Adaptable Prosthetic Socket

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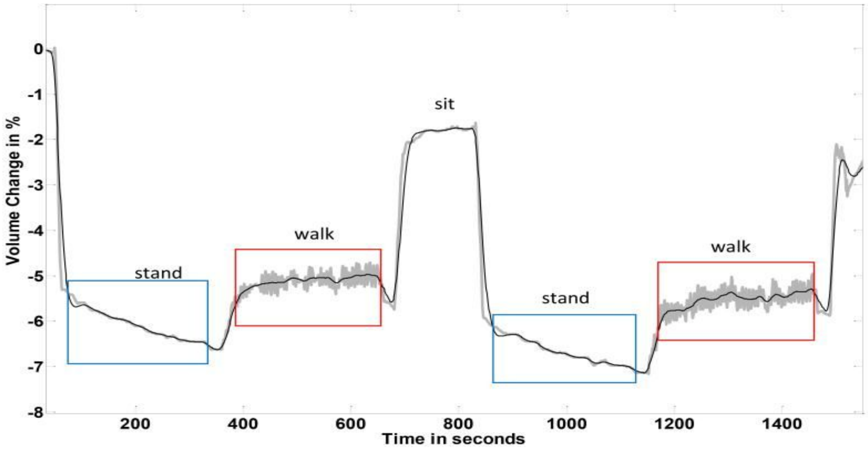
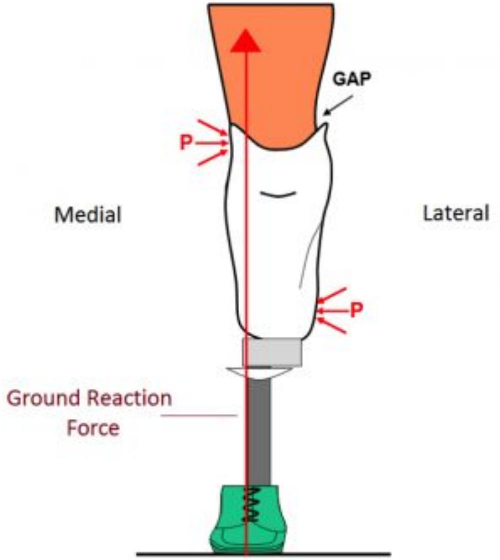
The Problem

Volume reduction ⟶ loose socket fit

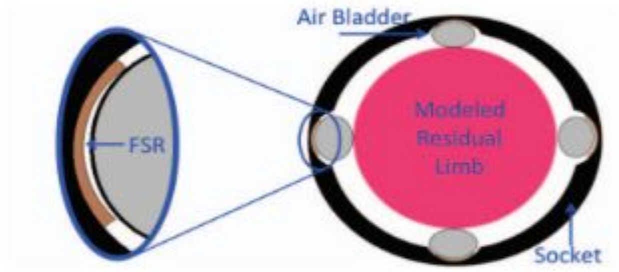
Volume expansion ⟶ increases tissue pressure in the residual limb



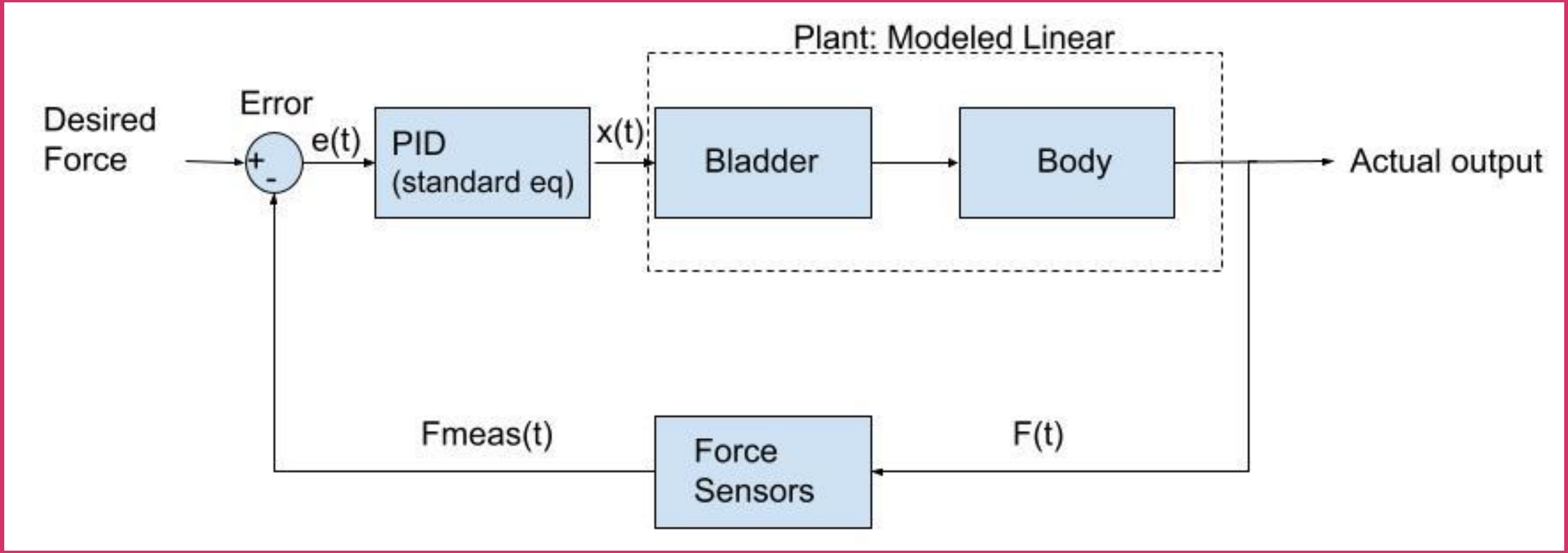


Goals

- To design a PID control system based on spring-damping model accounting for volumetric changes of residual limb, pressure on the force sensing resistors along the socket, and subsequent volumetric changes in socket air bladder.
- To eventually implement such a system in practice to ensure greater lower limb prosthetic fit.



The Desired Feedback

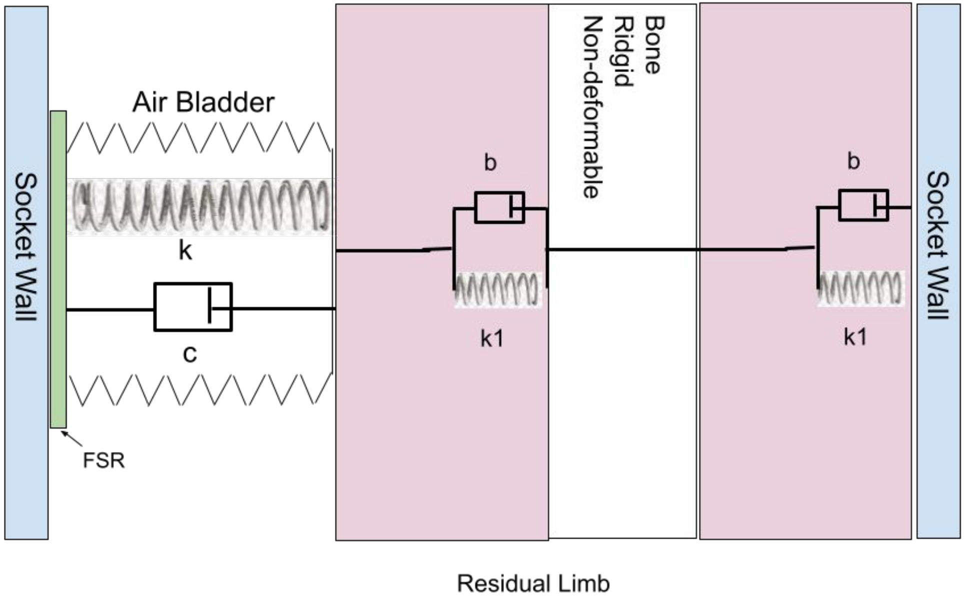


The Model

We were able to model the airbag and body as 3 spring dampers in series

Assumptions

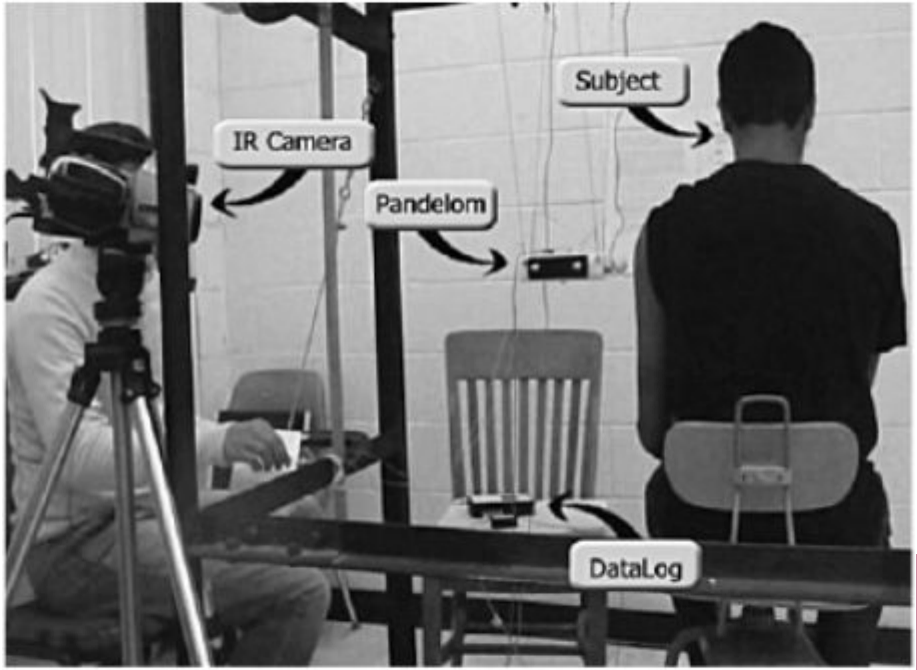
- The skin/muscle is modeled as a spring and damper in parallel until a rigid non deformable material is reached
- The air bladder is also a spring damper in parallel



Finding the spring (k1)/damping (b) coefficients of soft tissues

In the literature, through multiple steps of process, the spring constant and damper constant of the skin part are determined.
The 90 estimates of K_1 had an average of **18.470 kN/m**, a standard deviation of 0.61 and a range of 23.339 (8.833 to 32.172 kN/m)
The 90 estimates of b had an average of **1.824 kNs/m**, a standard deviation of 0.65 and a range of 4.504 (from .0122 to 4.626).

K_1 = 18470 N/m
b = 1824 Ns/m



Determining the spring (k)/damping (c) coefficients

Measured the height of the air-bladder without mass attached: **29/32 inches**
Attached weights to the bottom: **11.2oz**
Measured the air-bladder with the weight attached: **33/32 inches**
Calculate change in x: **⅛ inches**
Converted values to metric
Calculated the mass of the weight: **3.120N**

Used Hooke's law (F=-kx) to determine

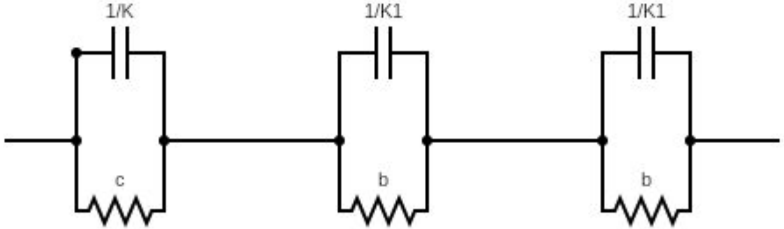
k = 982 N/m

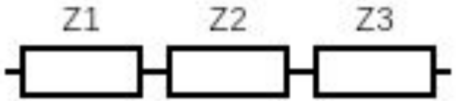
Given k, m and an estimated damping ratio of 20, we determined

c = 700 Ns/m

$$\zeta = \frac{c}{2\sqrt{mk}}$$

Modeling the system as a circuit





$$Z_c = \frac{1}{jwC} = \frac{1}{SC}$$

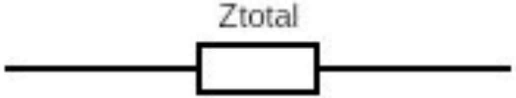
$$Z_R = R$$

$$Z_1 = \frac{1}{c} + \frac{1}{\frac{k}{S}} = \frac{1}{c} + \frac{s}{k}$$

$$Z_2 = \frac{1}{K_1} + \frac{1}{\frac{b}{S}} = \frac{1}{K_1} + \frac{s}{b} = Z_3$$

$$Z_T = Z_1 + Z_2 + Z_3 = \left(\frac{1}{c} + \frac{s}{K}\right) + \left(\frac{1}{b} + \frac{s}{K_1}\right) + \left(\frac{1}{b} + \frac{s}{K_1}\right) = \frac{KbK_1 + scbK_1 + 2KK_1c + 2sKcb}{cKbK_1}$$

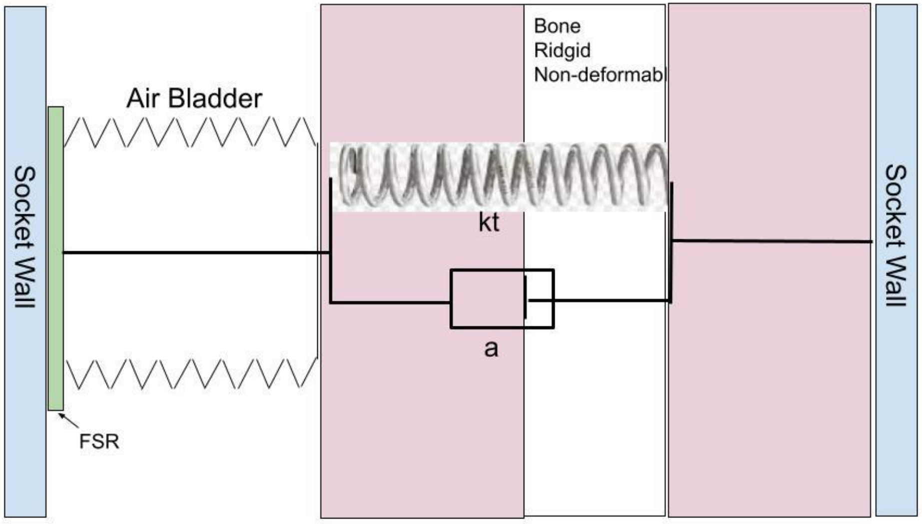
$$Z_T = \frac{b+2c}{cb} + \frac{K_1+2K}{KK_1}s = a + K_t s$$



$$new\ spring:\ K_t = \frac{KK_1}{K_1+2K} \quad new\ damper: a = \frac{b+2c}{cb}$$

The Simplified Model

We were able to model the airbag and residual limb as a spring mass damper system.



Residual Limb

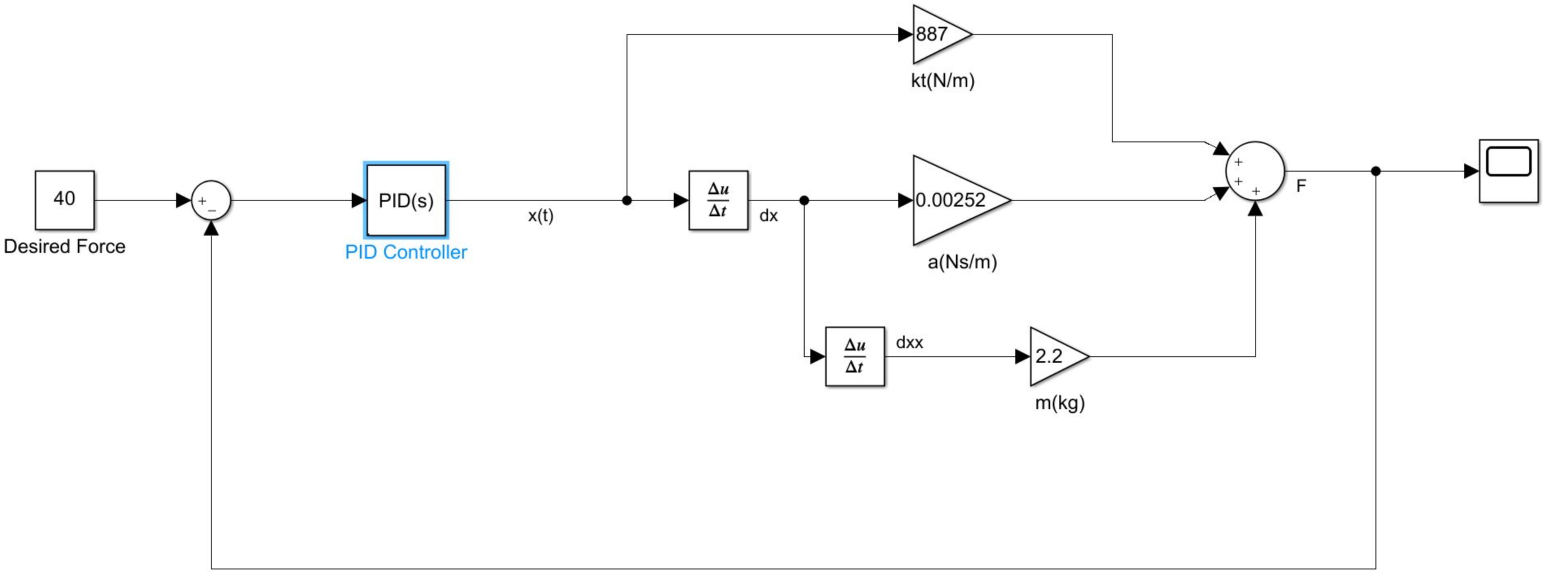
$$m\frac{d^2x}{dt^2} + a\frac{dx}{dt} + k_t x(t) = f(t)$$

$$\mathcal{L}(f(t)) = F(s) =$$

$$ms^2x(s) + asx(s) + k_t x(s)$$

$$\frac{F(s)}{X(s)} = ms^2 + as + k_t$$

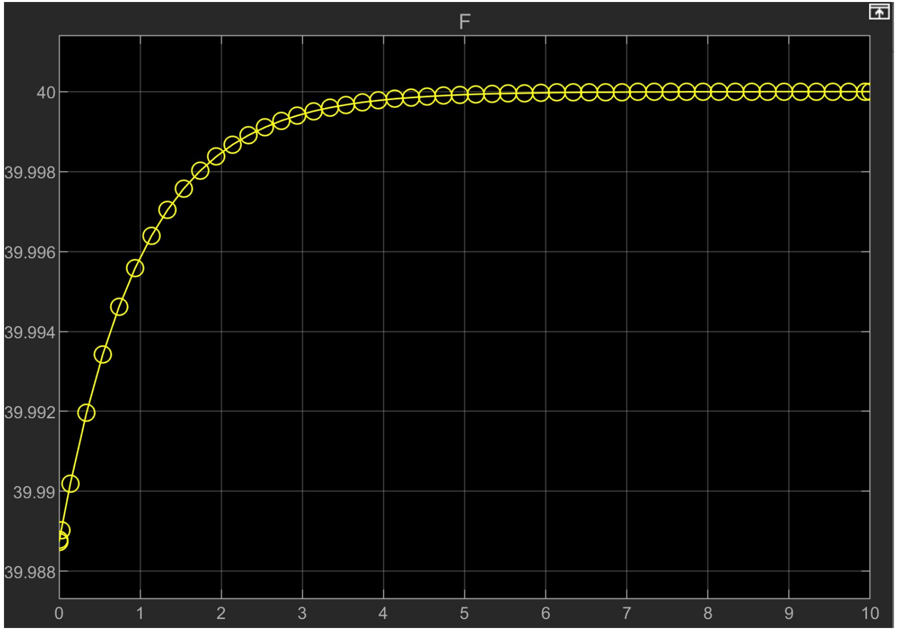
Modeled in Simulink



- Assuming that there is a totally perfect Force sensor with no error

Modeled in Simulink

Modeled the PID controller as a PI controller because it is a simple way to get a robust and fast response to a closed loop control while also eliminating any long term error in the system.



Disadvantages & Improvements

- The applied force is constant, but in the real world this is not true
- Force sensors are never ideal

$$\frac{dF_{meas}}{dt} = \frac{1}{\tau_{meas}}\left(F(t) - F_{meas}(t)\right)$$

- The air bladder and the skin act in unison
  - Make the model of the body separate from the air bladder
  - Measure the damping coefficient of the air bladder
- Air bladder is modeled as a piston
  - utilize $PV=nRT$

Clinical Relevance

The development of a prosthetic design that adjusts to a residual limb it fits can decrease the pistoning effect and other signs of discomfort, reducing clinical cases of reamputation.

References

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Any Questions?