Teleoperated Power Injector with Haptic Feedback for Angiography

Bolun Zhang[1], Erick Oberstar[1], Michael Zinn[1]

I. Introduction

Angiographic power injectors are commonly used in interventional radiology to introduce a contrast media into vascular structures. Commercially available power injectors are capable of injecting at fixed flow rates [1]. However, power injectors are not widely applied in neuroradiology due to the concern with excessive pressure that could cause aneurysm rupture. Previous work in teleoperated medical interventions has shown that haptic feedback provided to clinicians could enhance safety and improve user performances [2]. Inspired from these successes, we developed a bilateral teleoperated power injection system. With the haptic feedback, clinicians will be able to sense the injection pressure, detect abnormal issues to avoid damaging vascular tissues, while leveraging the power injector to inject at high flow rates. In this paper, we present the hardware, system modeling, and potential future work.

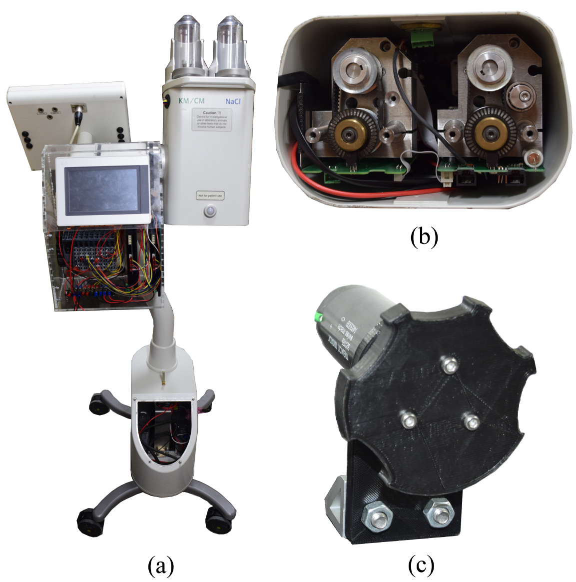

Fig. 1. Teleoperated power injector testbed: (a) Modified Medtron ACCUTRON HP-D constrast medium injector (b) Side-view of the ball-screw mechanism (c) Master haptic device

II. Hardware

Figure 1 shows the hardware of the proposed system. The master device consists of a Maxon RE 35 brushed DC motor with a 1024 CPT encoder. The slave device is modified from a Medtron ACCUTRON HP-D constrast medium injector. Each of the injection interfaces is powered by a Maxon EC 45 brushless DC motor with a 500 CPT encoder. A planeray gearhead with 26:1 reduction ratio is attached to the output shaft of the motor. A ball-screw mechanism converts the output torque of the gearhead to the plunger force applied to the syringe. We used B&R Powerlink to implement custom controls of the mechanical components and provide a graphical interface for clinicians to operate the injector.

[1]B. Zhang, E. Oberstar, and M. Zinn are with the Department of Mechanical Engineering, University of Wisconsin–Madison, Madison 53706, USA [bzhang65@|oberstar@engr.|mzinn@]wisc.edu

III. Future Work

Future work includes assessing the stability of the system via frequency-domain analysis using the analytical model shown in Figure 2, validating the assessment experimentally, and making improvement leveraging the state-of-art control approaches for bilateral teleoperation systems [3]. One particularly intriguing approach is the model-mediated control since our system is prone to instability to due large delay. In this case, the human operator interacts with a virtual model of the slave and the environment, and the virtual model is updating with the environment in real-time, thus avoiding the issue of delay and guaranteeing stability. Furthermore, we will explore how different control approaches affect users' perception and what haptic feedback strategies could improve user performances.

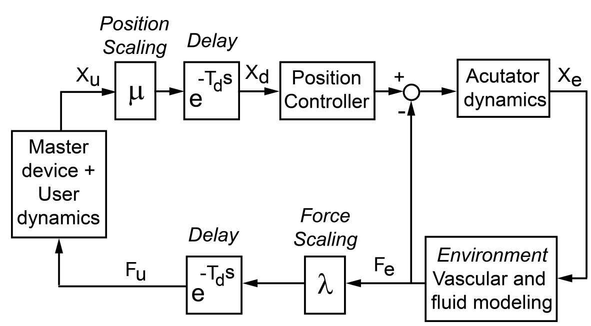

Fig. 2. Control structure of the teleoperated power injector

References

[1] E. L. Oberstar, S. Periyasamy, P. F. Laeseke, and M. A. Speidel, "Power injector for angiographic flow analysis using custom contrast density profiles," in *Medical Imaging 2020: Physics of Medical Imaging*, vol. 11312. SPIE, 2020, pp. 287–299.

[2] E. Abdi, D. Kulić, and E. Croft, "Haptics in teleoperated medical interventions: Force measurement, haptic interfaces and their influence on user's performance," *IEEE Transactions on Biomedical Engineering*, vol. 67, no. 12, pp. 3438–3451, 2020.

[3] S. N. F. Nahri, S. Du, and B. J. Van Wyk, "A review on haptic bilateral teleoperation systems," *Journal of Intelligent & Robotic Systems*, vol. 104, pp. 1–23, 2022.