Development of the 1DoF Haptic Renderer: Controller-Based Membrane Modeling for Haptic Devices

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Introduction: During procedures, microsurgeons primarily make use of visual feedback, because the involved forces are below the threshold of touch. Current haptic platforms that model tissue interaction, such as the Geomagic Touch and the Butterfly Haptics Magnetic Levitation Haptic Device (MLHD), are expensive, limited in force output, and subject to inertial effects due to their heavy actuators platforms. The 1DoF Haptic Renderer was developed to address these limitations [1]. It uses a woofer loudspeaker actuator with force and displacement sensors to simulate tissue interaction. We describe here Proportional-Integral-Derivative (PID) control of the 1DoF to improve its performance in rendering tissues and assisting with the development of future haptic surgical tools.

Materials and Methods: The 1DoF actuator is an 80W subwoofer speaker (Faital PRO 5FE120) with a 5 inch (12.7 cm) diameter. It is capable of 9.5 mm displacement from rest and can move steadily against forces up to 10 N. As actuators, speakers have the advantages of low mass, fast response, and low cost. A custom scaffold with a Honeywell FS03 Force Sensor is attached to the center of the speaker cone to measure force of interaction with a tool, and a reflective optical sensor (Vishay TCRT5000L) is used to measure speaker position. The 1DoF is controlled using an Analog Devices ADuC7026 microprocessor, where we implemented a PID feedback controller to regulate speaker current based on force and displacement measurements. Two primary modes of PID were developed: (1) Virtual Wall (VW) mode, in which a set-point is chosen based on the desired displacement, yielding an error used to resist displacement from the set-point with maximum force. (2) Zero Stiffness (ZS) mode in which speaker current was used to minimize force detected by the sensor. In each case, PID was used to apply proportional gain (K_p) to the error, integral gain (K_i) to a sum of previous errors, and differential (K_d) gain to predict future errors. Open-loop Ziegler-Nichols tuning was performed to empirically determine the PID gains from the ultimate gain (K_u), the value of K_p at which the system began oscillating, and the period (T_u) of oscillation for each mode. Anti-windup control was implemented by scaling down the integral component by the difference in the calculated controller output and the maximum actuator output. A slew-rate limiter and a low pass filter were also added to compensate for signal noise accentuated by the derivative gain term.

Results and Discussion: PID implementation resulted in significant improvements to 1DoF control and functionality. Tyreus-Luyben PID controller settings were found to be the most stable. With these settings, VW mode attained an increase in stiffness and stability. ZS mode granted almost full compliance towards user loading at every position in the actuator's displacement range.

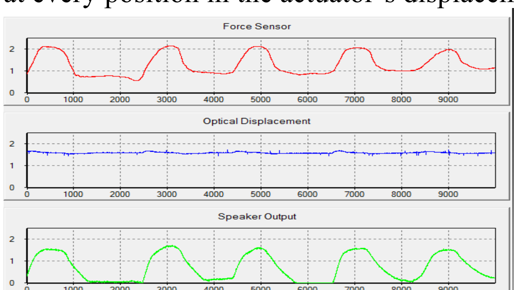

Figure 1

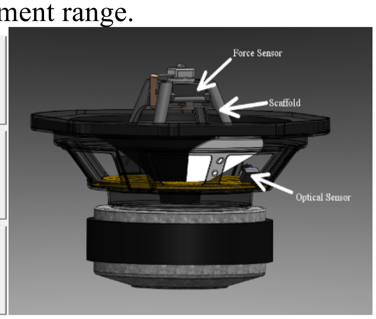

Figure 2

Figure 1: Output of sensor and actuator voltages for Virtual Wall. Large changes in force (top) produce minimal displacement (middle) and corresponding actuator voltage changes (bottom)

Figure 2: Solidworks model of actuator with Force Sensor, Scaffold, and Optical Sensor indicated

Conclusion: The PID control system resulted in significant improvements to the 1DoF's performance, facilitating future development of simulated tissues models for microsurgical simulation.

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References:

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