Experiencing Torque Control

A Literary Review

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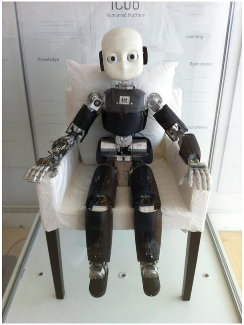
Outline

Introduction
Introduction

The idea of Torque Control will be discussed in the following ways:

- Definitions
- Problems
- Techniques
- Interesting Concept
- Takeaway Points

ICUB[1]



[1] https://twitter.com/icub

Definitions

Let's All Speak The Same Language

- Asymptotic Stability
- Lyapunov Stability
- Fuzzy Logic

General Issues:

- Must manipulate end effector (or end joint) positions to execute a desired command [**?**]
- Must minimize or reject disturbances [**?**, **?**]
- Conventional controllers need exact dynamical models [**?**]
- Extremely nonlinear [**?**, **?**, **?**]
- Autonomous platforms (especially walking) must have torque controlled joints [**?**]

PID Controllers [**?**]

- Must decouple each joint
- Good for slow motion but degradation at faster speeds

Torque Controllers:

- Excellent control comes at the cost of flux [**?**]
- Powerful nonlinear controller that is widely used in robotic manipulators

Techniques

Super-Twisting Sliding Mode [?]

- Fast switching of control inputs
- Produces a stable response
- The closed loop response is stable if external influences are bounded and gains set to large values
- Works well with PWM and inverter switching
- STSM control is a second order scheme
- Asymptotic convergence

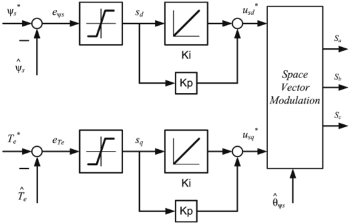


Figure 3. The sliding-mode direct torque and flux controller ($r = 0$).

Techniques

Super-Twisting Sliding Mode [?]

- The nonlinearity of the device can be controlled by changing the exponent r such that $0 \leq r \leq$
- Step 1: with $r = 0$, select K_P for the desired response time
  - the flux rising time has a strong impact on startup peak current
- Step 2: with $r = 1$, select K_I for the desired overshoot and settling time.
  - Try to not have a visible overshoot and smooth settling
- increase r until the torque and flux ripples vanish

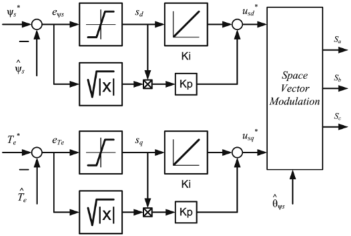


Figure 1. The STSM-DTC controller for IM drives.

- Fuzzy logic parameters can compensate for dynamic parameters
- Much simpler to implement than regular torque control problems
- Based on Brunousky canonical form

$$\dot{x} = Ax + Bu$$

$$\dot{x} = \begin{bmatrix} 0 & I \\ 0 & 0 \end{bmatrix} x + \begin{bmatrix} 0 \\ I \end{bmatrix} N$$

$$N = B(q)[\dot{q}\dot{q}] + C(q)[\dot{q}]^2 + G(q)$$

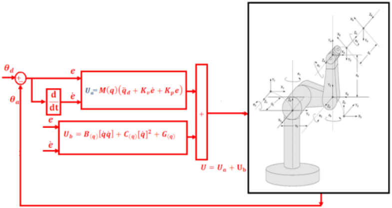


Fig 1: PD CTC with application to rigid manipulator

Techniques

PD Plus Gravity [?]

For the PD Feedback for $N(t)$:

$$\tau = M(q)(\ddot{q}_d + K_D\dot{e} + K_P e) + N(q, \dot{q})$$

When gravity is added into the feedback system:

$$\tau = M(q)(\ddot{q}_d + K_D\dot{e} + K_P e) + G(q)$$

The above has been found to be stable in Lyapunov sense

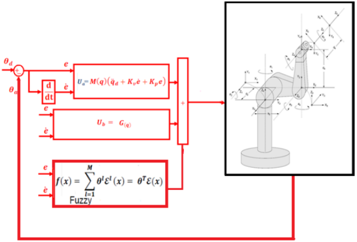


Fig 3: Block diagram of proposed fuzzy PD plus gravity with application to robot manipulator

Techniques

Dynamic Torque Control [?]

- Robots are generally modelled as rigid body systems
- Use torques as inputs
- High fidelity is key
- Outer position loop and inner torque loop
- Torque comes from inverse dynamics to change the set-point
- Both loops run a PID
- Feedback entirely based on the error

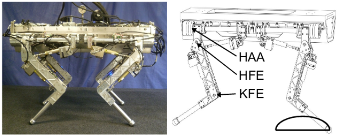


Fig. 1. HyQ: Hydraulic Quadruped robot. **Left:** picture of the robot. **Right:** sketch with labels of the three leg joints, hip abduction/adduction (HAA), hip flexion/extension (HFE) and knee flexion/extension (KFE) and endeffector trajectory of the trot experiment presented in Section V.

Techniques

Dynamic Torque Control [?]

- Using force and flow balance and neglecting hydraulic friction the force F is:

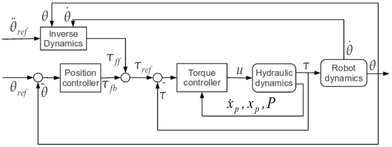
  $$\dot{F} = f(P, x_p) + g(x_p, \dot{x}_p)u$$

- $f(P, x_p)$ is a function of position and pressure
- $g(x_p, \dot{x}_p)$ depends of velocity and natural feedback

$$g(P, x_p) = K_v A_p \beta \left[\frac{\sqrt{P_S - P_A}}{V_A(x_p)} + \frac{\alpha\sqrt{P_B - P_T}}{V_B(x_p} \right]$$

$$f(x_p, \dot{x} = -A_p^2 \beta \left[\frac{1}{V_A(x_p)} + \frac{\alpha^2}{V_B(x_p)} \right] \dot{x}$$

- α is piston area ration; β is oil stiffness; $V.(x_p)$ are chamber volumes



Takeaway
What did we learn?

In conclusion, several items were learned:

- Robotic manipulators and joints are highly nonlinear
- Torque control has several different ways to solve
- Stability criteria can be met
- Other methods exist such as phase angle [**?**]
- Latex Beamer is just not fun

References I