoother and more precise fit. In the ball catching experiment the robotic arm could dynamically adjust its stiffness upon impact with the ball leading to a smoother catch with reduced bouncing.

Results showed that tele-impedance control allowed for better force control and smoother interactions compared to constant stiffness settings on the robotic arm. The study only investigated replicating the overall stiffness of the operator's arm, not the directional variations.

Question 2





The given system appears to be unstable, and not transparent.

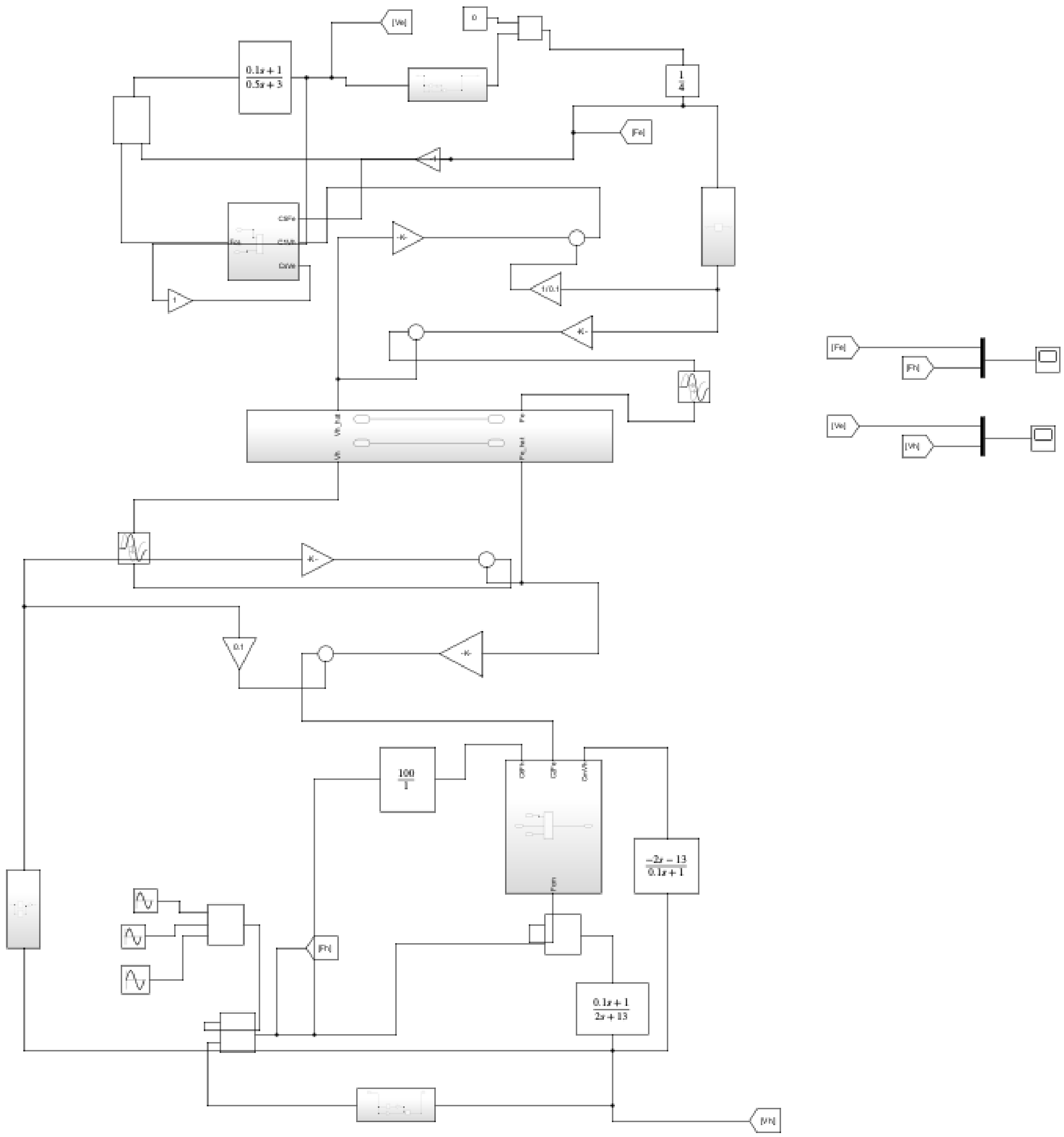
A)

Closed loop stability of a two channel telerobotic system

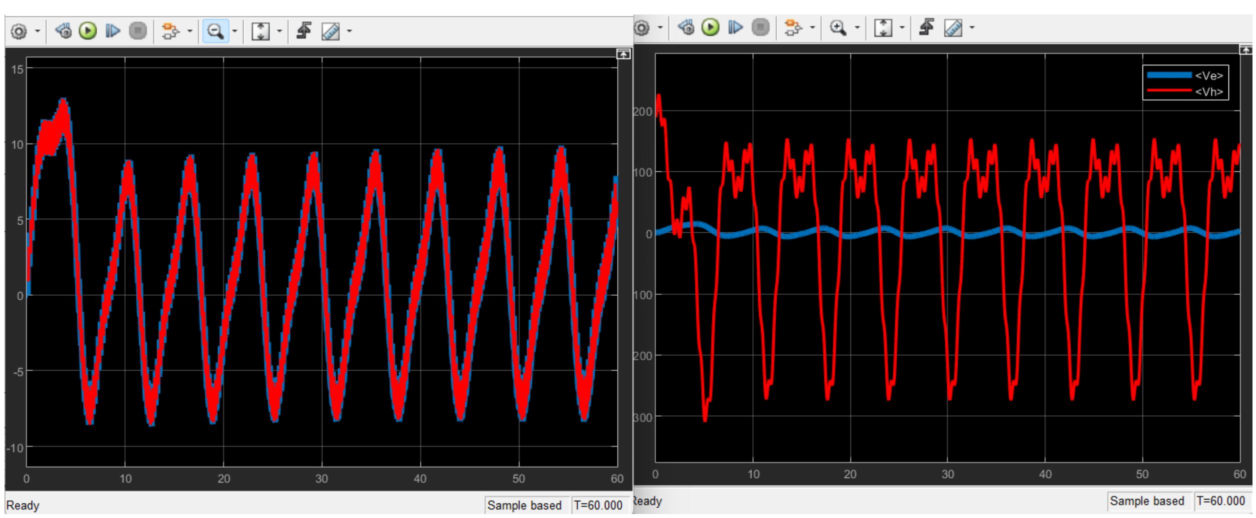
$$\Delta_C = 1 + \frac{Z_e}{Z_h} e^{-2sT}$$

- $Z_e > Z_h$, small gain stability is not satisfied
- Negative damping injection ($C_s < 0$) can lead to instability if it overcomes the inherent passivity of the system

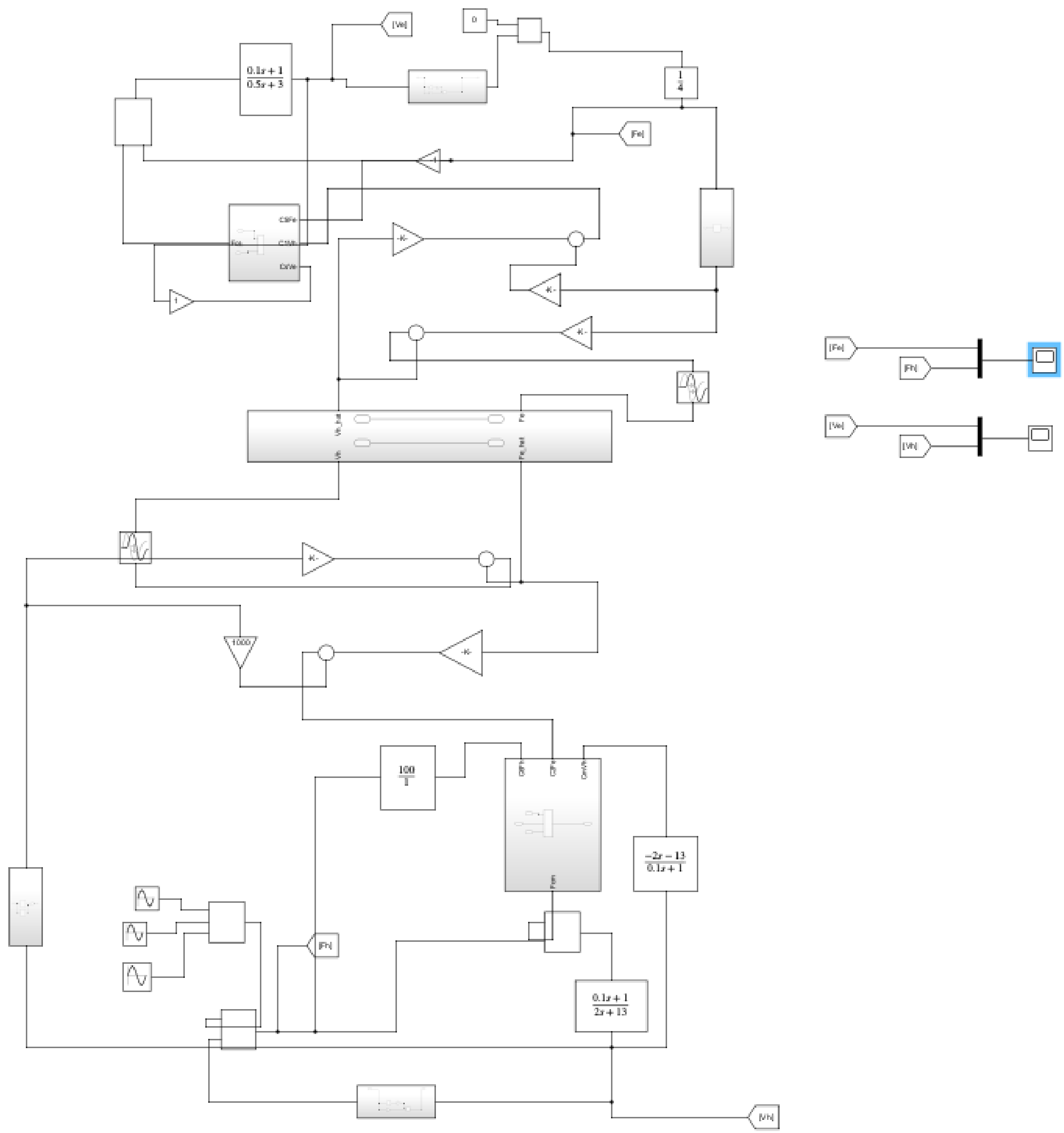
System is unstable as it does not satisfy nyquist theory & small gain stability

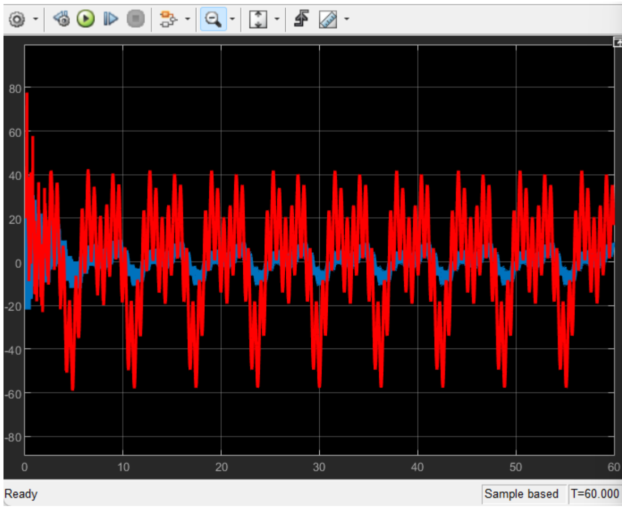

[Ve]
0.1s+1
0.5s+3
[Fe]
-K-
1/0.1
[Fh]
[Vh]
0.1
100
1
-2s-13
0.1s+1
0.1s+1
2s+13

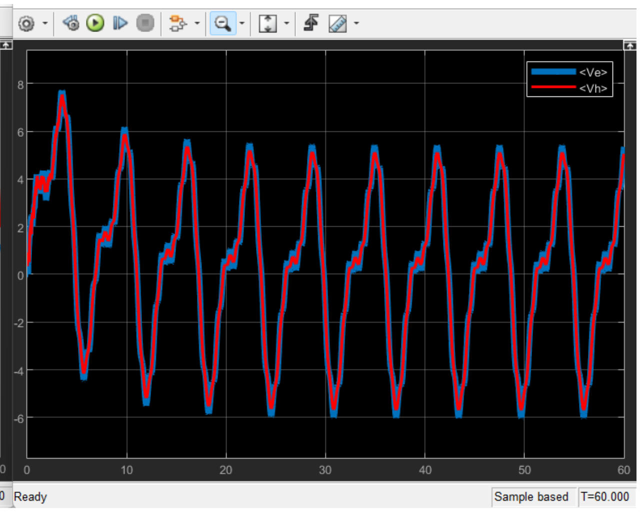
B)


<Ve>
<Vh>
Ready
Sample based
T=60.000

Value of B is assumed to be 0.1. At this value the force appears to be near transparent, this reduces force tracking error significantly.







Value of B is assumed to be 1000. At this value the velocity appears to be near transparent, this reduces velocity tracking error significantly.

For the assumed values of b – 0.1 and 1000 the systems are transparent and the system is stable for the values of b. For force tracking the system becomes transparent with a lower value of b where as for velocity tracking the system becomes transparent with a higher value of b.