

Transparency Optimization of the Galen Surgical System with a Frequency Domain Admittance Controller Design

Students: Brevin Banks

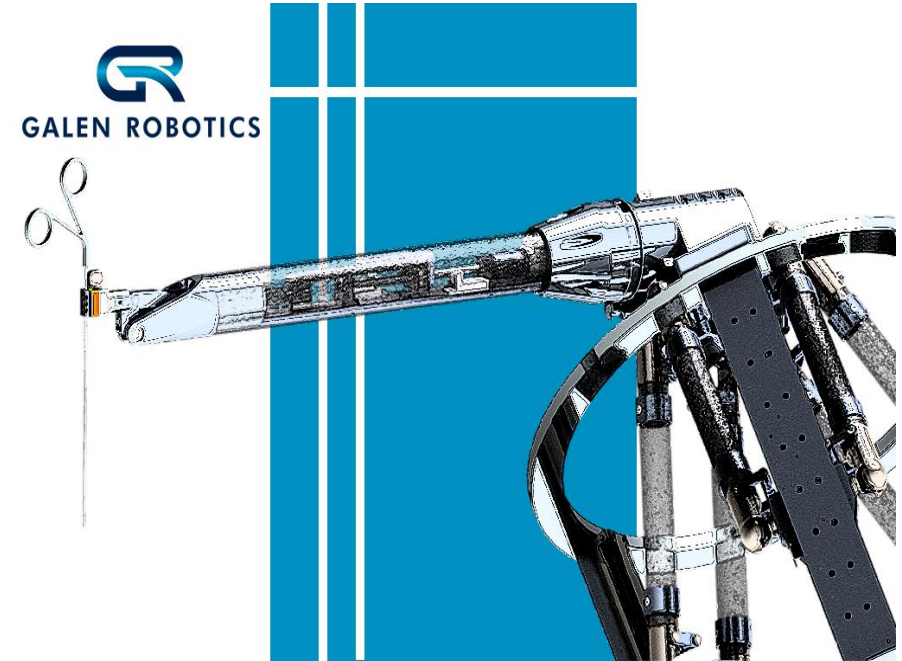
Mentors: Ugur Tumerdem, Manish Sahu, Adnan Munawar, Mohammad Salehizadeh, Russell Taylor

Project Introduction

The outcome of this project is a new functional frequency domain-based admittance controller that optimizes the transparency of the current Galen robot system in the mock OR while maintaining system stability.

This will be accomplished by reimagining the current control system entirely with basic linear models and then introducing an admittance controller with loop-shaping to better compensate for stability issues that are presently experienced when forces are applied to the robot by the environment.

Furthermore, the controller will be designed and optimized with hand over hand transparency in mind and allow for the application of virtual fixtures.



<https://www.galenrobotics.com/about-galen-robotics/>

Background

The current Galen campus robot controller faces performance and stability issues when forces are applied.

In addition to controller stability improvement, we want to optimize the transparency with a new controller.

Stability innately affects the transparency of the control system and cannot be easily adjusted by simply tuning gains. There is much work to be done in the field of transparency optimization.

Significance

- Natural and Steady Movements in the Operating Room
- Easy application of Virtual fixtures
- Could be Adapted to Make Quicker and More Accurate Procedures

Deliverables

Minimum:

- A stable frequency domain admittance controller in MATLAB code for the Galen surgical robot in the AMBF simulation environment
- A simulated control system package with optimized transparency containing code files that can be used in AMBF and MATLAB and is transferable to hardware

Expected:

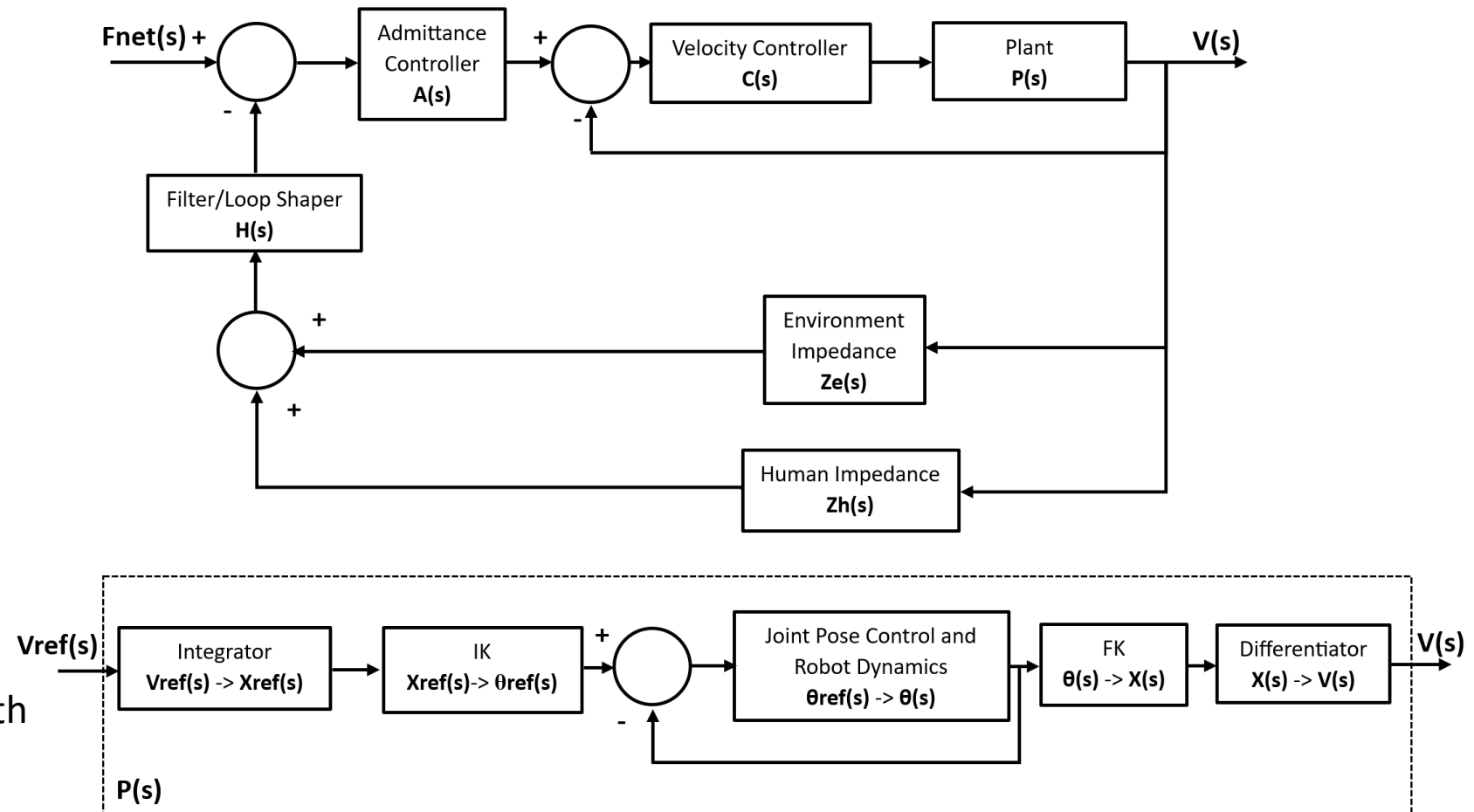
- An applied control system package to the low-level Galen controller that is stable and optimized for transparency including virtual fixtures
- A validated objective improvement in transparency according to specified metrics

Maximum:

- A completed user study to investigate subjective transparency preference with different controllers on the Galen robot

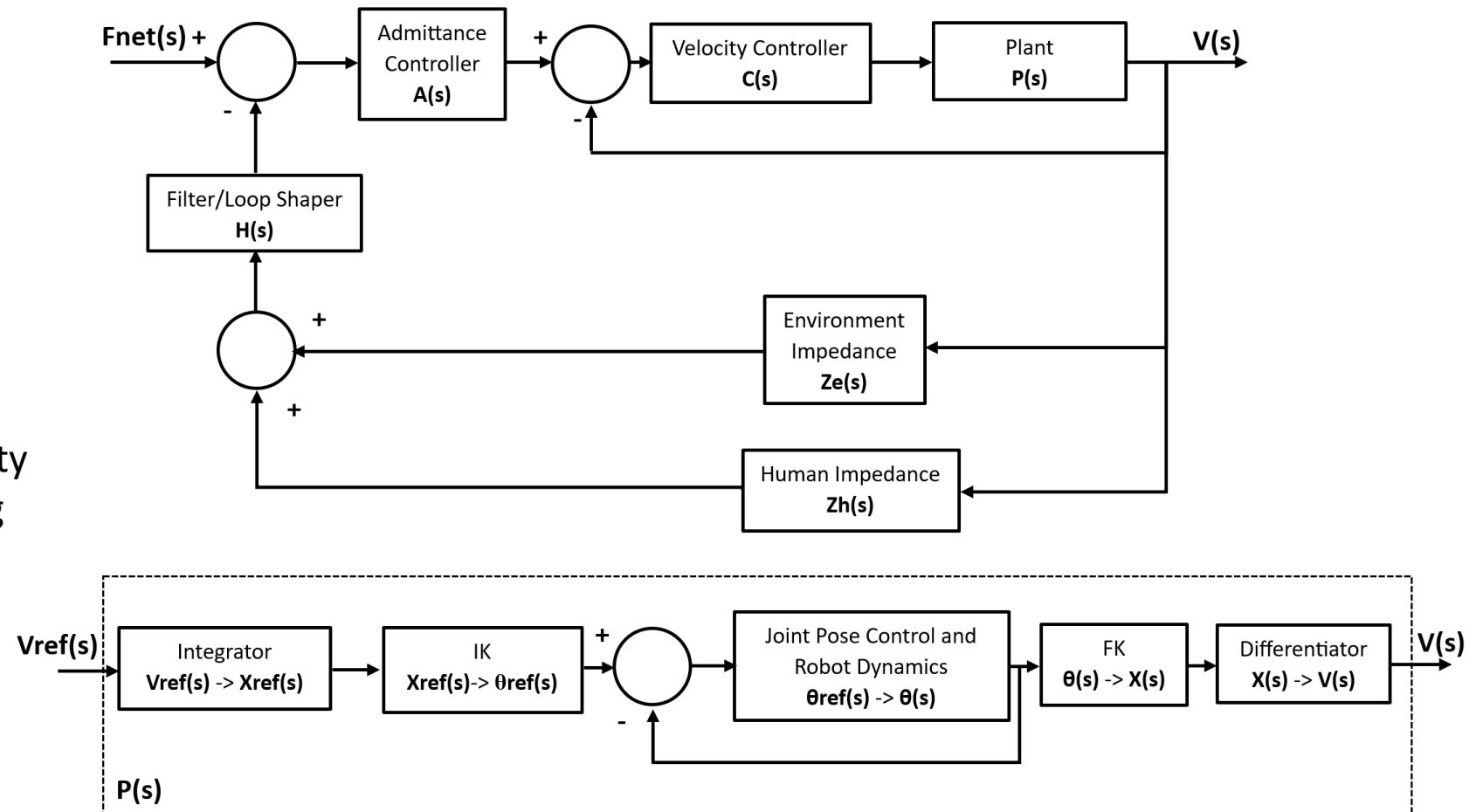
Technical Approach

- Start with a basic linear system for the robot in simulation to develop controller architecture (Either Velocity or Position Control)
- Include environment and human impedance factors
- Apply Admittance Controller and Frequency based filters to tune the controller performance
- Identify robot dynamics for plant with LTI approach or similar method

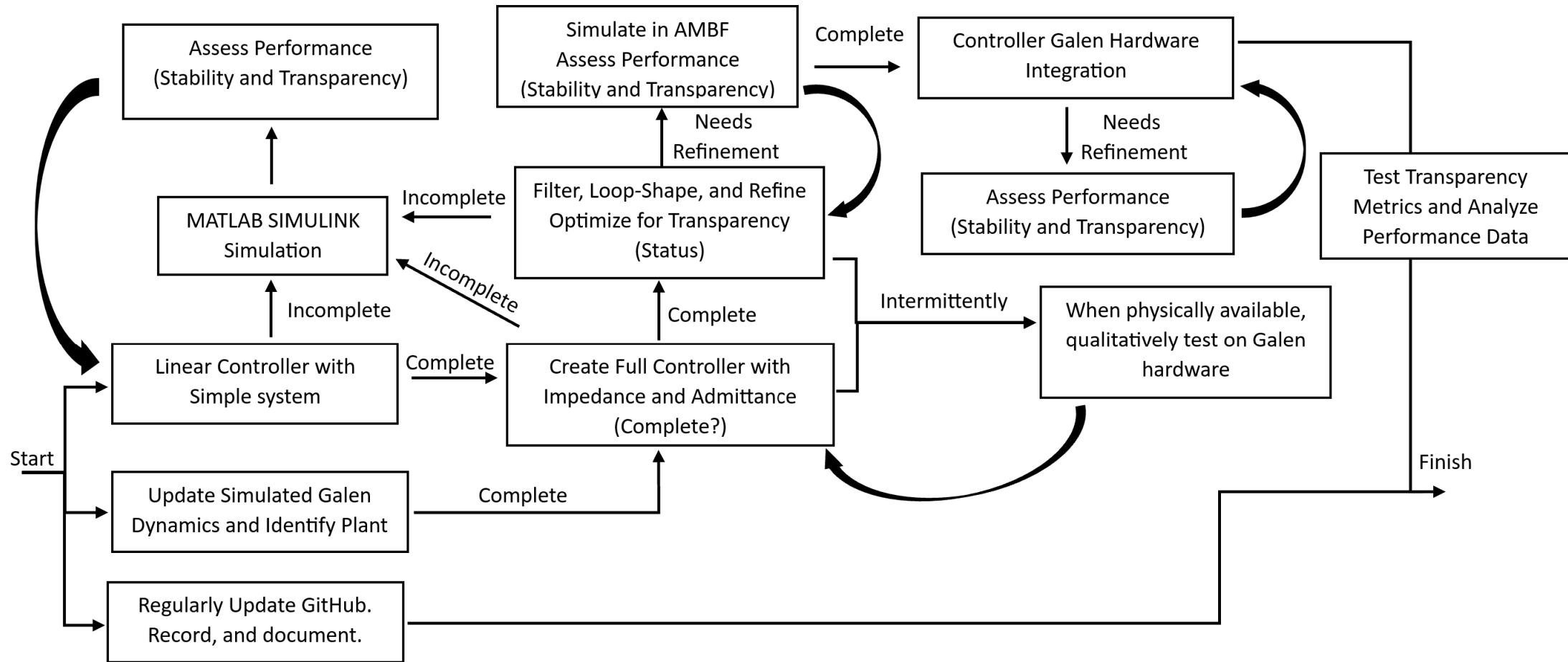


Technical Approach

- Bound the human impedance and environment impedance with estimated values
- Aim for High Admittance a high impedance while maintaining stability and watching the effects of damping



Technical Approach Continued



Project Dependencies

Dependency	Need	Contingency Plan	Planned Deadline	Hard Deadline	Status
Access to Computer	Need a computer with a Linux platform	Use a lab computer	8-Feb	13-Feb	Completed
Access to Galen AMBF Model	File access and editing permissions	Create a basic 3D model and crude dynamics	14-Feb	20-Feb	Awaiting Files
Software Installation MATLAB SIMULINK	License	Use Lab Computer with preinstalled software	8-Feb	13-Feb	Completed
Software Blender and AMBF Addon	Installation Instructions	Use Lab Computer with preinstalled software	8-Feb	13-Feb	Completed
Galen Robot and Controller Access	Anton and Adnan complete controller pipeline for Galen task space and joint space control	Go without Galen hardware implementation. Implement on similar robot or move on without implementation	15-Mar	15-Apr	waiting
IRB for user study	IRB Approval	Go without the User Study	(Submission 20-Feb) 3-Apr	(Submission 24-Feb) 17-Apr	Waiting

Key Milestones

Group 1:

Task 1.1 (2/13 - 2/20) Connect and Familiarize with AMBF and MATLAB Environment for Simulation

↳ Task 1.2 (2/20 - 2/27) Update Simulated Galen Robot Dynamics

Group 2:

Task 2.1 (2/13 – 2/20) Brainstorm Methods for Implementing Simple Admittance Controller and Choose Transparency Metrics

↳ Task 2.2 (2/20 – 2/27) Implement a Linear Controller Modeling the Galen as Mass Spring Damper in MATLAB Simulink Simulation

↳ Task 2.3 (2/27 – 3/13) Assess and Optimize Transparency and Stability of Controller in MATLAB

↳ Task 2.4 (3/13 – 3/27) Convert the Controller Plant to Robot dynamics, Update, and apply to AMBF Simulation

↳ Task 2.5 (3/27 – 4/3) Add Virtual Fixture to the Controller in AMBF

Group 3:

Task 3.1) (2/20 – 3/20) Apply Simulated Controller to Real Galen Hardware

↳ Task 3.2) (3/20 – 4/3) Testing of the Controller

Group 4:

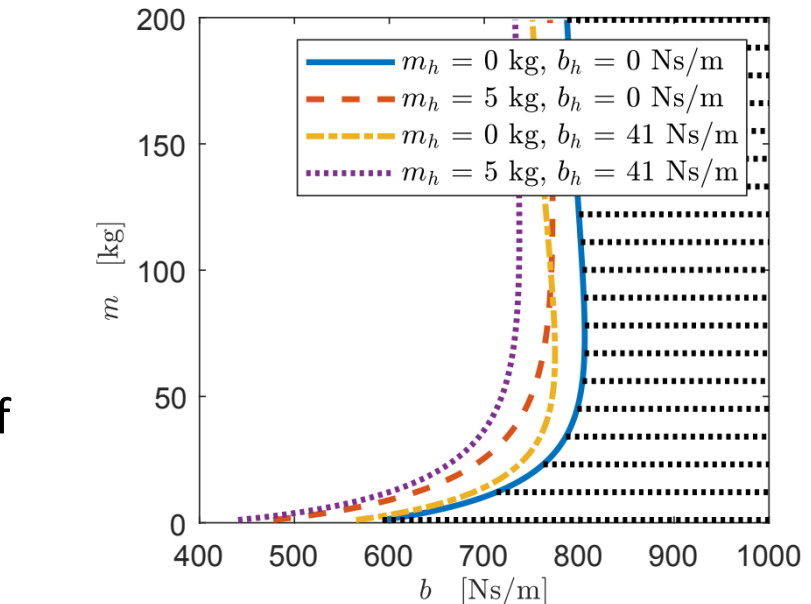
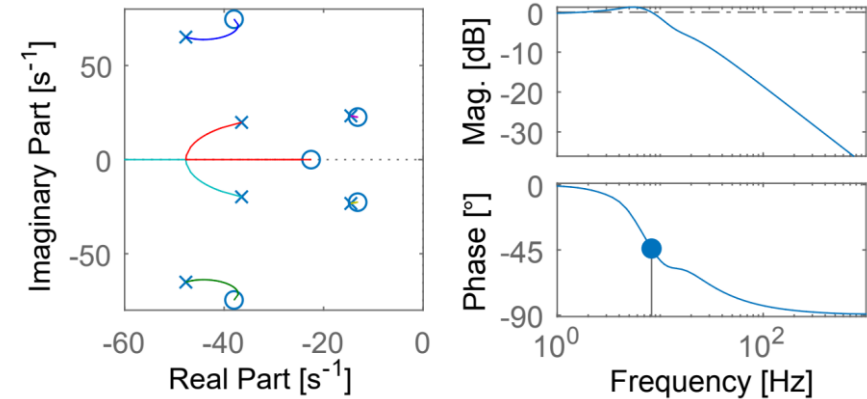
Task 4.1) (2/20 – 3/20) Design User Study for Testing New Galen Controller with Respect to the Current Controller, Obtain IRB Approval

↳ Task 4.2) (4/3 – 4/17) Recruit Users and Perform Testing

↳ Task 4.3) (4/17 – 5/7) Analyze Data and Conduct Further Research/Write Paper

Testing Plan

- Nyquist plot or Root Locus to assess stability across both extreme bounds for human impedance and environment.
- Observe stability in bode plot phase and gain margin. (Key for loop-shaping)
- Produce Stability Map
- Organize and carry out user study with ENT surgeons to collect qualitative performance data on the transparency of the controller compared to the current controller



<https://doi.org/10.48550/arXiv.2007.14503>

Team

- Student:
 - Brevin
 - Roles: Admittance Controller Design, Simulation, Hardware Integration
- Mentors:
 - Ugur Tumerdem, Ph.D.: Primary Lead, Controls Lead
 - Manish Sahu, Ph.D.: Coding Consultant
 - Adnan Munawar, Ph.D.: AMBF and Galen Lead
 - Mohammad Salehizadeh, Ph.D. Galen Consultant
 - Russell Taylor Ph.D.: General Consultant

Meetings and Data Management

- Regularly scheduled weekly meetings with mentor: 4pm Thursdays
- Weekly correspondence with the current week's deliverables and updates delivered before the weekend by email to mentor
- Attend Weekly meetings for Galen Robot Controller team: TBD
- All code files and deliverables are to be uploaded to GitHub and the project wiki. This includes MATLAB, C++, Word, Excel, PowerPoint, and PDF files
- Code files are regularly pushed and updated to GitHub repository

Readings

- Alonso, V., & de la Puente, P. (2018). System transparency in shared autonomy: A mini review. *Frontiers in Neurorobotics*, 12. <https://doi.org/10.3389/fnbot.2018.00083>
- 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>
- Feng, A. L., Razavi, C. R., Lakshminarayanan, P., Ashai, Z., Olds, K., Balicki, M., Gooi, Z., Day, A. T., Taylor, R. H., & Richmon, J. D. (2017). The Robotic Ent Microsurgery System: A novel robotic platform for Microvascular Surgery. *The Laryngoscope*, 127(11), 2495–2500. <https://doi.org/10.1002/lary.26667>
- Huang, S. H. (2019). Optimizing for Robot Transparency. *UC Berkeley*. ProQuest ID: Huang_berkeley_0028E_19188. Merritt ID: ark:/13030/m5mq08z2. Retrieved from <https://escholarship.org/uc/item/5q20h9cs>
- J. Fong, V. Crocher, Y. Tan, D. Oetomo and I. Mareels, "EMU: A transparent 3D robotic manipulandum for upper-limb rehabilitation," *2017 International Conference on Rehabilitation Robotics (ICORR)*, London, UK, 2017, pp. 771-776, doi: 10.1109/ICORR.2017.8009341.
- 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

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>
- *Democratizing Robotic Surgery and Microsurgery*. Galen Robotics. (2022, November 15). Retrieved February 13, 2023, from <https://www.galenrobotics.com/>
- *Simple gantt chart*. Microsoft 365 Templates. (2022, August 13). Retrieved February 13, 2023, from <https://templates.office.com/en-us/simple-gantt-chart-tm16400962>
- Munawar, A., Wang, Y., Gondokaryono, R., & Fischer, G. S. (2019). A real-time dynamic simulator and an associated front-end representation format for simulating complex robots and environments. *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*. <https://doi.org/10.1109/iros40897.2019.8968568>
- Munawar, A., Wu, J. Y., Fischer, G. S., Taylor, R. H., & Kazanzides, P. (2022). Open simulation environment for learning and practice of robot-assisted surgical suturing. *IEEE Robotics and Automation Letters*, 7(2), 3843–3850. <https://doi.org/10.1109/lra.2022.3146900>
- Varier, V. M., Rajamani, D. K., Tavakkolmoghaddam, F., Munawar, A., & Fischer, G. S. (2022). AMBF-RL: A real-time simulation based Reinforcement Learning Toolkit for Medical Robotics. *2022 International Symposium on Medical Robotics (ISMR)*. <https://doi.org/10.1109/ismr48347.2022.9807609>