Robot tool position estimation using an IMU

Erik Hedberg, Johan Norén, Mikael Norrlöf, Svante Gunnarsson

Summary

Robot tool position estimates from forward kinematics and inertial measurements were fused using a complementary filter (CF) and an extended Kalman filter (EKF) respectively.

Setup

- 6-DOF industrial robot with motor joint angle sensors
- High performance IMU (STIM-300) mounted on tool
- Accurate position ground truth from laser tracker system

Complementary filter

Inertial measurements were rotated to world coordinate frame and integrated to obtain position estimates p_{imu}. They were then fused with the kinematic estimates p_{fk} in the following manner:

$$\hat{P}(s) = G(s)\hat{P}_{fk}(s) + (1 - G(s))\hat{P}_{imu}(s)$$

$$\hat{p}_{fk} = p + e_1, \quad \hat{p}_{imu} = p + e_2$$

Where $G(s)$ is a lowpass filter with cut-off frequency 30Hz. Thus the filtering acts only on the error, illustrating why complementary filtering is also called distortionless filtering.

Extended Kalman Filter

The EKF was implemented using a constant translational acceleration and constant angular velocity model for the robot tool. Noise covariances were tuned using a genetic optimization algorithm, and the resulting process noise covariance totally dominated the measurement noise covariance, expressing the same beliefs as the assumptions behind the CF.

Results

Evaluation was performed on two trajectories, the first a cube with a brief stop at each corner and the second the so-called ISO trajectory representing motion typical in industrial applications. Figure 1 and 2 illustrates typical performance for the two trajectories. The error peaks of the forward kinematics shown in Figure 2 corresponds to changes of direction in the ISO trajectory.

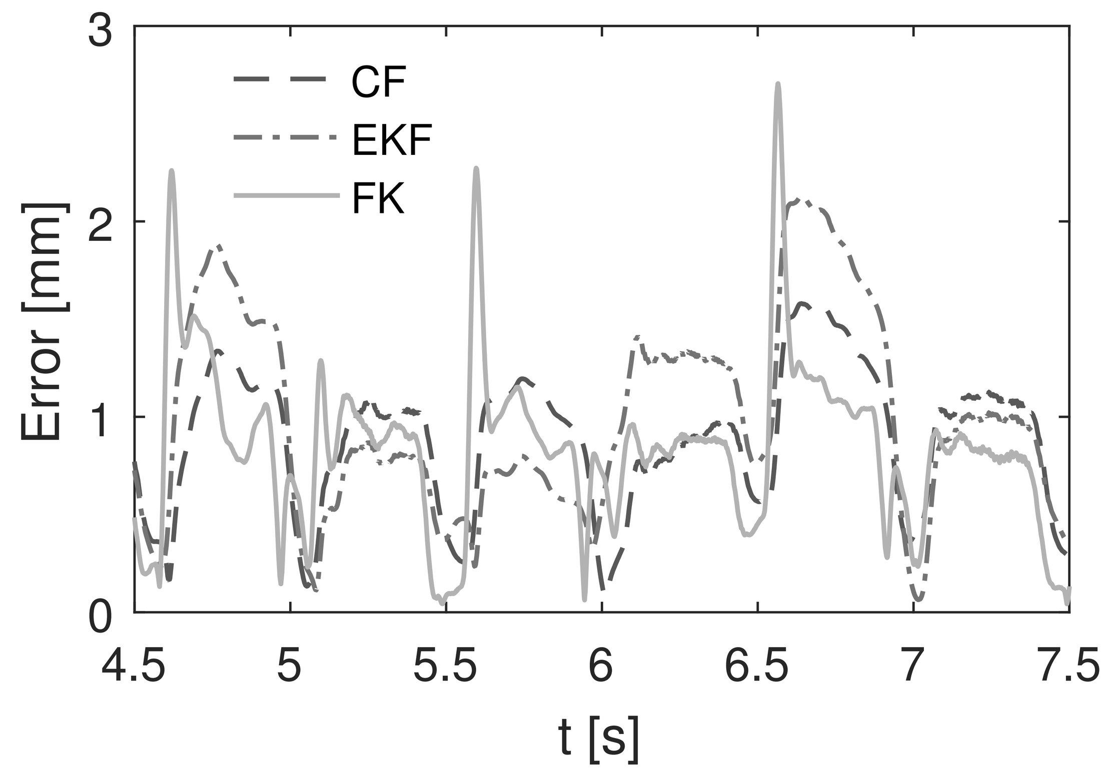

Figure 1: Cube trajectory, target speed 80mm/s.

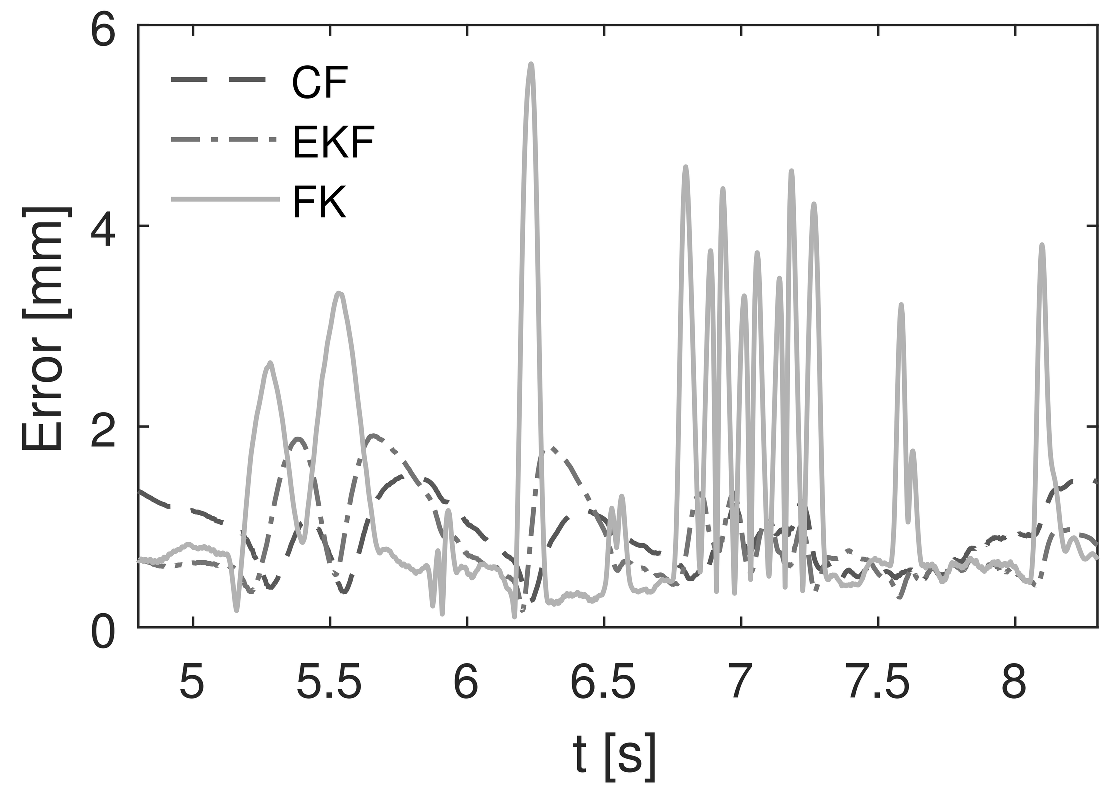

Figure 2: ISO trajectory, target speed 200mm/s.

The table below summarizes the results in terms of root mean square error in mm:

Trajectory	CF	EKF	FK
ISO (fast)	0.95	0.94	1.44
Cube (slow)	0.81	0.93	0.79

Conclusions

- The complementary filter and EKF performed similarly, with the complementary filter being computationally cheaper.
- Inertial measurements were beneficial only during large dynamic excitation, suggesting improvement is possible by assuming variable noise variance in the filtering.

LINKÖPING UNIVERSITY
LINK-SIC
LINKÖPING UNIVERSITY
DIVISION OF AUTOMATIC CONTROL