Design and Implementation of sensor fusion techniques in digital motion control of mobile robots with low resolution encoders and accelerometers

Abstract

The implementation of an educational micromouse is presented in this paper. The micromouse is cost-effective because sensor fusion and time-based diagonal maze solving algorithms are devised to improve the resolution of low-cost home-made encoders with accelerometers, and its performance. The related contests are fun for students such that the micromouse is a suitable project for senior undergraduate students to learn about mobile robots. Although the educational micromouse uses toy dc motors (~$USD 3 each) and home-deceleration, although extra torque is needed in making turns. For 4 robot, whose objective is mainly on its cost (under USD$100)

Hardware development of an educational micromouse

The educational micromouse is a 4-wheel differential driven robot, whose objective is mainly on its cost (under USD$100) and not sacrificing too much of its performance. The reason for 4-wheel differential driven configuration is the higher coefficient of friction it can provide during acceleration and deceleration. The use of toy dc motors (~$USD 3 each) and home-deceleration is the key of cost reduction in comparisons with the dc servo motors adopted by most international contestants. Since the resolution of the home-made encoders is quite low (6 pulses per revolution), an inertia measurement unit (IMU) is also included in the micromouse for sensor fusion algorithms to improve the position and velocity estimates.

Sensor Fusion Algorithms

Observer-based

\[
\begin{align*}
\dot{\hat{p}}_c &= \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} f_c + k_v \left[ p_c - \hat{p}_c \right], \\
\hat{p}_c &= \begin{bmatrix} 1 & 0 \end{bmatrix} f_c
\end{align*}
\]  

\[ a_x \]  

The control gains can be easily decided with the idea of damping ratio ζ and natural frequency \( \omega_n \) by setting \( k_p = \omega_n^2 \), and \( k_v = 2\zeta \omega_n \).

Kalman filter based

Predictor:

\[
\begin{align*}
\hat{p}_k (k+1) &= \hat{p}_k (k) + H \hat{x}_k (k) + L (w_k - \hat{u}_k (k)), \\
\hat{x}_k (k+1) &= \hat{x}_k (k) + H \hat{x}_k (k) + L (w_k - \hat{u}_k (k)),
\end{align*}
\]  

Where \( P_k (k) = E[\hat{x}_k (k) \hat{x}_k (k)^T] \) is the covariance matrix for \( e_k (k) \), and \( P_k (k+1) = E[\hat{x}_k (k+1) \hat{x}_k (k+1)^T] \) is the covariance matrix for \( e_k (k) \). \( P_k (k) = E[\hat{x}_k (k) \hat{x}_k (k)^T] \) is the covariance matrix for \( e_k (k) \), and \( Q_k = E[w(k)w^T (k)] \) is the covariance matrix of the input disturbance, \( w(k) \).

Updator:

\[
\begin{align*}
K_{k+1} & = P_k (k+1) H^T (HP_k (k+1) H^T + R_{k+1})^{-1}, \\
\hat{x}_{k+1} (k) &= \hat{x}_{k+1} (k) + K_{k+1} (\hat{z}_{k+1} - H \hat{x}_k (k) - R_{k+1}), \\
P_{k+1} (k+1) &= P_k (k+1) - K_{k+1} H P_k (k+1).
\end{align*}
\]

Conclusions

An educational micromouse is designed and implemented in this project with cost under USD$100 for international contests and mobile robot education. To make the micromouse competitive, two new sensor fusion algorithms for improving the resolution of position and velocity estimations and a time based diagonal maze solver are also devised and presented. Although the educational micromouse uses toy dc motors, it still manages to run as fast as 3 m/s and won the 6th place in the 2017 international APEC micromouse contest, the 3rd prize in the 2017 micromouse Portuguese contest.