Observer-based ILC applied to the Gantry-Tau parallel kinematic robot

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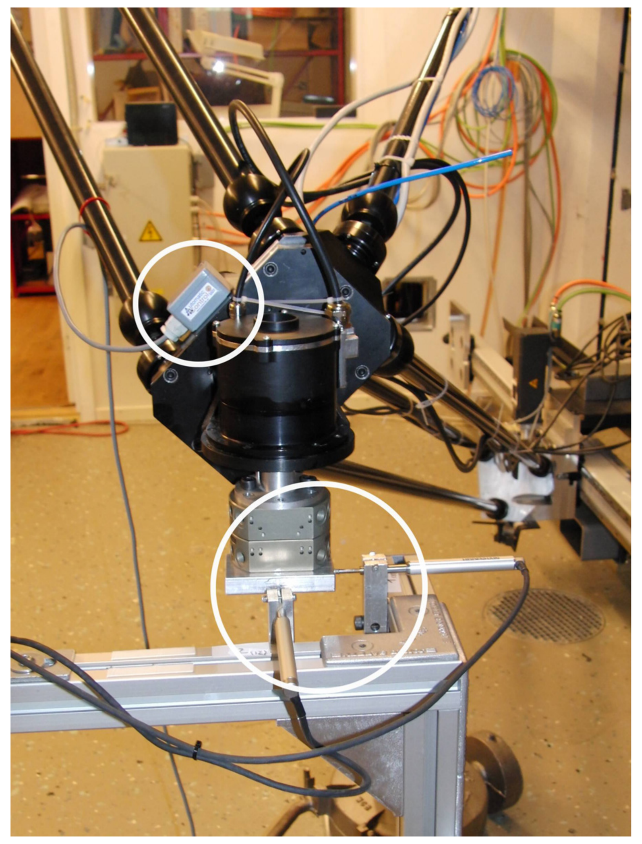
Conclusion

- Illustrated what can be gained by using estimates in ILC algorithms.
- ILC applied to a parallel kinematic robot.
- Error components also above the resonance frequencies of the system are learned.
- ILC combined with a trajectory having lead-in/lead-out.

Tool performance improved by using tool-position estimates in the ILC algorithm, compared to when using motor-angle measurements.

Robot

Gantry-Tau robot controlled by ABB IRC 5 control system with extension. Data from external sensors (accelerometer and length gauges) synchronised with the robot system at 250 Hz.

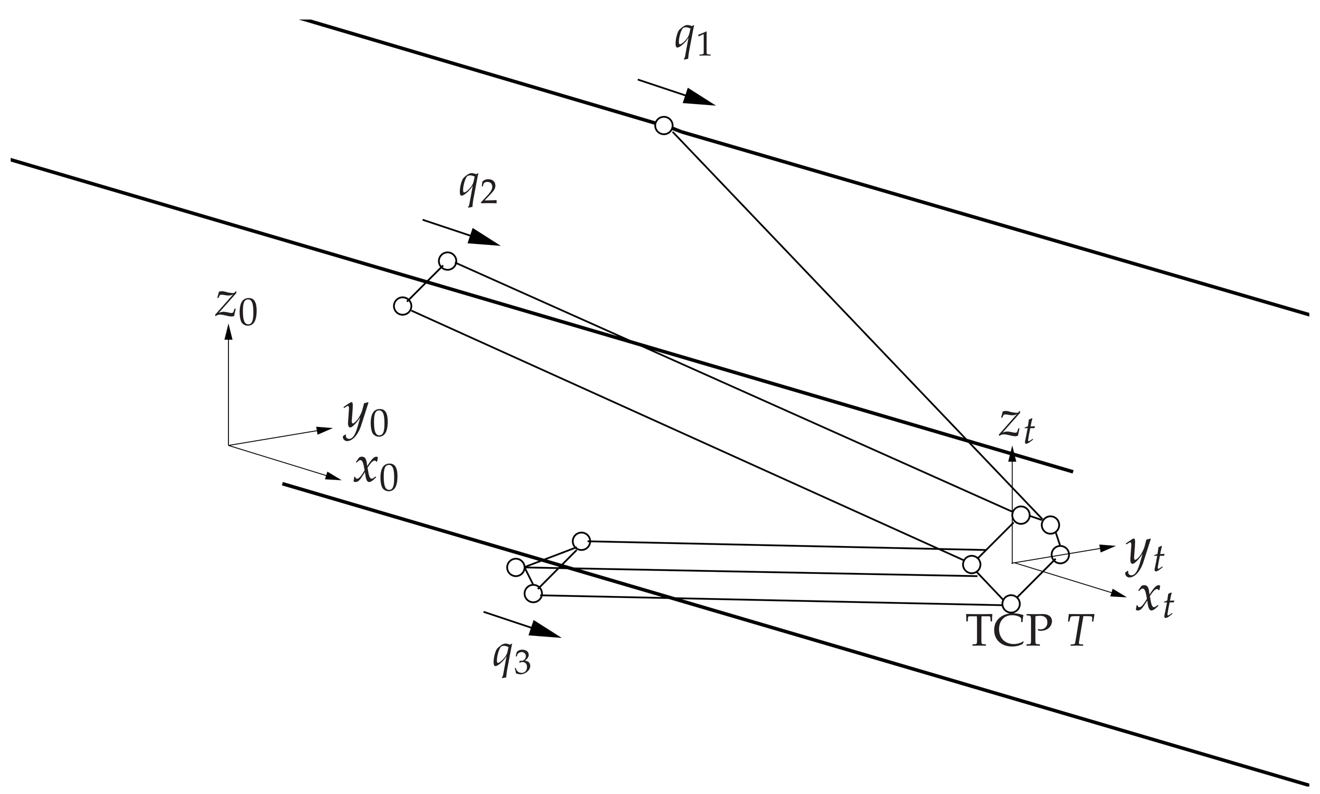


Impulse-response experiments:

- 11.5 Hz in y-direction, dominating
- 7.4 Hz in x-direction, smaller

Tool-position measurements limited to xy-direction. Zero error assumed in z-direction.

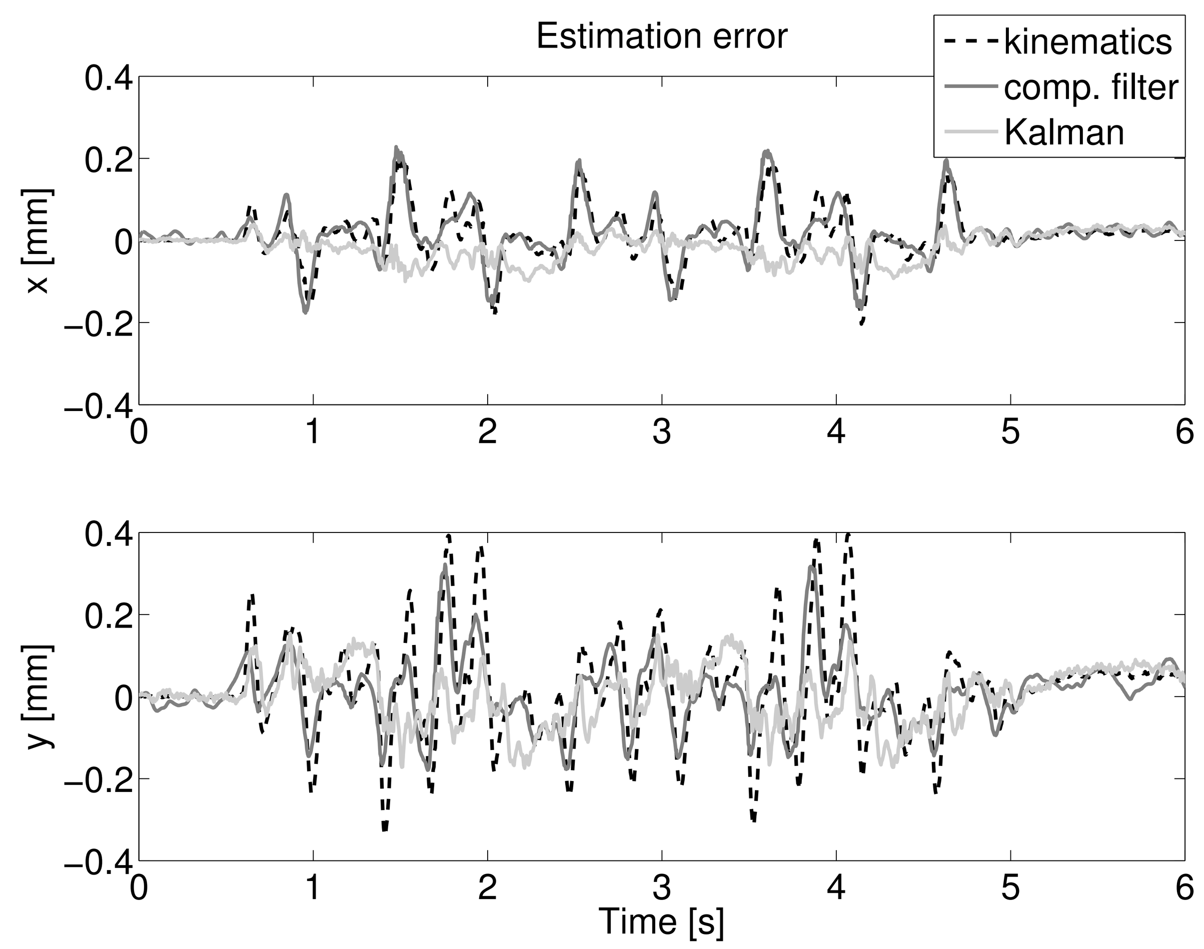
Tool trajectory to be followed with high programmed tool velocity, $v(t) = 100\,\mathrm{mm/s}$.



Estimation of tool position

Case A) Estimate $\hat{z}_k(t)$ by using complementary filter.
Case B) Estimate $\hat{z}_k(t)$ using the Kalman filter.

Error $z(t) - \hat{z}(t)$ for the estimates A-B compared to when using only motor-angles transformed by the robot forward kinematics.



Experiments

Linear discrete-time ILC algorithm

$$u_{k+1}(t) = Q(q)\big(u_k(t) + \gamma q^{\delta} \epsilon_k(t)\big)$$

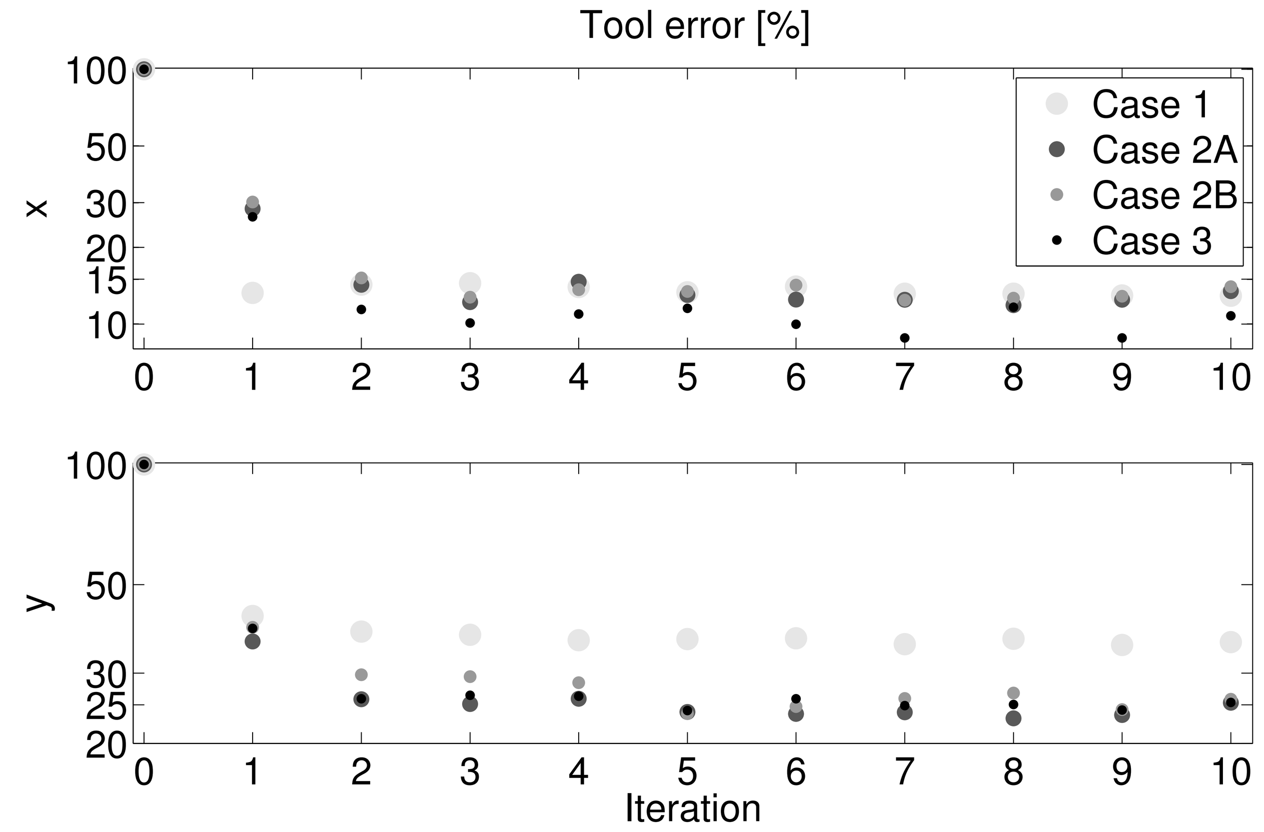
Tuning of filter $Q(q)$ from models, applied by forward-backward filtering. The ILC algorithm based on the errors $\epsilon_k(t)$:

Case 1) Motor-angle measurements, $\epsilon_k(t) = r_y(t) - y_k(t)$.
Case 2) Estimates of tool position, $\epsilon_k(t) = r(t) - \hat{z}_k(t)$, using estimate A or B.
Case 3) Measurements of tool position, $\epsilon_k(t) = r(t) - z_k(t)$ (for comparison).

Reduction of the 2-norm of error at iteration k given in percentage of nominal error $\boldsymbol{e}_{z,i,0} = \boldsymbol{r} - \boldsymbol{z}_{i,0}$ for direction $i = x, y$ as

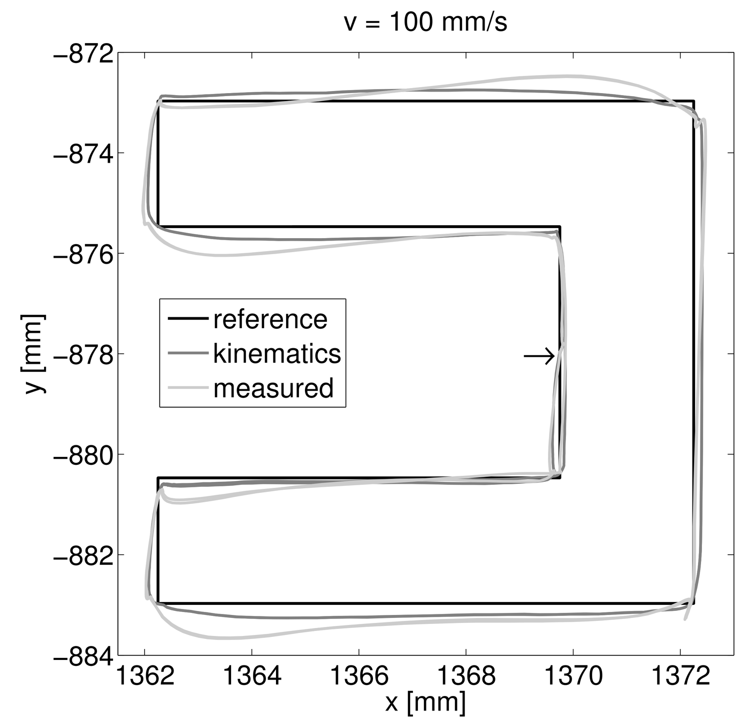
$$\bar{e}_{z,i,k} = 100 \cdot \frac{\|\boldsymbol{e}_{z,i,k}\|_2}{\|\boldsymbol{e}_{z,i,0}\|_2} \quad [\%] \qquad (1)$$

Results



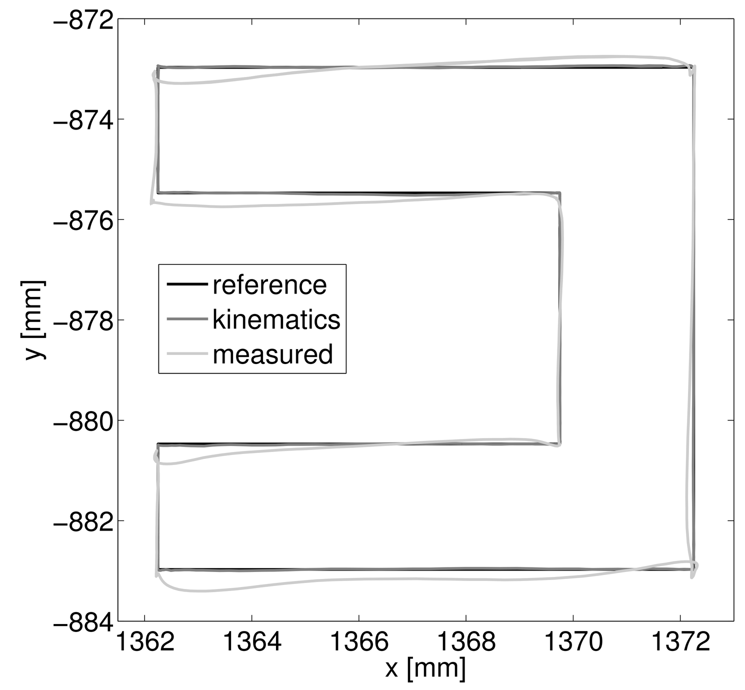
Nominal performance

- *Reference:* Tool reference, equal to motor-angle references transformed by forward kinematics.
- *Kinematics:* Motor angles transformed by forward kinematics.
- *Measured:* Tool position.



Case 1

- Small motor-angle errors remaining.
- Resulting measure (1) large in weaker y-direction.



Case 2

- Improved tool performance compared to results for case 1.
- Measure (1) similar with the measure for case 3.