

Conclusion

- Illustrated what can be gained by using estimates of the controlled variable 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

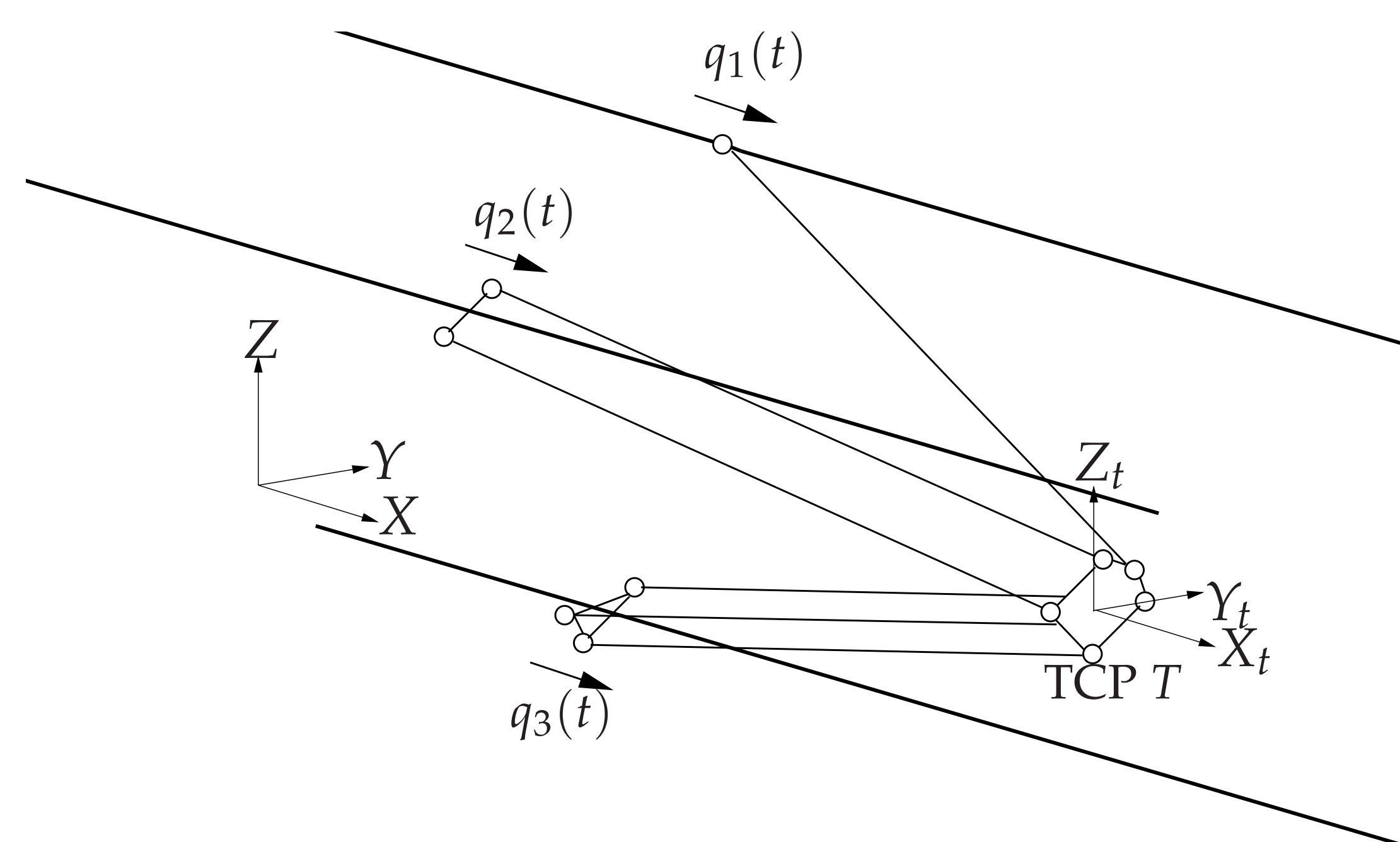
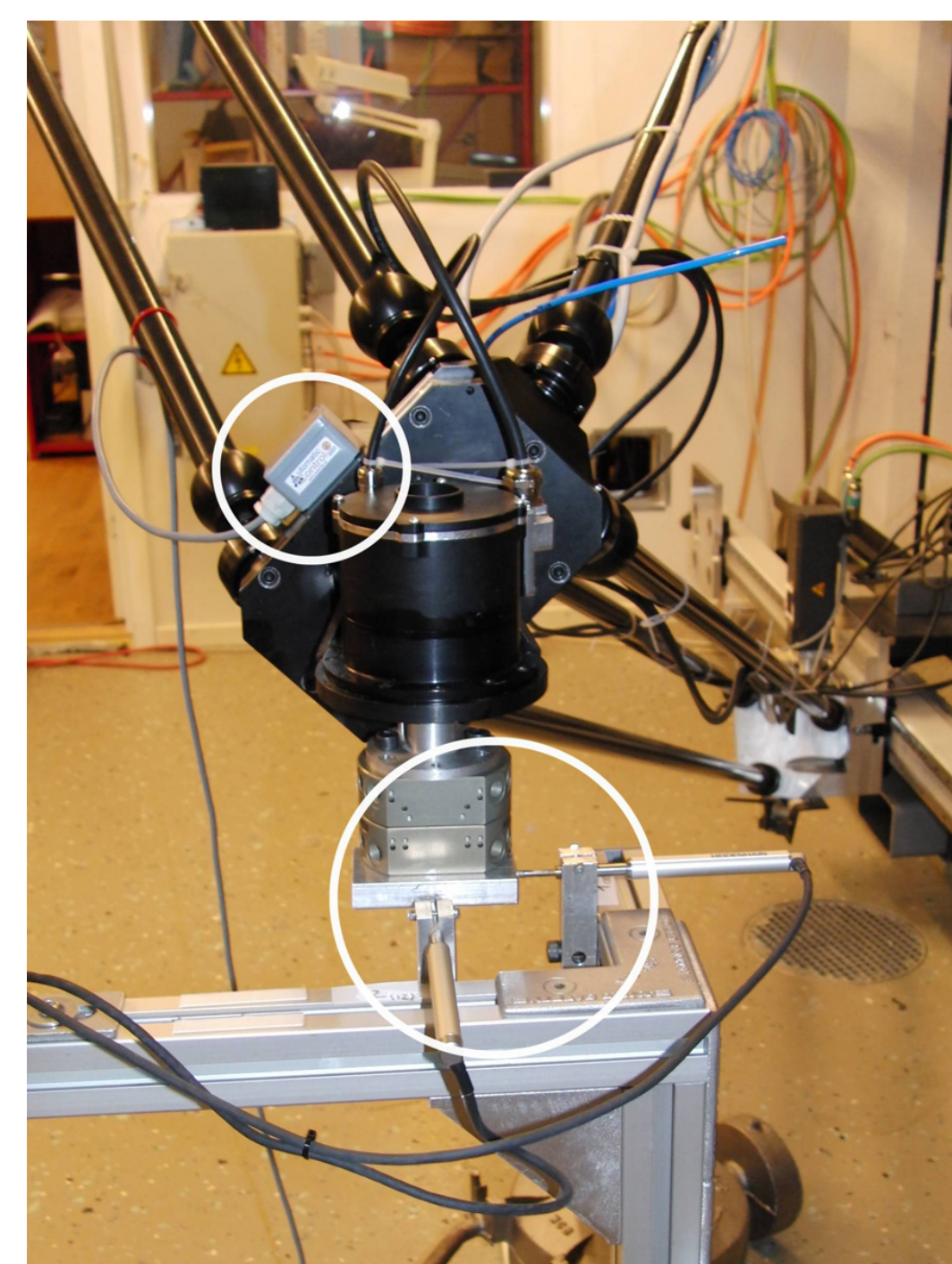
Gantry-Tau robot controlled by ABB IRC5 control system with extension. Data from external sensors (accelerometer and length gauges) synchronised with the robot system at 250 Hz.

Impulse-response experiments give:

- 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.

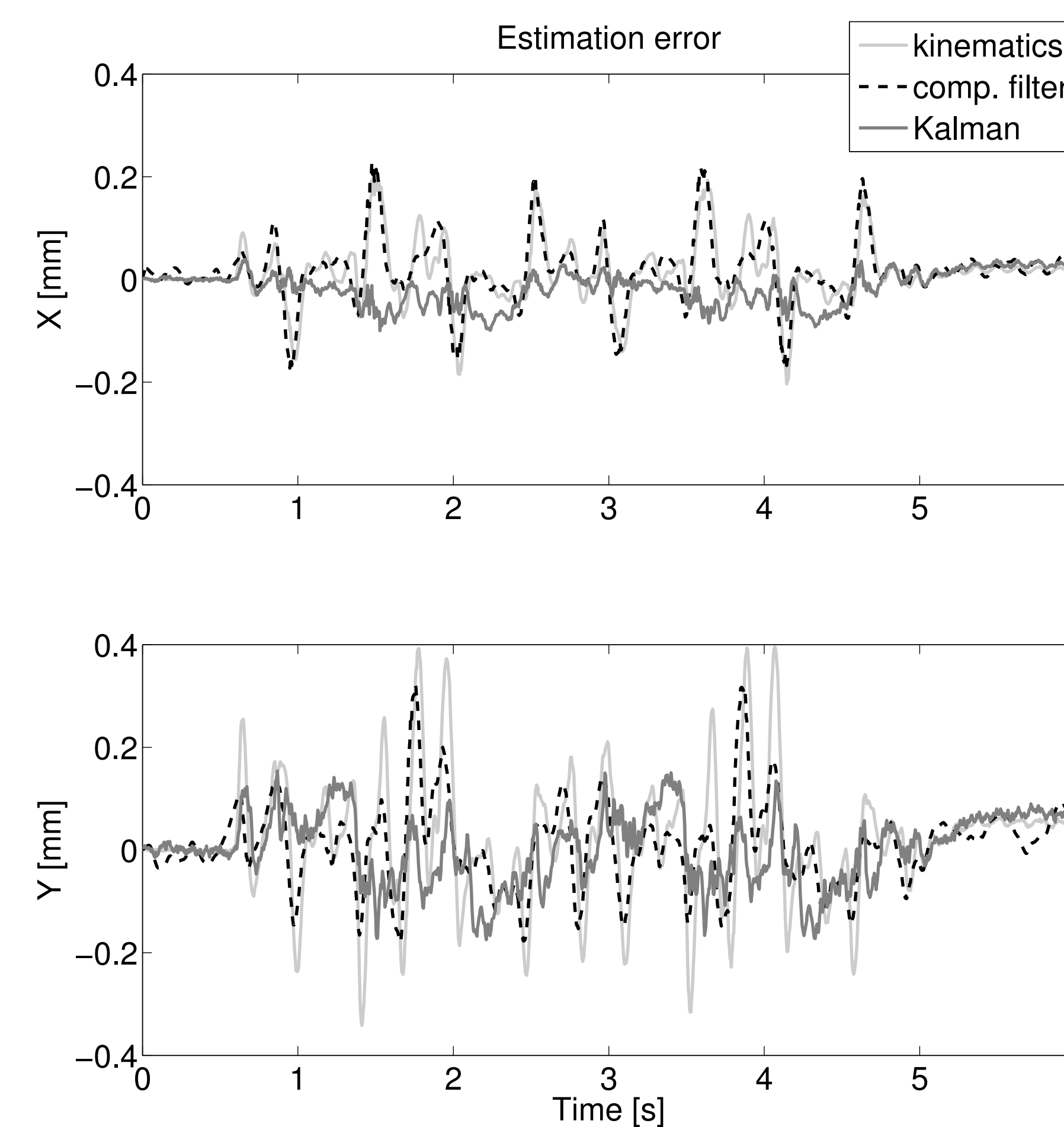
Tool trajectory to be followed with high programmed tool velocity, $v(t) = 100$ mm/s.



Estimation of tool position

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

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

Tuning of filter $Q(q)$ from models, applied by forward-backward filtering.

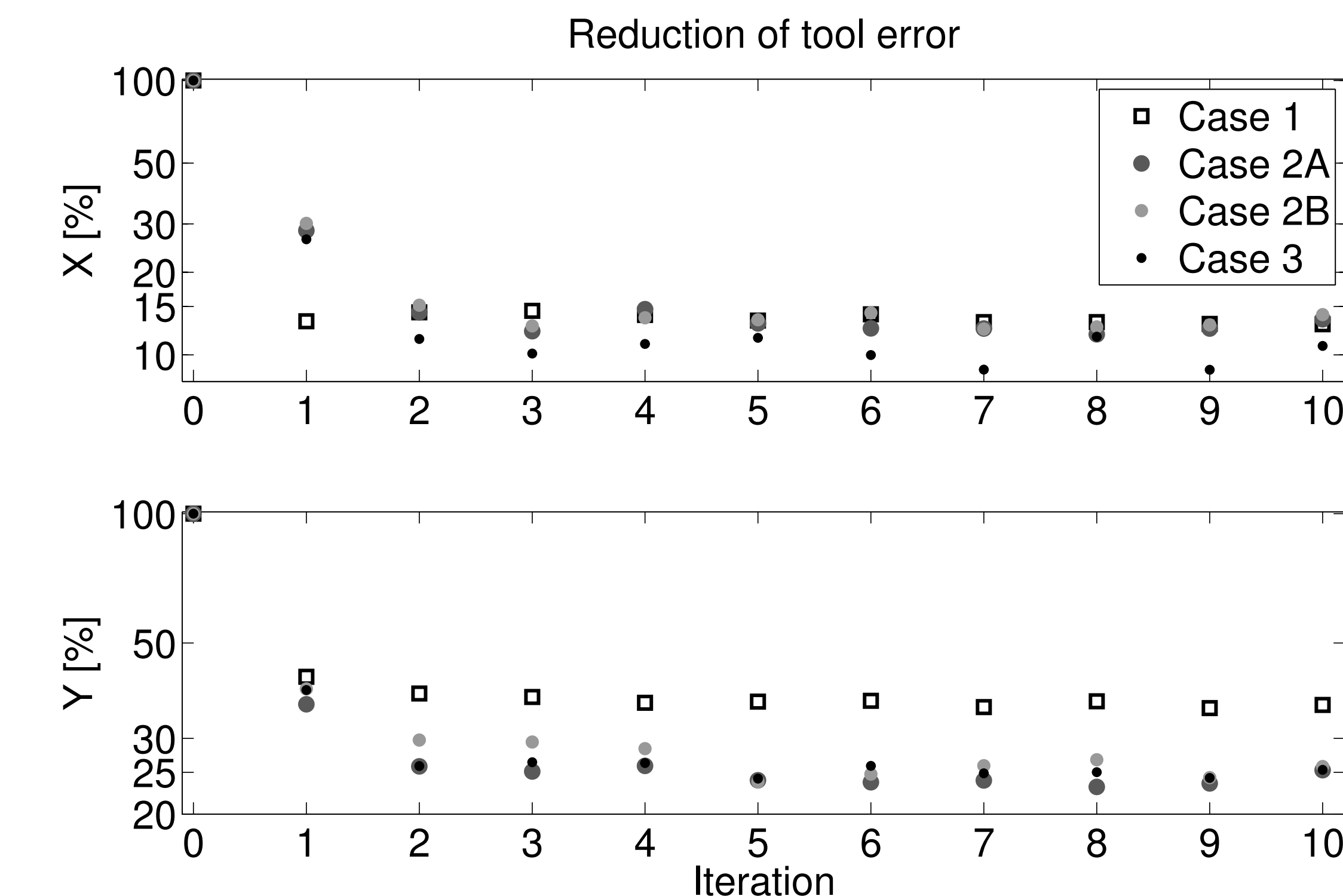
The ILC algorithm based on the errors $\epsilon_k(t)$:

- Case 1) Motor-angle measurements, $\epsilon_k(t) = r_m(t) - q_m(t)$.
- 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 tool error at iteration k given in percentage of nominal error $e_{z,0}^j = r^j - z_0^j$ for direction $j = X, Y$ as

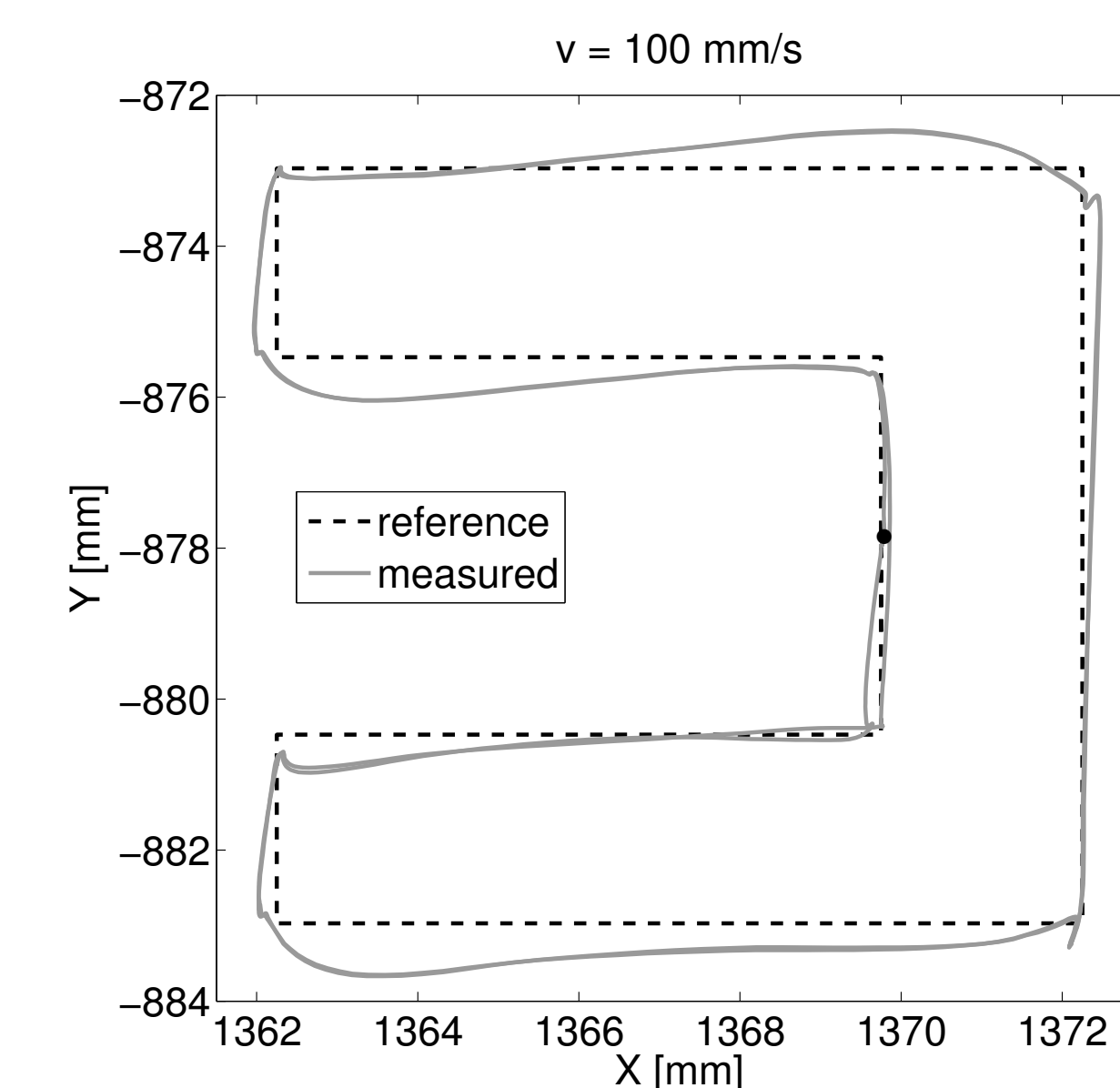
$$\bar{e}_{z,k}^j = 100 \cdot \frac{\|e_{z,k}^j\|_2}{\|e_{z,0}^j\|_2} [\%], \quad j = X, Y \quad (1)$$

Results



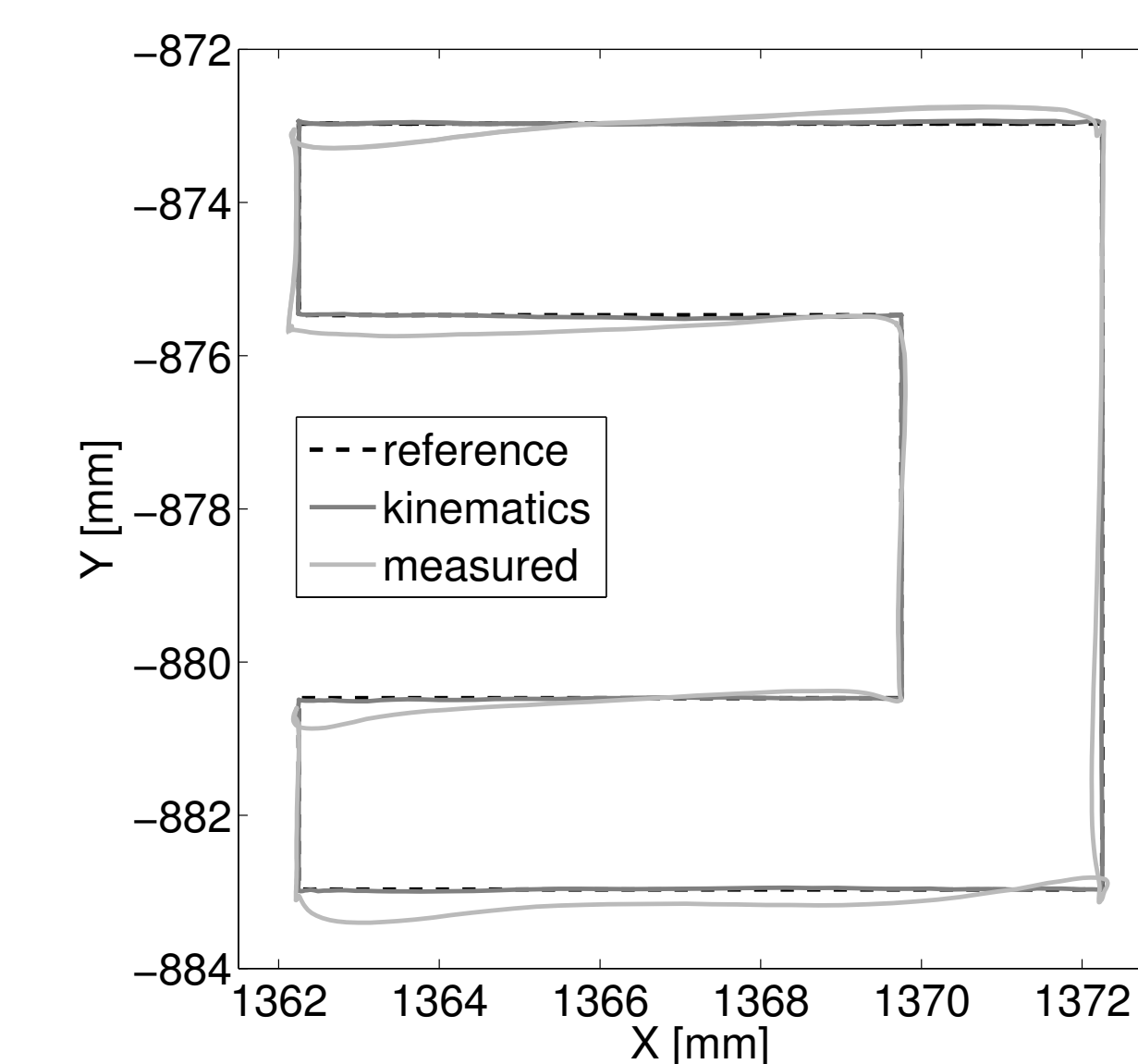
Nominal performance

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



Case 1

- *Kinematics*: Motor angles transformed by forward kinematics.
- 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.

