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, a simplifying mechanical schematic has been drawn. This schematic can be seen in figure 1. The equations of motion

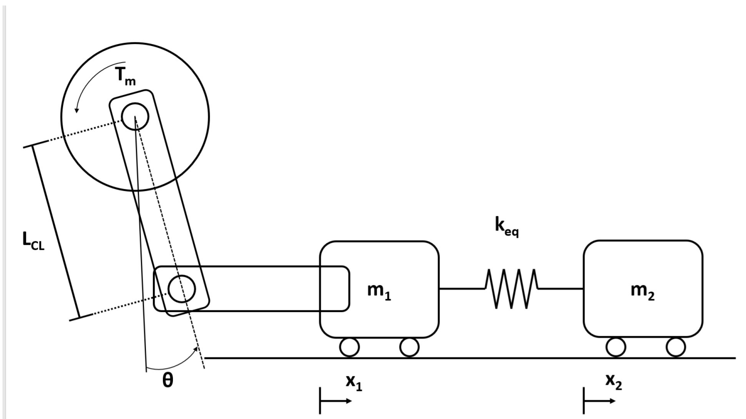

Figure 1: Simplifying mechanical schematic of the actuation system with the stimulator.

can be formulated with the major parameters defined in the schematic. A full explanation of all parameters can be seen in table **??**. The variables with subscript 1 refer to the first mass element, the carriage in its guideway, whereas variables with subscript 2 refer to the stimulator, the palm pad. For the motor the subscript m has been used.

Assumptions

First of all, it is important to mention that the transfer function is non-linear, due to the motor angle θ that determines the force that acts on the carriage c_1. As an initial approach however, this effect has been neglected . More specifically, it is assumed that $\theta \ll 1$ and $\cos\theta\frac{T_m}{L_{CL}} = F_{carr}$ becomes $\frac{T_m}{L_{CL}} \simeq F_{carr}$. Furthermore, there are two types of friction in the system. Once from the interior of the motor and bearings and the carriage in its guideway, and then of the second mass, the stimulator also called the palm pad. These two types of friction can be modeled as visquous damping with coefficients b_1 and b_2 respectively.
As a first approach, it is assumed that both types of friction can be neglected since the stimulator is not touching the walls of the controller and the carriage in its guideway has been optimally manufactured for low friction.

Expected Transfer Functions

The system can be cut into two major transfer functions. The block diagram including these two transfer functions is depicted in figure 2.

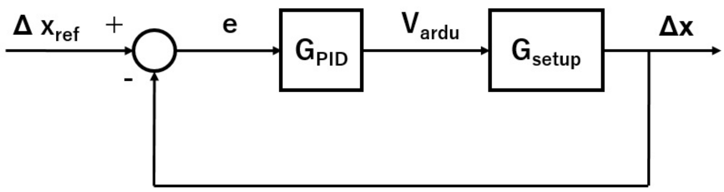

Figure 2: Block diagram with two different transfer functions.

According to this figure one can obtain a transfer function of the following form:

$$F(s) = G_{PID}(s)G_{setup}(s) = \frac{V_{ardu}}{E}\frac{\Delta X}{V_{ardu}} = \frac{\Delta X(s)}{E(s)} \tag{1}$$

Using this form one can calculate the individual transfer functions and finally relate the compression of the springs Δx to the compression given as reference Δx_{ref}.

PID Transfer Function The transfer function given by the PID controller is very straightforward and can be taken out of the books. Specific for this case is the multiplication factor K_{b2V} to get from the 8-bit value to the Arduino voltage level. The transfer function is given in equation 2.

$$G_{PID}(s) = \frac{V_{ardu}(s)}{E(s)} = K_{b2V}(K_P + \frac{K_I}{s} + K_D s) \tag{2}$$

Motor Equations The second transfer function relates the motor torque T_m to the Arduino voltage as well as the output Δx to T_m. Due to the back electromotive force these two parts are related and have to be treated as a whole.

The output torque T_m of the motor can be calculated using the sums of all torques and the conversion parameters intrinsic to the motor.
Similar to the setup and analysis in [Junior et al., 2016] the equations of the motor are given as:

$$L_a\frac{di_a}{dt} + R_a i_a + K_{emf}\dot{\theta} = V_a - V_{offset} \tag{3}$$

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:

$$J_T\ddot{\theta} + b_1\dot{\theta} - k_{eq}\Delta x L_{CL} = T_m = K_\tau i_a \tag{4}$$

In equation 4 the parameter J_T stands for the total equivalent inertia of the motor and the clamping link, b_1 is the viscous coefficient used for modeling friction in the motor and c_1 and K_τ is the proportional current torque gain constant. The moment of inertia can either be calculated as the sum of all inertias seen by the motor shaft, or measured in a simple test.
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 $K_{ampl} = 10\text{Volt/Volt}$. To this voltage an offset voltage of $V_{offset} = -20\text{V}$ is added.
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_1. 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 $J_{carr} = m_1 L_{CL}^2$. The gear box increases the inertia seen by the motor shaft by the square of its ratio R:

$$J_{load,\ motor\ side} = R^2 J_{load} \tag{5}$$

We have therefore a total inertia of:

$$J_T = J_m + J_g + n^2 J_{CL} + n_2^2 m L_{CL}^2 \tag{6}$$

where J_{CL} can be calculated by approximating it as a cantilever with an off-center axis of distance l:

$$J_{CL} = \frac{1}{12} m_{CL}(A^2 + B^2 + 12l^2) \tag{7}$$

where A and B are the width and length respectively.
n_2^2 is the equivalent reduction ratio at the point mass m_1 taking into account the lever of L_{CL}.

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 expansion gives:

$$L_{CL}\theta \simeq x_1 \tag{8}$$

The output Δx is the compression of the springs and is given by $\Delta x = x_2 - x_1$. For finding x_2 the equation of motion given by Newtons law has to be considered.

$$m_2\ddot{x}_2 = -k_{eq}(x_2 - x_1) - b_2\dot{x}_2 \tag{9}$$

Analogously, b_2 is the friction coefficient. Using the Laplace transform and equation 9 one finds the expression of x_2:

$$X_2 = \frac{k_{eq}}{s^2 m_2 + b_2 s + k_{eq}} X_1 \tag{10}$$

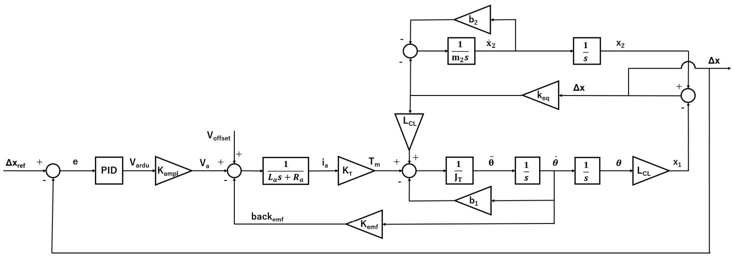

Figure 3: Complete block diagram relating the output Δx to the input ΔX_{ref}.

Motor and Spring Transfer Function Combining all the equations one can find the final block diagram, which can be seen in figure 3

From this diagram and the equations mentioned above, one can obtain the transfer functions that relate the output x and input x_{ref} as introduced in equation 1, where $X(s)$ and $X_{ref}(s)$ are the Laplace transforms of the output and input functions respectively.
It is thus possible to study the frequency response by simulating the this setup with the assumptions mentioned earlier.

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.