MATHEMATICAL MODELLING AND CONTROL OF A LIGHTWEIGHT ROBOTIC ARM

University of BRISTOL

INTRODUCTION

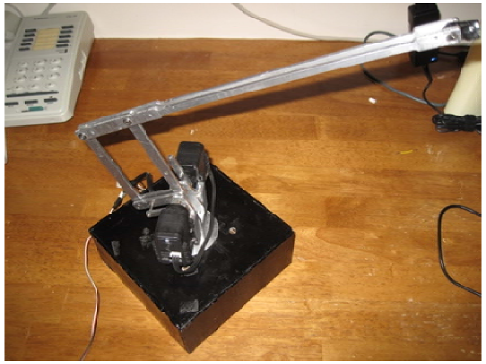

Figure 1: The constrained link robot arm designed and built for the purpose of the project

A constrained link robot arm design differs from the conventional design in the way of actuator mounting;

- conventional robot arms have their actuators mounted on all joints
- constrained link robot arms have their actuators congregate as close as possible to the fixed base.

The conventional design has the advantage of being relatively easy to model and control, and versatility (by having minimal workspace restrictions) but the actuators located further from the fixed base adds unnecessary inertia to the system.

Placing the actuators close to the fixed base as in a constrained link design reduces the inertia of the system, allowing less powerful actuators to be used and can thus lead to cost savings; however, this design has the disadvantage of having a reduced workspace due to interferences from the extra links.

The constrained link design would be well suited for industrial purposes, where cost efficiency is of prime importance; the reduction in versatility is tolerable due to the repetitive and predictable nature of work in an industrial environment.

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MATHEMATICAL MODELLING

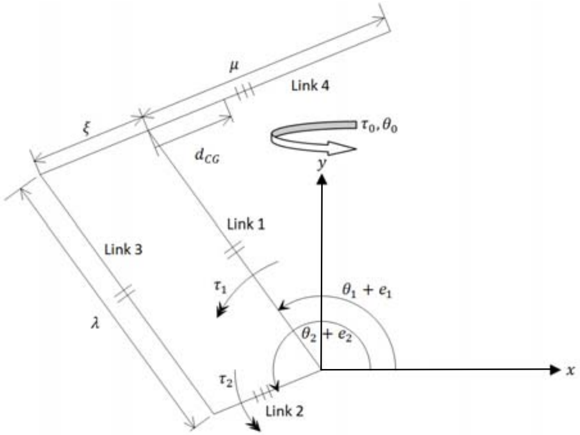

Figure 2: A simplified model of the robot arm

- Robot arm modeled as a four-link system plus a lumped mass at the origin
- The whole system possesses three degrees of rotational freedom, with two degrees of freedom about the global z-axis and one degree of freedom about the global y-axis.

Modelling Assumptions and Simplifications

- Minimal friction
- All elements have uniform mass distribution
- Ignore minor elements, e.g. fasteners and bearings
- Reduce geometry of elements to simple shapes, e.g. cuboids and cylinders

The main objective of the mathematical modeling stage is to obtain the equation of motion of the robot arm and express it in the following form:

$$\mathrm{T} = M(\theta)\ddot{\Theta} + V(\theta,\dot{\theta})\dot{\Theta} + G(\theta)$$

To obtain this result, the kinetic, KE and potential energies, PE of all moving elements need to first be derived, followed by applying Lagrangian mechanics principles to obtain joint reaction torques;

$$\tau_i = \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{\theta}_i}\right) - \frac{\partial L}{\partial \theta_i}$$

where $L = \sum_{i=1}^{4} KE_i - PE_i$

CONTROLLER DESIGN AND SIMULATION

Control performance targets:

1. zero overshoot
2. zero steady-state error
3. critically damped motion

Initial control law development was first attempted using feedback linearization method, which delivered the control law

$$\mathrm{T}_c = V(\theta,\dot{\theta})\dot{\Theta} + G(\theta) + M\ddot{\Theta}_d + MK_d(\dot{\Theta}_d - \dot{\Theta}) + MK_p(\Theta_d - \Theta)$$

From simulations done in Simulink, it appeared that this control law did not satisfy conditions 1 and 3 (likely caused by inaccuracies in the modeling of the system), which merits improving the initial control approach with a sliding mode control scheme, from which a new control law is obtained:

$$\mathrm{T}_c = V(\theta,\dot{\theta})\dot{\Theta} + G(\theta) + M\ddot{\Theta}_d + MK_d(\dot{\Theta}_d - \dot{\Theta}) + MK_p(\Theta_d - \Theta) - M\Gamma\frac{s}{|s| + \sigma}$$

The simulated performance under the improved control scheme appears to satisfy all of the listed targets; Figure 3 below displays the result of the simulation.

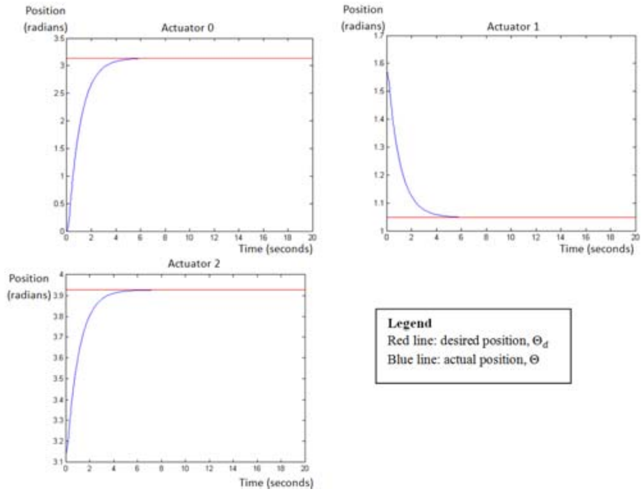

Figure 3: Simulated system response under sliding mode control

IMPLEMENTATION TO REAL-LIFE SYSTEM

- Three Dynamixel AX-12+ servos, programmed to emulate standard DC motors are used as the actuators.
- All servos underwent torque and speed calibration processes to determine the torque and speed resolutions accurately.
- The derived control law is adapted as a Matlab M-File program and used to control the servos, with a USB2Dynamixel interface module acting as the PC-servo interface.

Mechanical Engineering