Lecture 14

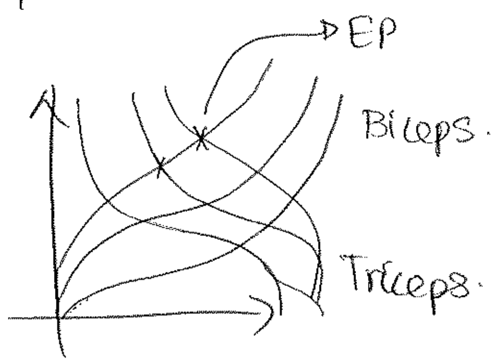
PT

Last time: Started on higher-level motor control.

Talked about Equilibrium Point theory.

EP - The position to which the neuromuscular sys. is driving the limb.

Elbow w/ 2 muscles. (Bizzi, 1982)

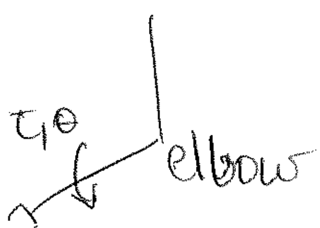


Virtual Trajectory Theory (Hogan, 1984)

- the CNS specifies a series of EPs and the limb impedance takes care of the details of the movement production.

dynamic

Quantitatively: $\tau_{joint} = I\ddot{\theta}$



@ EP by definition $\tau_j = 0$

$\ddot{\theta} = 0$

$\dot{\theta} = 0$

$\theta = \theta_0$

or the set of α

$\{\alpha\}$

But $\alpha_s \neq 0$

does not have to be

One interpretation: Muscle activations α <u>always</u> define a virtual E.P. of the joint.

($\{\alpha\}$ encodes a lot more than that, but this is one interpretation)

So V.T. hypothesis – a time history of ~~t~~ virtual E.P.s is generated w/ varying αs $\{\alpha\}$

↳ position specified by $T_{\{\alpha\}}(t)$

↳ $\theta_0\{\alpha\}(t)$

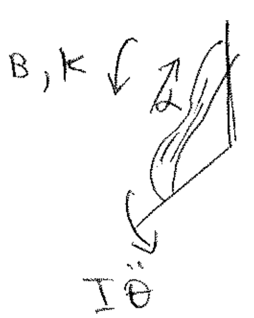
The actual V.T. hypothesis does not assume linearity btwn $T_{muscle}, x_m, \dot{x}_m$, but we will assume x_m + $\dot{x}_m$ are uncoupled and linear wrt. τ_m

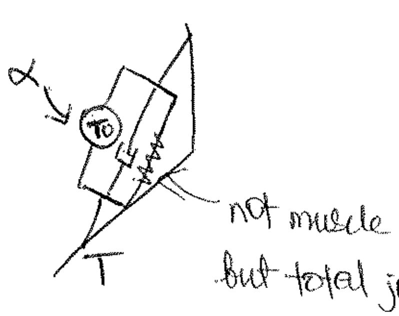
Then $$\tau_j = I\ddot{\theta} = T_{\{\alpha\}}(t) \underbrace{- b\dot{\theta} - k\theta}$$

↑ produced by offbalance in $\{\alpha\}$

↓ – total impedance @ joint caused by co-contraction that does not affect τ

– these could vary w/ time, but we ignore it.





Assume $\{\alpha\}$ defines EPs & $\tau_{\{\alpha\}}(t)$ specifies EPs

$\uparrow$ $\theta_0\{\alpha\}(t)$

Then @ EP $\quad \tau = 0 = \ddot{\theta} = \dot{\theta} = 0$

$$\theta = \theta_0$$

$$\tau(t) = \cancel{I\ddot{\theta}}^{\to 0} = \tau_{\{\alpha\}}(t) - \cancel{b\dot{\theta}}^{\to 0} - k\,\theta(t)$$

$\uparrow$ $\theta_0\{\alpha\}$.

$$\Rightarrow \quad \tau_{\{\alpha\}}(t) = k\,\theta_0\{\alpha\}$$

If V.T. is a series of $\theta_0\{\alpha\}$ over time,

then $\tau_{\{\alpha\}}(t) = k\,\theta_0\{\alpha\}(t)$ ← plug this back in

$$I\ddot{\theta} = k\,\theta_0\{\alpha\}(t) - b\dot{\theta}(t) - k\,\theta(t)$$

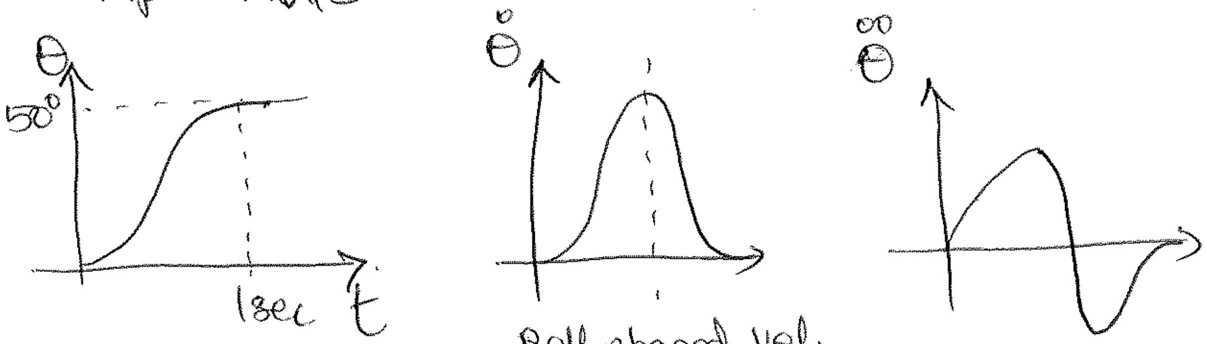
$$\boxed{I\ddot{\theta} + b\dot{\theta} + k\theta = k\,\theta_0\{\alpha\}(t)}$$

actual joint coord $\qquad$ virtual joint coord.

You will play w/ virtual vs real joint mvts in PS 4

Ex. Human / Monkey / Animals / Biological Sys. have typical mvts @ medium speeds (most commonly used)

Simple mvts



Bell-shaped vel. profile

More on this in a lecture or 2.

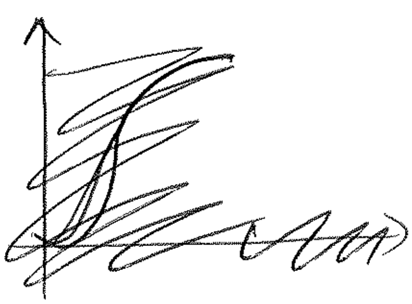
For typical values of I, B, K

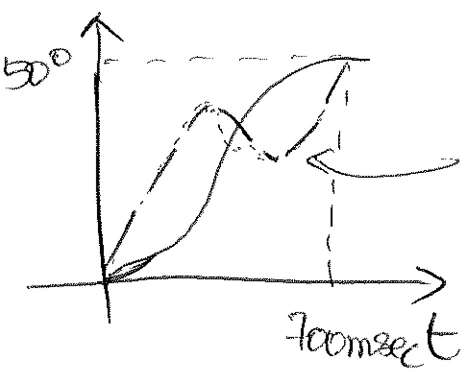
$I = 0.014\ kg/m^2$

$B = 0.173\ Nms/rad.$

$K = 1.48\ Nm/rad$

Moving 50° in ~700msec

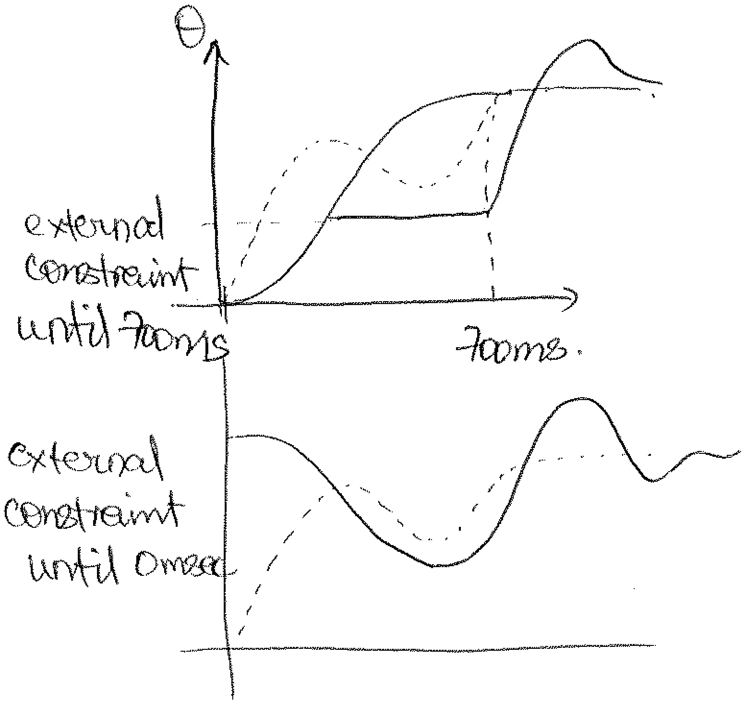




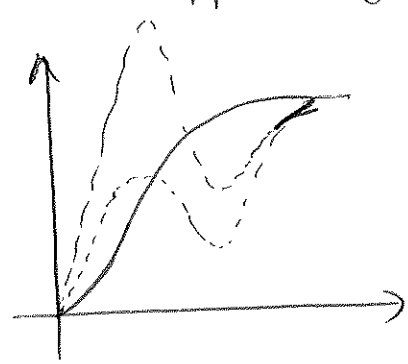
calculated $\theta_D\{\alpha\}$

It so turned out if $\{\alpha\}$ is recorded, it has similar profile to this!

Using computer, you can simulate limb dynamics under the same V.T. but w/ constraints



Now what happens for really fast mvts?



For the same I, B, K, large fluctuation in $\theta_0(\alpha)(t)$ and has abrupt change

However when $\{\alpha\}$ is recorded, they do not fluctuate as much & don't have the abrupt change (as if V.T was scaled)

So what changed? B & K!

Remember K is controllable w/ co-contraction
(& B changes w/ K)

Increasing B & K allows smoother V.T.

↳ Intuitively, we increase K when we make fast mvts

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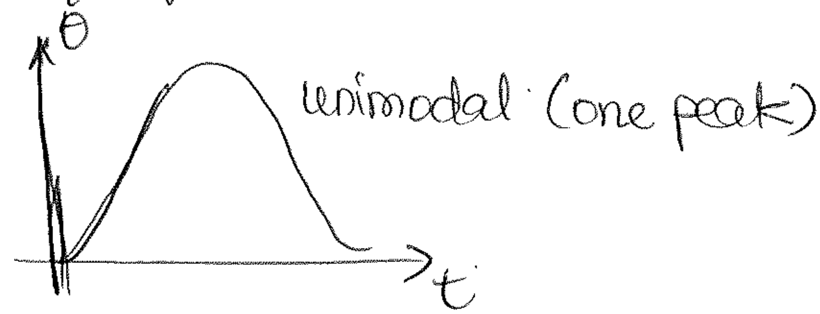
Going back to the bell-shaped velocity profile mentioned earlier.

↳ For a variety of joints (fingers, arm, hip, jaw, etc.) + a variety of species, one thing that is common is the shape of the velocity profile.



Relate to dynamic optimization:

What does optimization here mean?

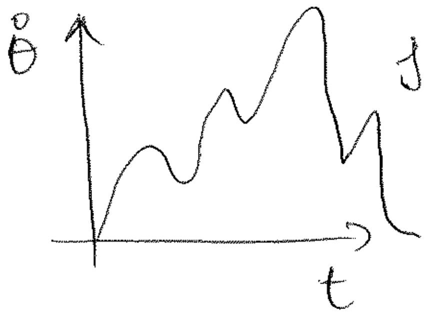
- Out of so many options to make a mvt. from one place to another, somehow one strategy is used by all of us.

- What is so good about this strategy?

- " is this strategy exactly?

- What parameters are minimized optimized?

Another interesting thing → babies' mvts donot have unimodal bell-shaped vel. profile



So we "learn" to ~~pf~~ "optimize" Something over time

Main characteristics of learned mvts : smoothness.

Smoothness is quantitatively characterized by

$$\int_0^d \frac{1}{2} \frac{d^3\theta}{dt^3}\, dt$$

d = moving duration

θ = joint angle.

3rd derivative of position → jerk

Optimizing smoothness ⇒ minimizing jerk.

$$\min \int_0^d \frac{1}{2} \frac{d^3\theta}{dt^3}\, dt$$

"Minimum jerk theory" Flash & Hogan (1982-85)

More on this next time.