Monthly Report (Yamamoto Lab.)

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Research theme: **Haptic Feedback Controller with Palm Pressurization**

— Research Plan —

Term \Month	2	3	4	5	6	7	8	9	10	11	12	1
Literature review	■											
Design PlayStation Controller	■	■										
Test PlayStation Controller			■	■	■							
Frequency Response Analysis				■	■							
Design Pilot Controller			■	■	■							
Test Pilot Controller					■	■						
Theoretical Analysis					■	■						
Analyze data and compare						■	■					
Write Thesis							■					

— Work Contents —

1 Introduction

This report is the continuation of the first two reports about the project "Haptic Feedback Controller with Palm Pressurization". The last report has left off ...

2 Theoretical analysis

To come up with a theoretical analysis of the transfer function, all parameters that play a role have been identified.
The transfer function is non-linear, but this effect can at first be neglected (the force on the carriage changes with the angle of the motor). There are two types of friction in the system, first in the angular direction from the interior of the motor and bearings, and then in the linear direction namely the carriage in its guideway. These two types of friction can be combined and modeled as visquous damping.
Similar to the setup and analysis in [Junior et al., 2016] the equations of the motor are given as:

$$L_a \frac{di_a}{dt} + R_a i_a + K_{emf}\dot{\theta}_m = V_a \tag{1}$$

where L_a is the armature inductance, R_a the armature resistance and i_a the armature current of the motor. K_{emf} is the back electromotive force constant also given by the motor. V_a is the armature voltage and θ is the angle of the motor shaft. Furthermore, with Newtons law, the sum of all torques must be zero, or:

$$J_{tot}\ddot{\theta}_m + b_{visc}\dot{\theta} = K_\tau i_a \tag{2}$$

In equation 2 the parameter J_{tot} stands for the total equivalent inertia of the motor and the clamping link, b_{visc} is the viscous coefficient used for modeling friction and K_τ is the proportional current

torque gain constant. Ideally this should be the same as the K_{emf}. For an initial analysis these two parameters are treated to be identical, but if the results are inconsistent, a more thorough analysis shall be done where these two parameters should be measured in a set of tests.
Finally, there is also the gain of the amplifier in voltage mode, which converts the voltage of the Arduino into the voltage applied to the motors. This gain is $K_{ampl} = 10\text{Volt/Volt}$.

The total inertia of the system is determined by the inertia of the rotor J_m, the gear inertia J_g, the inertia of the clamp link J_{cl} as well as the inertia of the carriage assembly with mass m. The last one can be found by simplifying the load to a point mass at distance of the clamp link length L_{CL}, which is given by $J_{carr} = mL_{CL}^2$. The gear box reduces the inertia seen by the load by the square of its ratio R:

$$J_{load,\ motor\ side} = \frac{J_{load}}{R^2} \tag{3}$$

We have therefore a total inertia of:

$$J_T = J_m + J_g + n^2 J_{CL} + n^2 m L_{CL}^2 \tag{4}$$

where J_{CL} is simplified as a cantilever with an off-center axis of distance l:

$$J_{CL} = \frac{1}{12} m_{CL}(A^2 + B^2 + 12l^2) \tag{5}$$

where A and B are the width and length respectively.

The conversion between the angle θ and the distance x can be found by assuming that the horizontal displacement of the carriage is given by $L_{CL} sin(\theta) = x$. For small angles of θ the Taylor expansen gives $L_{CL}\theta = x$.

Combining all these equations one can find the block diagram as depicted in figure 1.

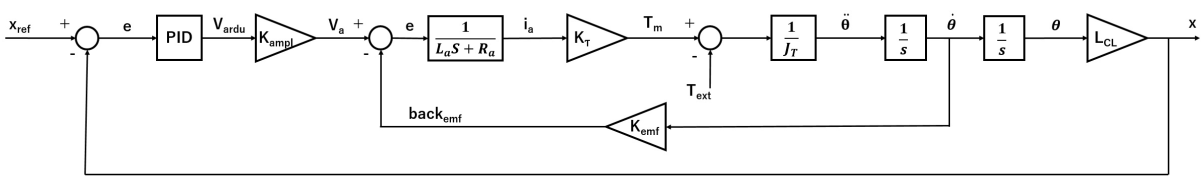

Figure 1: Complete block diagram.

From this diagram and the equations mentioned above, one can obtain the transfer functions that relate the output x and input x_{ref} as defined in equation 6.

$$F(s) = G_{PID}(s)G_{setup}(s) = \frac{X(s)}{X_{ref}(s)} \tag{6}$$

where $X(s)$ and $X_{ref}(s)$ are the laplace transforms of the output and input functions respectively.

$G_{setup}(s)$ can be calculated with the known parameters and a first assumption of negligible viscous friction. This sets external torques T_{ext} to zero.
The parametrical representation of this transfer function is:

$$\frac{X(s)}{U_1(s)} = G_{setup}(s) = \frac{K_\tau K_{ampl} L_{CL}}{J_T L_a s^3 + J_T R_a s^2 + K_\tau K_{emf} s} \tag{7}$$

In equation 7 $U_1(s)$ is the laplace transform of the output of the PID. The transfer function of the PID block is given in equation 8.

$$\frac{U_1(s)}{E(s)} = G_{PID}(s) = \frac{K_I + K_P s + K_D s^2}{s} \tag{8}$$

Here $E(s)$ stands for the laplacian of the error between the reference signal x_{ref} and the output x.

With the Bode plot of the $G_{setup}(s)$ and the known allures of the desired final transfer function $F(s)$ one can find the shape of the desired PID transfer function G_{PID}. The advantage of the Bode plots is that the multiplication of the transfer functions becomes an addition in the diagram.

3 Discussion

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4 Conclusion

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5 Outlook

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References

[Junior et al., 2016] Junior, A. G. L., de Andrade, R. M., and Bento Filho, A. (2016). Series elastic actuator: Design, analysis and comparison. In *Recent Advances in Robotic Systems*. InTech.