

Literature Review:

Towards Collaborative Drilling with a Cobot Using Admittance Controller

Yusuf Aydin, Doganay Sirintuna, and Cagatay Basdogan (2020)

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Project Review: Admittance Controller Design

Problem: Current Galen robot controller not well optimized for transparency, and sometimes unstable

Project Goal:

Improve the transparency and stability of the Galen robot with a new controller with verified measurable and quantifiable performance metrics using an Admittance based design

Project Deliverables:

1. A fully developed, stable, and tested controller that optimizes Galen robot transparency in Simulation
2. A fully developed, stable, and tested controller that optimizes Galen robot transparency on Hardware
3. Controller performance maps in stability and transparency
4. A completed user study for qualitative feedback of controller performance

Literature Selection:

Towards Collaborative Drilling with a Cobot Using Admittance Controller

Aydin, Y., Sirintuna, D., & Basdogan, C. (2020). Towards collaborative drilling with a Cobot using admittance controller. *Transactions of the Institute of Measurement and Control*, 43(8), 1760–1773.
<https://doi.org/10.1177/0142331220934643>

Justification:

1. The project features the design of an admittance controller for robot human interaction
2. Uses stability and cost impedance maps to predict the desired performance of the robot
3. Utilizes system dynamics type Identification of the robot in a similar way to our project

Key Terms for Comprehension

Cobot –

Robot that is intended to interact with humans or in close human proximity

Admittance –

Allowance of external force (removal of robot impedance or resistance felt by the human user)

Stability –

A bounded input (force, velocity, etc.) results in a bounded output (velocity, position) that is controllable and safe

Transparency –

A metric to represent the lack of impedance or resistance felt by the human user due to the robot

Towards Collaborative Drilling with a Cobot Using Admittance Controller

Summary:

- Developed admittance controller scheme that allows for selecting the optimal values of admittance for increasing the transparency of a given system.
- Their goal was to drill a hole in a board with a cobot.
- Showed how stability maps can be coupled with cost impedance maps to quantify transparency

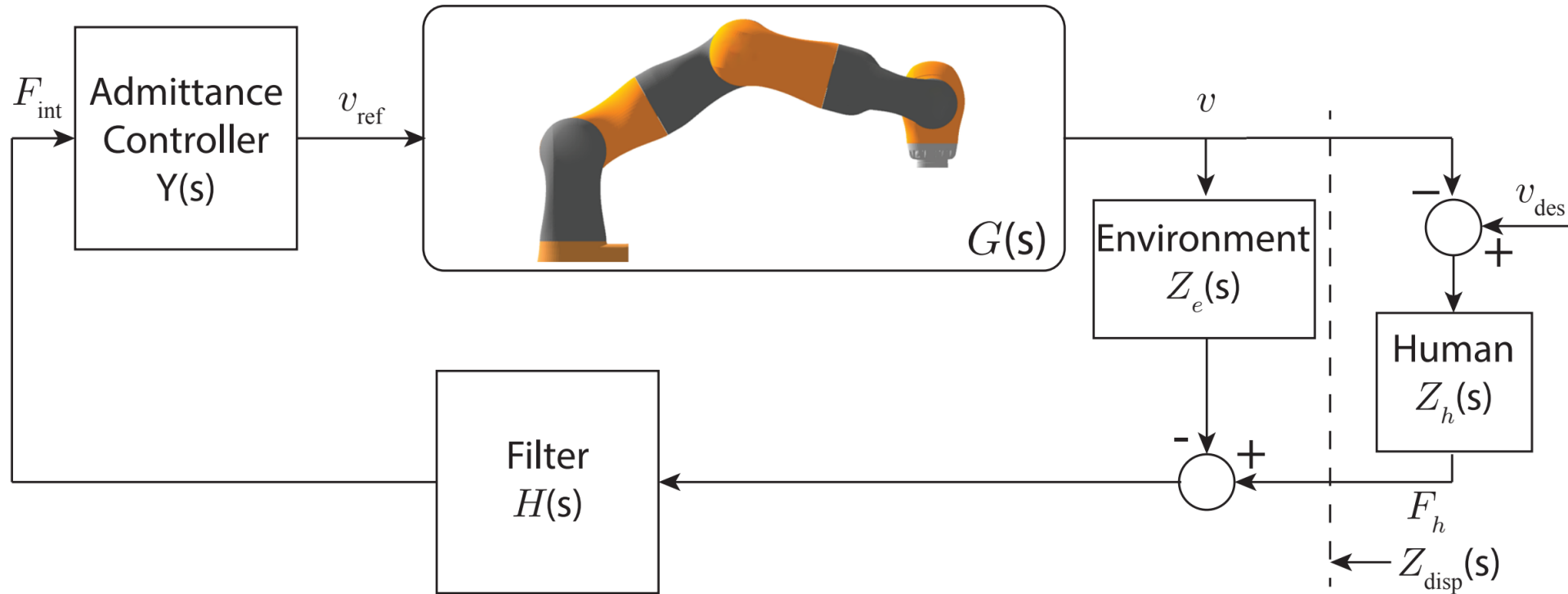
Results:

- A single cartesian directional transparency optimized cobot

Significance

- Showed how admittance controllers can be applied to many nonlinear cobot systems while keeping them stable.
- Defined easy to follow, robust, quantifiable metrics for transparency
- **The control scheme outlined in this paper provides the backbone of our project approach**

Controller Design



Transfer Function

$$T(s) = \frac{V(s)}{F_{\text{ref}}(s)} = \frac{G(s)Y(s)}{1 + G(s)Y(s)H(s)Z_{\text{eq}}(s)}$$

Total Impedance felt by human

(cut at $Z_{\text{disp}}(s)$)

$$|\Delta Z(j\omega)| = 1/|G(j\omega)Y(j\omega)H(j\omega)|$$

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Controller Design

Used system identification with a frequency analysis to capture $G(s)$

$G(s)$ contains both the plant and controller

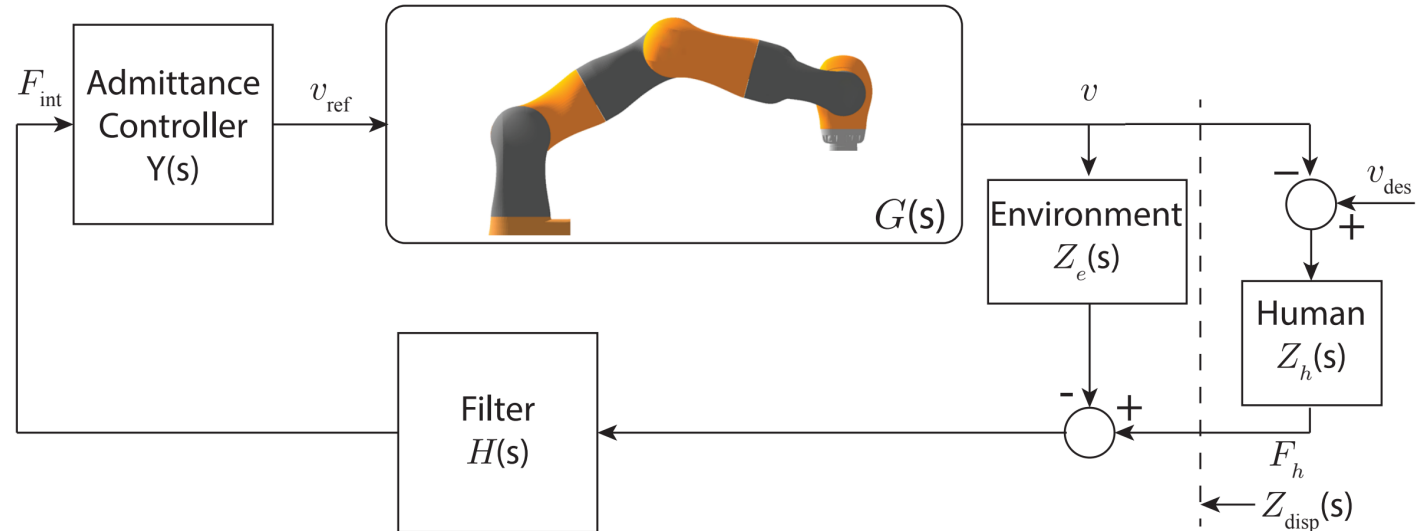
Introduce an admittance controller $Y(s)$.

m - is the desired mass felt by the user

b - is the desired damping felt by the user

Low pass filter $H(s)$ combats force noise

Impedances $Z_e(s)$ and $Z_h(s)$ added by test case



$$Y(s) = \frac{1}{ms + b}$$

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Equivalent Impedance

- Impedance from the human or environment (e.g. board or table) are hard to measure directly since they vary
- Bound the values of human and environment impedance for best case and worst-case scenarios

$$\begin{aligned} Z_{eq}(s) &= Z_h(s) + Z_e(s) \\ &= m_h s + b_h + \frac{k_h}{s} + \frac{k_e}{s} \end{aligned}$$

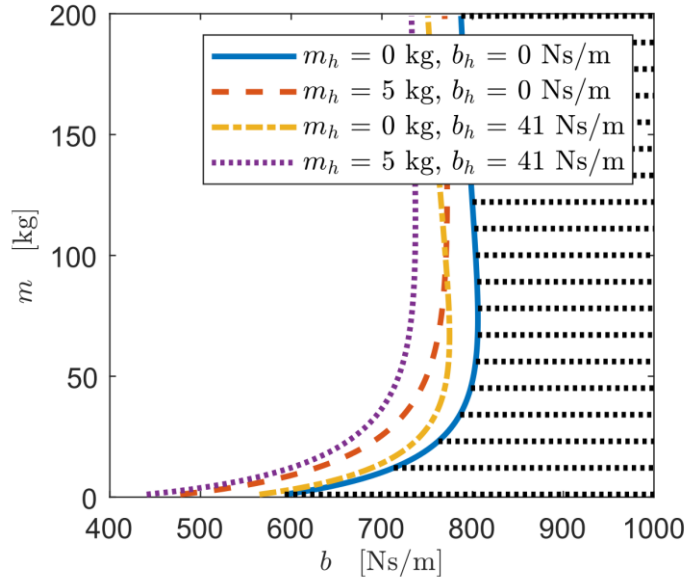
Case	Human mass m_h	Human damping b_h	Human stiffness k_h	Environment stiffness k_e
Best	0 kg	0 Ns/m	401 N/m	0 N/m
Worst	5 kg	41 Ns/m	401 N/m	16499 N/m

Stability and Transparency

Stability:

Check for positive closed loop poles

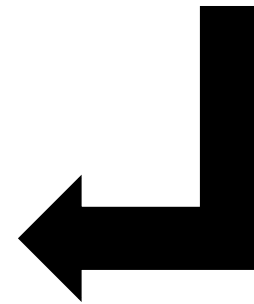
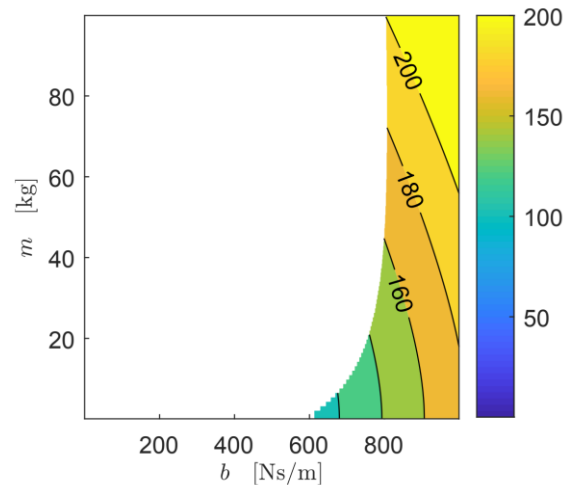
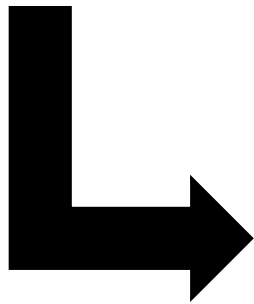
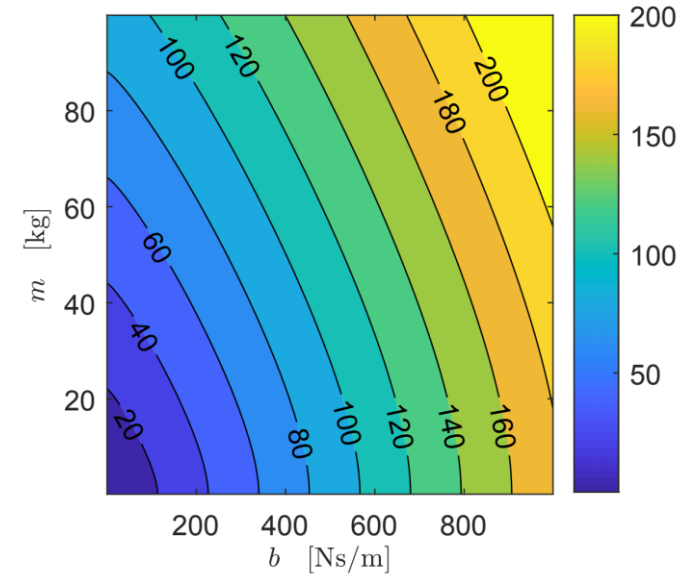
In some cases, evaluate the sign of the phase margin



Transparency:

Evaluate the impedance felt by human between 0.01Hz and 20Hz

Find weighted sum of impedance magnitudes



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Experiment

Test different selection of m and b values for $Y(s)$ that are in the stable region on robot while drilling a piece of wood

	m [kg]	b [Ns/m]
I	20	1500
II	20	900
III	50	900

Observe

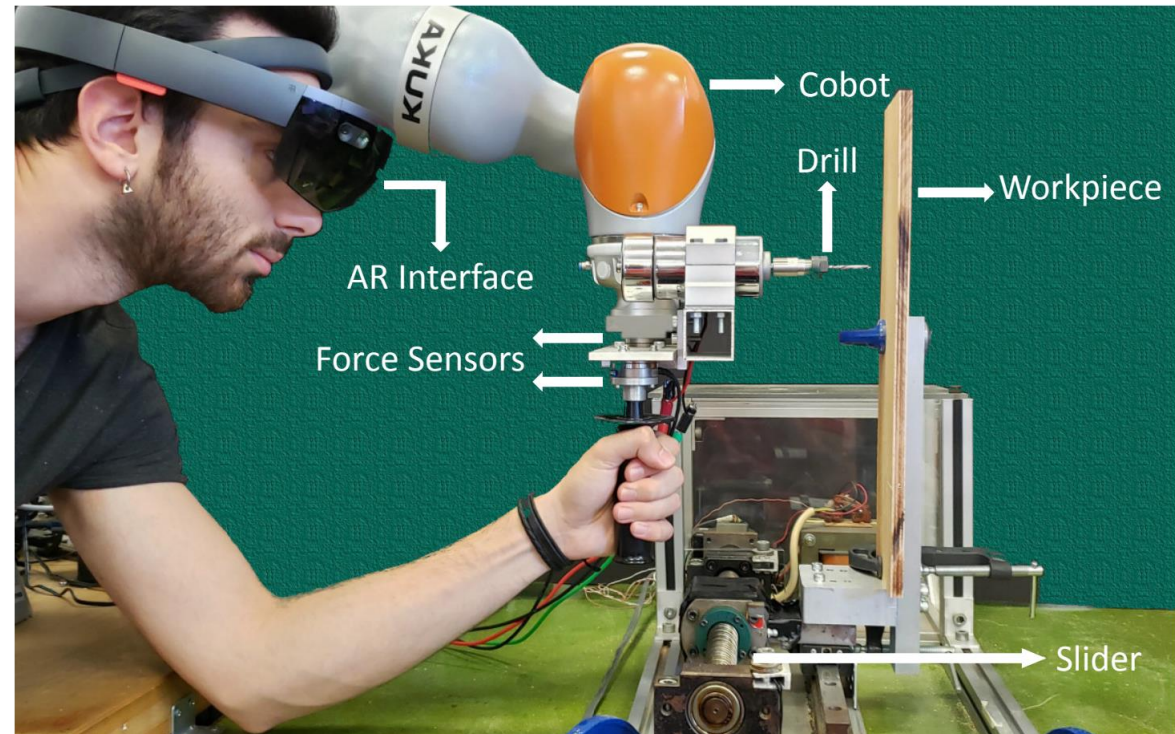
- Human input force
- Resultant velocity
- Accuracy of the hole depth

12 trials performed

4 repetitions for each of the 3 controllers

AR interface displayed the current drill depth relative to the desired drill depth

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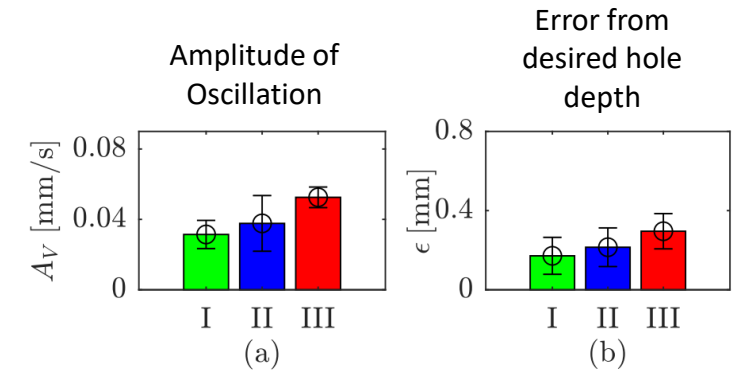
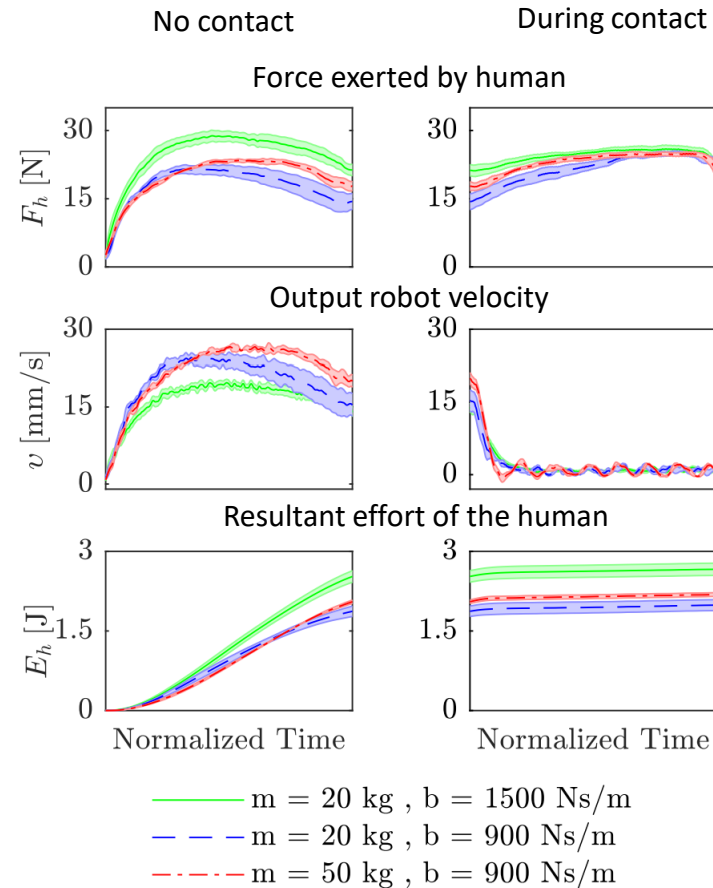
Results

The effects of damping strains the user greater than the effects of mass

Larger masses result in greater amplitudes of oscillation

A fine balance of damping to mass in the stable region will produce a higher accuracy permitting controller

Lower m and b resultant in more transparency or human effort



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Reflection

Next Steps

- Apply to more than one cartesian dimension
The constraints of one dimension allow a linear control scheme to function quite well, but how would that performance look in 3D.
- Test the robot in activities besides drilling
How does the human effort change within the test cases with tasks like pick and place
- Test greater range for damping values that could cause instability
The paper mentions that higher damping can result in non-passive unstable systems, but they did not thoroughly investigate this with their setup
- Test Robust Stability
Evaluate the effects of disturbances, noise, feedforward, etc.

Reflection

Critiques

- The system identification method performed here results in a system order that is exceptionally high (around 15th order) that should be discussed
- Their stability maps may be incorrect or lacking information. More detail on their construction is needed. Given their data, our team has been unable rebuild identical stability maps.
- They do not go in depth enough on how they perform their stability analysis besides looking at the close loop poles and potentially the phase margin.
- They do not thoroughly discuss why they chose their test m's and b's, and the repetitions and range of their tests are quite small.
- The control scheme they use focuses on an input desired human velocity that results in the same transfer function in the case they focused on an input human force. An input human force seems more intuitive and directly related the output of their results and is more applicable to other robot control schemes as is found in other related literature.

Conclusion

- The design of this admittance controller can be used to work on higher dimension robotics applications to increase transparency. This can be applied to our Galen robot system.
- The stability maps and impedance cost maps can be used in conjunction to get a measurement of transparency quality. This will help us choose m and b .
- More robust stability analysis is needed to build more accurate impedance maps and guarantee the system identified is truly stable.

References

- Aydin, Y., Sirintuna, D., & Basdogan, C. (2020). Towards collaborative drilling with a Cobot using admittance controller. *Transactions of the Institute of Measurement and Control*, 43(8), 1760–1773. <https://doi.org/10.1177/0142331220934643>
- Buerger SP and Hogan N (2007) Complementary stability and loop shaping for improved human–robot interaction. *IEEE Transactions*
- Keemink AQ, van der Kooij H, Stienen AH. Admittance control for physical human–robot interaction. *The International Journal of Robotics Research*. 2018;37(11):1421-1444. doi:10.1177/0278364918768950

Supplemental Material 1: Robot Control Information

- Robot Type -LBR iiwa 7 R800 robot (KUKA Inc.)
- Controlled through the Fast Robot Interface (FRI) and through C/C++
- Joint position controller
- The force data from 2 sensors acquired at 10 kHz
- Control loop was updated at 500 Hz

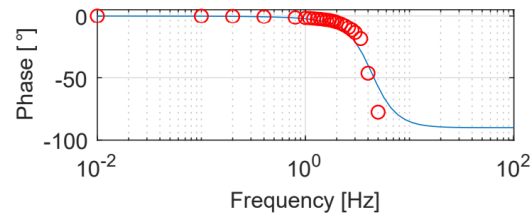
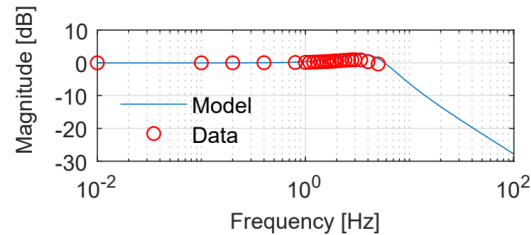
Supplemental Material 2: System Identification

Move the arm on select frequencies between 0.01Hz to 20Hz

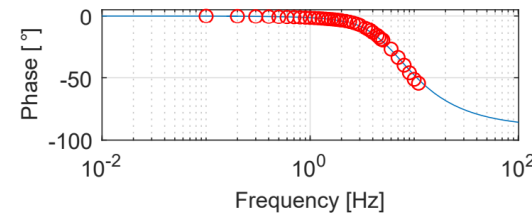
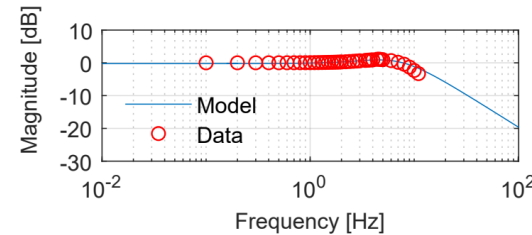
Identify the transfer functions for each joint.

Sum the different joint transfer functions to get $G(s)$

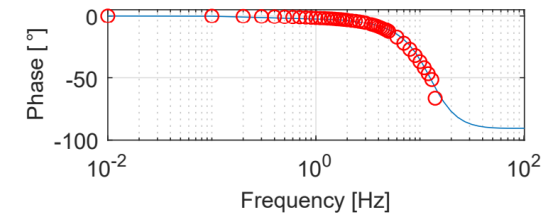
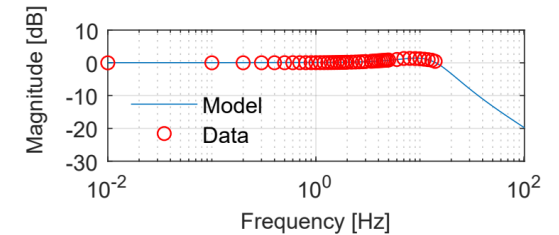
Check stability of $G(s)$



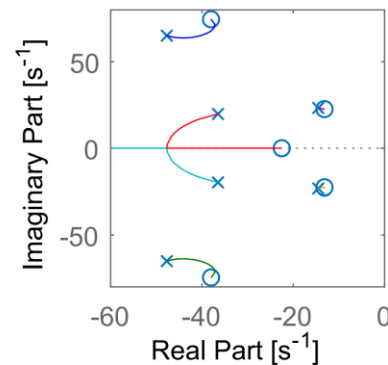
(a) 2nd joint



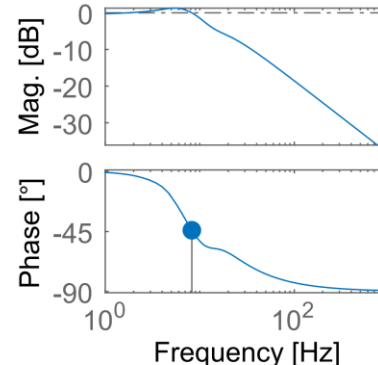
(b) 4th joint



(c) 6th joint



(a)



(b)

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