A novel method for fast identification of a machine tool selected point temperature rise based on an adaptive unscented Kalman filter

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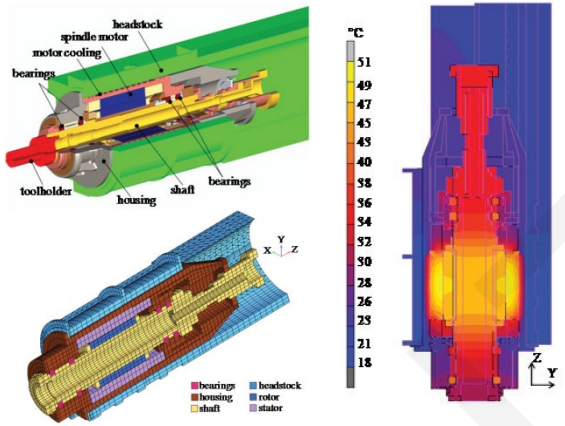
State-of-the art of thermal characteristics identification

In precision machine tools, up to 75% of the overall geometrical errors of machined workpieces can be induced by the effects of temperatures. –Mayr J et al. Thermal issues in machine tools

Temperature field distribution and selected points temperature rise

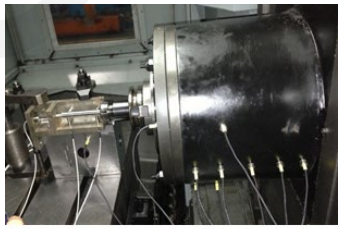
Numerical simulation by FEM



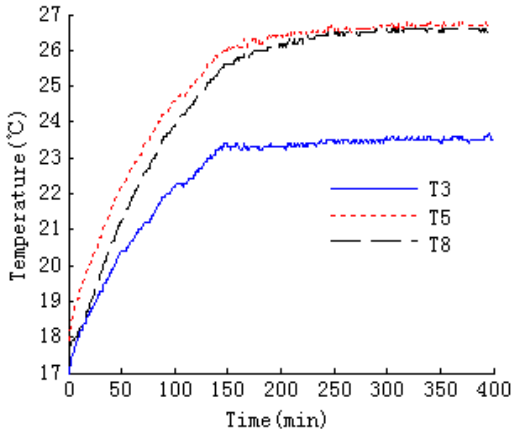
Disadvantage:
Inaccurate result with the actual situation because thermal boundary conditions in FEM are simplified and estimated

Temperature rise tests

machine tool



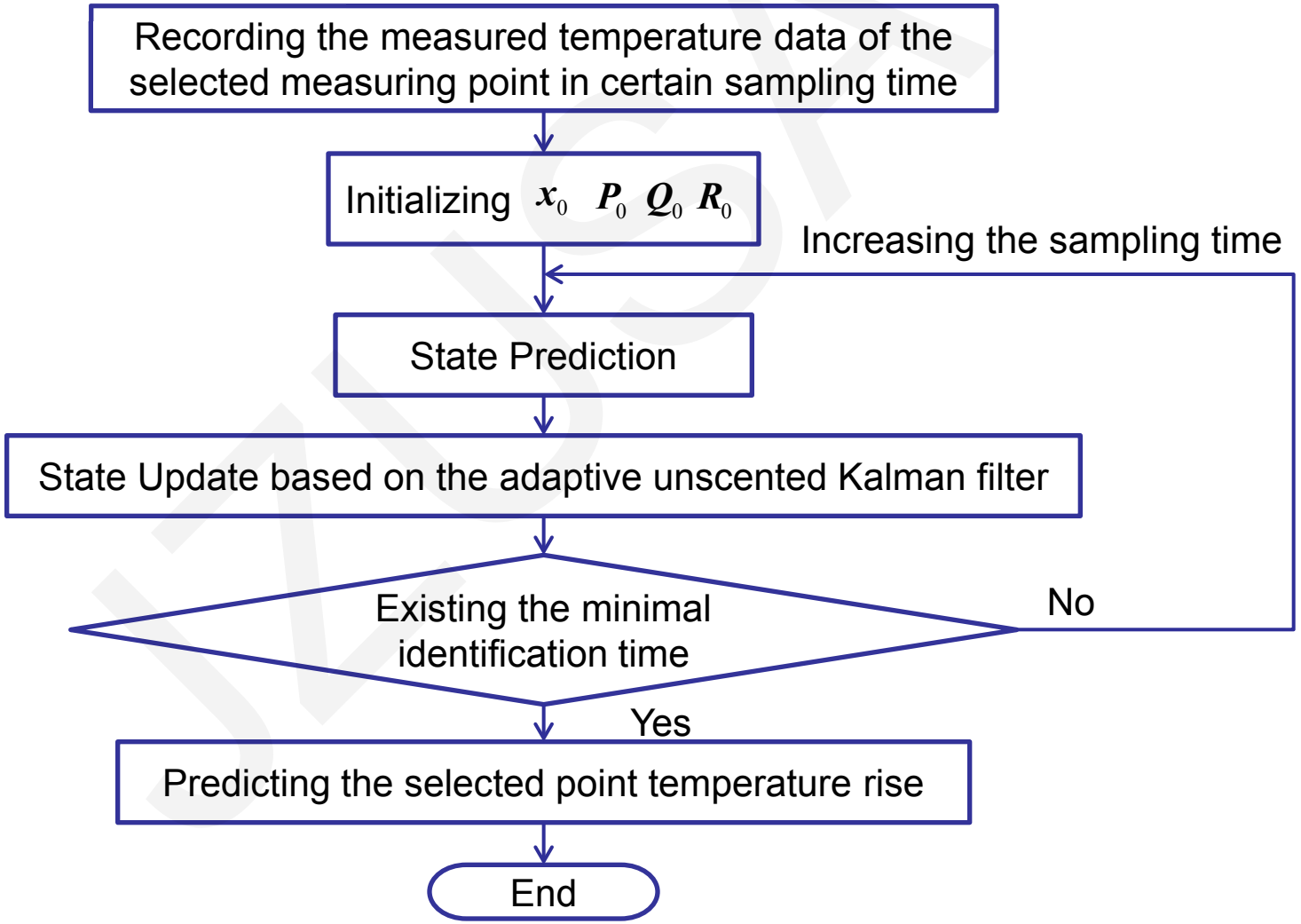
Temperature sensors



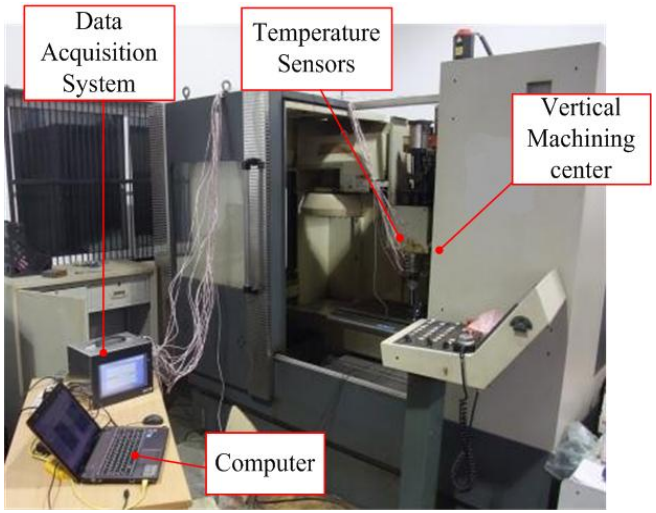
Disadvantage:
Too long time for temperature rise tests like 3 to 6 h

Fast identification of temperature rise based on an adaptive unscented Kalman filter

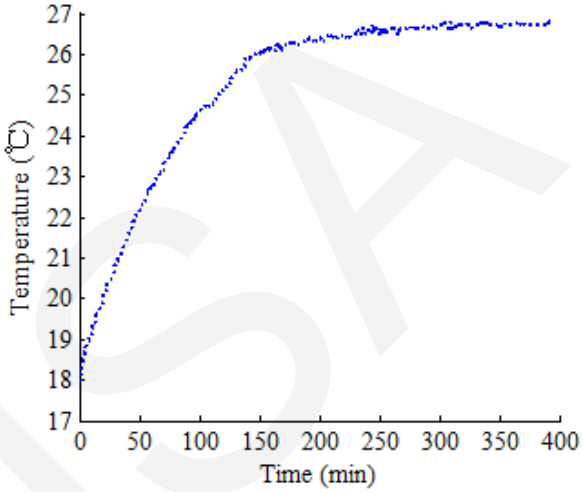
Flowchart of the method



Application of the fast identification method based on the adaptive UKF



The temperature rise test system



The measured temperature of a selected point

Experiment condition

- Room temperature – 17.9℃
- Spindle speed – 5000 r/min
- Sampling interval – 1 min

Definitions of thermal equilibrium state and thermal equilibrium time

When the temperature reaches to 95% of the maximum temperature rise, this state is called thermal equilibrium state, and that moment is thermal equilibrium time.

Initialized parameters

$$\hat{\boldsymbol{x}}_0 = \boldsymbol{x}_0 = \begin{bmatrix} T_0 & \lambda_0 & T_{\infty,0} \end{bmatrix}^{\mathrm{T}} = \begin{bmatrix} 10 & 0.01 & 30 \end{bmatrix}^{\mathrm{T}}$$

$$\boldsymbol{P}_0 = \mathrm{diag}\{0.5^2, 0.1^2, 0.1^2\}$$

$$\boldsymbol{Q}_0 = \mathrm{diag}\{0.001^2, 0.001^2, 0.001^2\}$$

$$\boldsymbol{R}_0 = 0.001^2$$

$$\boldsymbol{q}_0 = \mathrm{diag}\{0.001, 0.001, 0.001\}$$

$$\boldsymbol{r}_0 = 0.001$$

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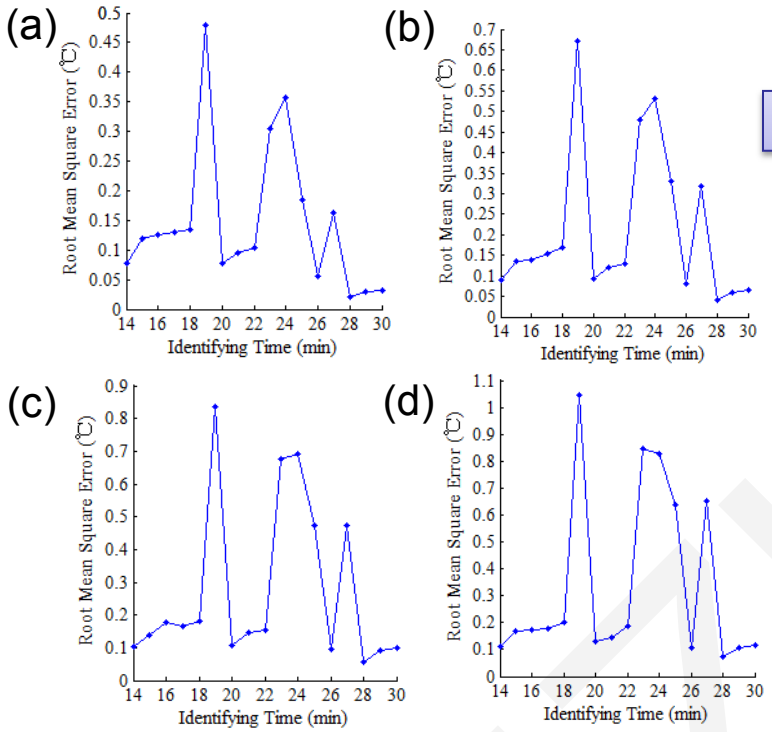
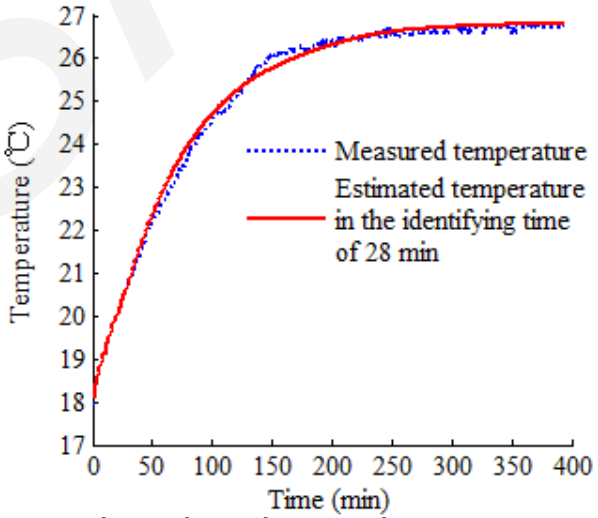


The change in RMSE with different identifying times for different sampling periods of the selected point: (a) 35 min; (b) 40 min; (c) 45 min; (d) 50 min

From these four figures, we can easily see that the RMSE is minimal at the same identifying time of 28 min. Therefore, the selected point temperature rise can be predicted accurately within 28 min.



Measured and estimated temperature rise of the selected point based on UKF with model adaptation

	Estimated	Measured
Steady-state temperature (℃)	26.797	26.7
Thermal equilibrium time (min)	197	195

Application of the fast identification method based on the adaptive UKF

A comparison of results from the unscented Kalman filter with and without model adaptation

The same initialized parameters

$$\hat{\boldsymbol{x}}_0 = \boldsymbol{x}_0 = \begin{bmatrix} T_0 & \lambda_0 & T_{\infty,0} \end{bmatrix}^{\mathrm{T}} = \begin{bmatrix} 10 & 0.01 & 30 \end{bmatrix}^{\mathrm{T}}$$

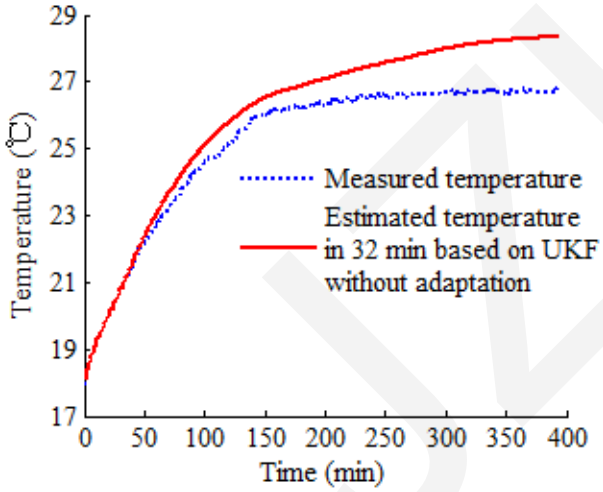
$$\boldsymbol{P}_0 = \mathrm{diag}\{0.5^2, 0.1^2, 0.1^2\}$$

$$\boldsymbol{Q}_0 = \mathrm{diag}\{0.001^2, 0.001^2, 0.001^2\}$$

$$\boldsymbol{R}_0 = 0.001^2$$

$$\boldsymbol{q}_0 = \mathrm{diag}\{0.001, 0.001, 0.001\}$$

$$r_0 = 0.001$$



Measured and estimated temperature rise of the selected point based on UKF without adaptation

Without adaptation, Q and R remain unchanged over time so that they do not match the true covariances in the real system. Therefore, the prediction of the selected point temperature rise is not good.

Conclusions

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Two advantages

- Predict the temperature rise in a short measuring time, 28 min in the application.
- Adaptive unscented Kalman filter is used to decrease the influence of external perturbations on temperature rise prediction.