Dual-Motor Control for Reduction of Backlash in Parallel-Kinematic Robot Joints

Mathias Artursson

Department of Automatic Control

Summary of master thesis *Dual-Motor Control for Reduction of Backlash in Parallel-Kinematic Robot Joints*, June 2018. Master thesis can be found at: `http://www.control.lth.se/publications`

Introduction

A new high-performance robot called the Gantry-Tau robot was developed by ABB Robotics, the Robotics Lab at Lund University and Güdel AG. This robot seemed promising in terms of speed, accuracy, stiffness and bandwidth of the motion control. However, the gears used for moving the robot joints introduced significant backlash into the system. To solve this problem, it was proposed to use two motors to control each joint, where the motors would go in opposite directions to ensure that the motors were in contact with the gears at all times. How this should be implemented is still under development.

The Gantry-Tau robot where the robot joints can be seen in orange.

This master thesis attempted to implement backlash compensation to be used together with the standard robot joint control, comprising position-, velocity- and acceleration-trajectories as well as torque feedforward. The goal was for the joint to have regular control for both motors when following trajectories, except for stationary points where the motors would go in different directions.

Test rack

For the master thesis, a test rack was provided by the Robotics Lab at Lund University and Cognibotics. The inputs to the control system were measurements from position encoders and the outputs were torque references to the motors. The test rack was equipped with a linear encoder measuring the cart position along the rail, and the two motors were equipped with rotary encoders. Using the difference between these encoders, then the position error from the backlash gap was determined to be approximately 260 μm for the primary motor and 160 μm for the secondary motor.

Trajectories

Two trajectories for position, velocity and acceleration were generated for the joint (i.e., the cart location) to follow. These two trajectories were for the joint to either take a step, or for it to oscillate according to a cosine function. In addition to generating desired position, velocity and acceleration for these trajectories, an array was initialised containing information about the next upcoming stationary position point. This was needed for the joint to ahead of time know where the motors should go in different directions.

Control without backlash compensation

The control structure without using any backlash compensation consisted of velocity being controlled with a PI regulator, and position then being controlled with a P regulator through a cascade structure. Torque feedforward was also implemented to help the regulators, where this feedforward consisted of a friction model and a dynamic model.

The friction model was implemented to compensate for friction effects. The magnitude of this model was determined as the torque required to maintain a constant velocity for the joint. The sign of this model was determined as the sign of the velocity trajectory, except for the case when the velocity trajectory became zero. In this case, then the sign of the friction model retained its previous value instead.

The dynamic model was implemented to compensate for dynamic aspects of the joint, as described by classical mechanics. This was done by doing a least squares fit of torque data using measurements of position, velocity and acceleration.

For the case with no backlash compensation, then both motors were fed the same torque at all times.

Control with backlash compensation

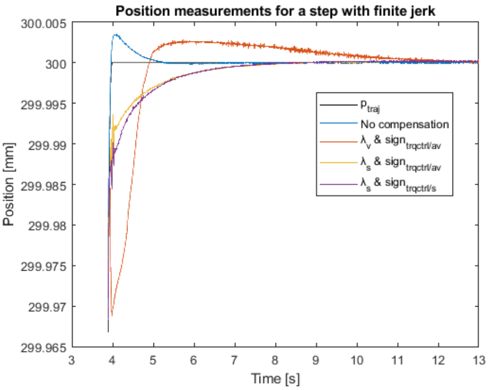
With backlash compensation the second motor was fed a different torque instead. This torque allowed the second motor to start transitioning to going in the opposite direction of the first motor. The transition for the second motor to go in the opposite direction of the first motor, was determined by a switching variable $\lambda \in [0, 1]$, where $\lambda = 1$ indicated the motors going in different directions (torque control) and where $\lambda = 0$ indicated the motors behaving identically (regular control). The direction of the second motor in full torque control ($\lambda = 1$) was supposed to be the opposite direction of the velocity, to ensure that the controlling motor did not have to go through the backlash gap. The direction of the second motor in full torque control was determined by a sign function $\text{sign}_{trqctrl}$ for the second motor.

The variables λ and $\text{sign}_{trqctrl}$ could be obtained in different ways. The variable λ could for example be determined using the velocity trajectory (λ_v) or stationary position points (λ_s). The variable $\text{sign}_{trqctrl}$ could for example be determined using the acceleration and velocity trajectories ($\text{sign}_{trqctrl/av}$), or stationary position points ($\text{sign}_{trqctrl/s}$).

Experimental evaluation

Performance was evaluated with and without external disturbances using either no backlash compensation or backlash compensation with different methods of obtaining λ and $\text{sign}_{trqctrl}$.

When evaluating performance with no external disturbances, then position accuracy using the step trajectory and cosine trajectory was investigated around the regions where torque control was active.



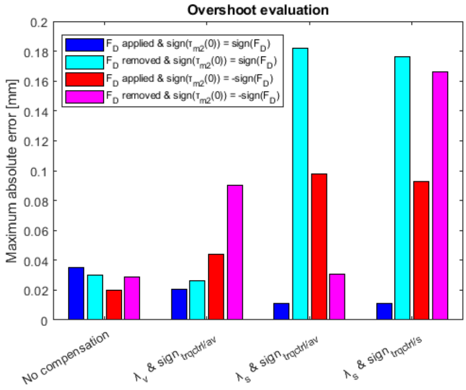
Evaluation of position accuracy without external disturbances using a step trajectory.

Performance with no external disturbances using a step trajectory yielded a very small overshoot when using no backlash compensation. This overshoot was approximately 1% of the position error due to the backlash gap, and was a result of shortcomings of the model used for position control. Using λ_s with either $\text{sign}_{trqctrl/av}$ or $\text{sign}_{trqctrl/s}$ resulted in a more dampened response than using no backlash compensation, and using λ_v resulted in poor performance.

Performance with no external disturbances using a cosine trajectory yielded similar results between all settings.

Performance with external disturbances was evaluated by investigating position overshoot and settling times when a constant disturbance F_D was applied and removed. This was made with different initial signs of the torque for the second motor. An analysis of the backlash traversal was also made for these cases to gain insight into previously observed data. This backlash traversal analysis was made by evaluating the encoder differences from the linear encoder and the rotary encoders in the motors.

Results from the overshoot analysis showed that the best overall performance was achieved using no backlash compensation. There were however cases where using backlash compensation significantly reduced overshoot. Results from the settling time analysis showed that the settling time either increased or remained the same as compared to not using any backlash compensation. The backlash traversal analysis indicated that the backlash compensation yielded poor performance whenever the controlling motor went through the backlash gap.



Overshoot evaluation when the joint was subjected to the external disturbance F_D

Conclusions

From the experiments conducted in this master thesis, it was concluded that using no compensation yielded the best overall results. The investigated backlash compensation methods all generally resulted in worse performance when the disturbance F_D was present, due to the first motor having to go through the backlash gap. However, using a switching variable λ based on stationary position points and using a sign function for torque control $\mathrm{sign}_{trqctrl}$ based on velocity- and acceleration trajectories seemed promising in some cases. Worth noting is that the experiment with the constant disturbance was not ideal, as only one magnitude of the disturbance was used as well as the repeatability of the data not being good. A step disturbance could also introduce mechanical resonances in the system, which would result in bad data. The disturbance used did not cause the joint to traverse far from regions where the switching variable λ was active, which was a big flaw in the experiment.

Future work is primarily to do more testing with a larger variety of external disturbances. The control structure is also in need of improvements, where for example the position overshoots without any compensation should be taken care of. The torque feedforward is also in need of improvements. Investigations could also be made about methods to make it so that the controlling motor does not lose contact for some situations with external disturbances. It could also be experimented to incorporate the torque feedforward model with the switching variable.