Towards improved performance for industrial robots

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The robotics activities within ISIS

- Iterative Learning Control
- Robot trajectory generation and optimization
- Robot modeling and identification
- Robot control
  - Joint level control
  - Multivariable control
  - Sensor fusion
- Robot diagnosis

Common factor for all the activities:

Increased robot performance!
The robot system and its components

- Links
- Joints
- Motors
- Gears
- Bearings

Main problems:
- Flexibilities
- Friction
- Sensor and actuator uncertainties

ISIS activities

- Control design
- Modeling
- Identification
- Trajectory generation and optimization
- Sensor fusion
Robot modeling

- Kinematics
- Elastostatic
- Rigid body dynamics
- Elastodynamic

Joint level modeling

Linear system approximation.
Robot modeling

Non-linear joint model

Non-linear mechanical system (manipulator)

Linear spring and damper (gear-box)
Non-linear joint model

**ISIS activities**

- Control design
- Modeling
- Identification
- Trajectory generation and optimization
- Sensor fusion
Identification

- Choice of excitation signal
- Measurements
- Stochastic disturbances
- Deterministic disturbances
- Transient and stationary behavior
- Non-linear system

ISIS activities

- Control design
- Modeling
- Identification
- Trajectory generation and optimization
- Sensor fusion

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Non-linear joint model

\[
\begin{align*}
&u \\
&J_m \\
&d_1 \\
&k_f \\
&J_{a1} \\
&k \\
&J_{a2} \\
&J_{a3} \\
&\theta_{\text{measured}} \\
&v
\end{align*}
\]

Measured output

SWEDISH OPEN CHAMPIONSHIP IN ROBOT CONTROL

The iterative learning control technique

\[
p_{k+1}(t) = p_k(t) + L e_k(t+1)
\]
The iterative learning control technique

$$p_{k+1}(t) = p_k(t) + L_e(t+1)$$

Iterative Learning Control
Iterative Learning Control

ISIS

DCT

Tower Automotive

80 ABB robots

650 ABB robots

ISIS activities

Control design

Modeling

Identification

Sensor fusion

Trajectory generation and optimization

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The basic idea:

"Use measurements from a sensor mounted at the tool to get better estimates of the position, velocity, and acceleration."

Using additional sensors

What can be achieved?
- Increased robustness
- Higher accuracy
- Increased stiffness
The “true” system

Non-linear mechanical system (manipulator)

Linear spring and damper (gear-box)

Evaluation of arm position estimation

EKF RMSE with/without accelerometer and CRBS
Other possible sensors

ISIS activities

Trajectory generation and optimization

Modeling

Identification

Control design

Sensor fusion

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The trajectory generation problem

Path generation Toolbox in Matlab

\[
p1 = [0.4,0.3,0.9]; \quad p2 = [0.1,0.45,1.1]; \\
p3 = [0.3,0.60,1.1]; \quad p4 = [0.2,0.8,1.1]; \\
zonel = 0.1; \quad zonemethod = 1; \quad v1 = 0.25; \quad v2 = 0.25; \\
esec = emptysec(p1); \\
lsec = moveline(esec,p2,zonel,[],v1); \\
csec = movecirc(lsec,p3,p4,0,1,v2); \\
rpath = makepath(lsec,csec)
\]
Path generation Toolbox in Matlab

Orientation information will be added in PGT v0.3

Dynamic optimization

- Path: \( P(l_c), \phi(l_c) \)
- Path speed and acceleration:

\[
\begin{align*}
\mathbf{v} &= \frac{dP}{dl_c} \frac{dl_c}{dt}, \\
\mathbf{a}_{\text{path}} &= \frac{d^2l_c}{dt^2} \\
\dot{\phi} &= \frac{d\phi}{dl_c} \frac{dl_c}{dt}, \\
\ddot{\phi} &= \frac{d^2\phi}{dl_c^2} \left( \frac{dl_c}{dt} \right)^2 + \frac{d\phi}{dl_c} \frac{d^2l_c}{dt^2}
\end{align*}
\]
Dynamic optimization

Let

\[ l(t) = \frac{a(t-t_p)^2}{2} + v(t-t_p) + l_p, \quad t \in [t_p, t_n] \]

A (sub) optimal minimum time trajectory is found by solving the following LP problem:

\[
\begin{align*}
\max_{\alpha} & \quad \alpha_1 \\
\text{s.t.} & \quad a_{\min} \leq a \leq a_{\max} \\
& \quad 0 \leq v(a) \leq v_d \\
& \quad \dot{\phi}_{\min} \leq \dot{\phi}(a) \leq \dot{\phi}_{\max} \\
& \quad \ddot{\phi}_{\min} \leq \ddot{\phi}(a) \leq \ddot{\phi}_{\max}
\end{align*}
\]
Conclusions

Impact on current and future products

- Auto tune
- Control design

Conclusions

Impact on current and future products

- Iterative Learning Control
- More flexible mechanical design

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Conclusions

Impact on current and future products

- Make better use of the robot performance
- Reduced price

Trajectory generation and optimization

"ISIS has activities in areas central for the future developments in industrial robotics"