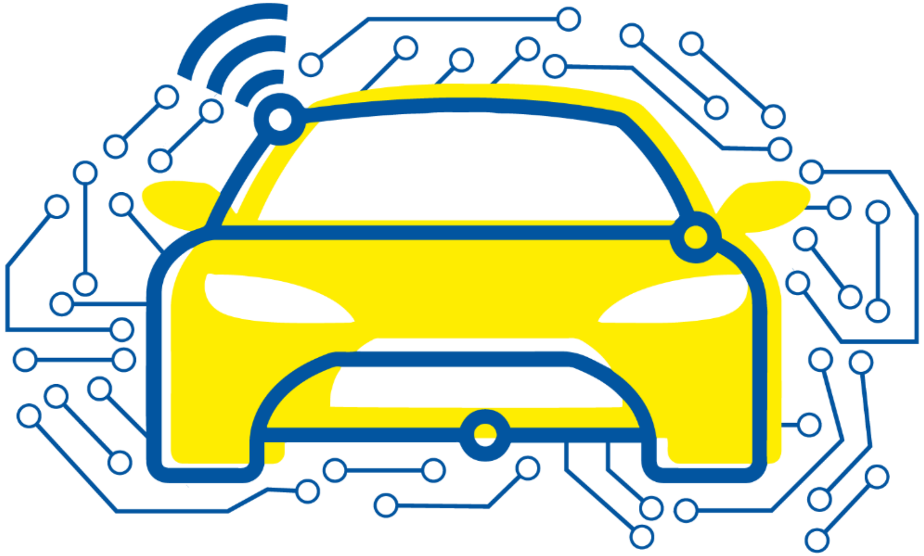
Automated and Connected Driving Challenges

Section 3 – Object Fusion and Tracking

Object Fusion

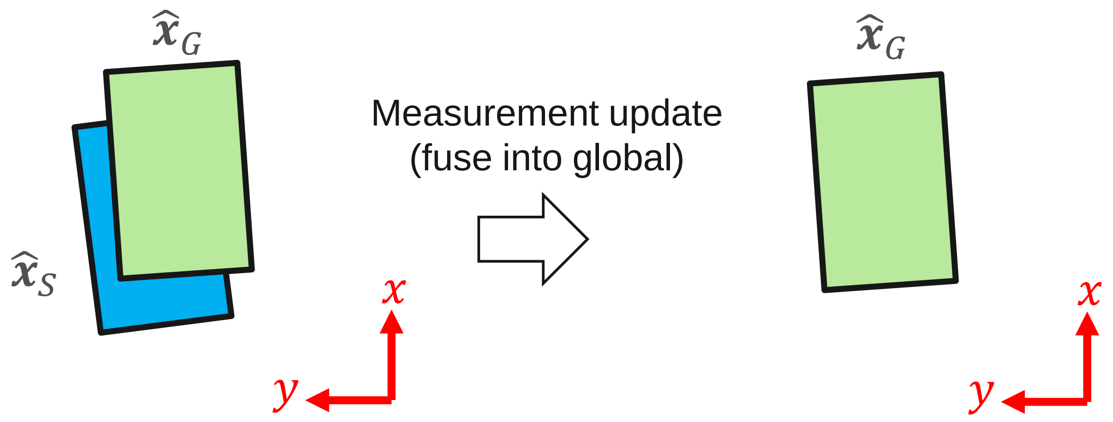


Bastian Lampe

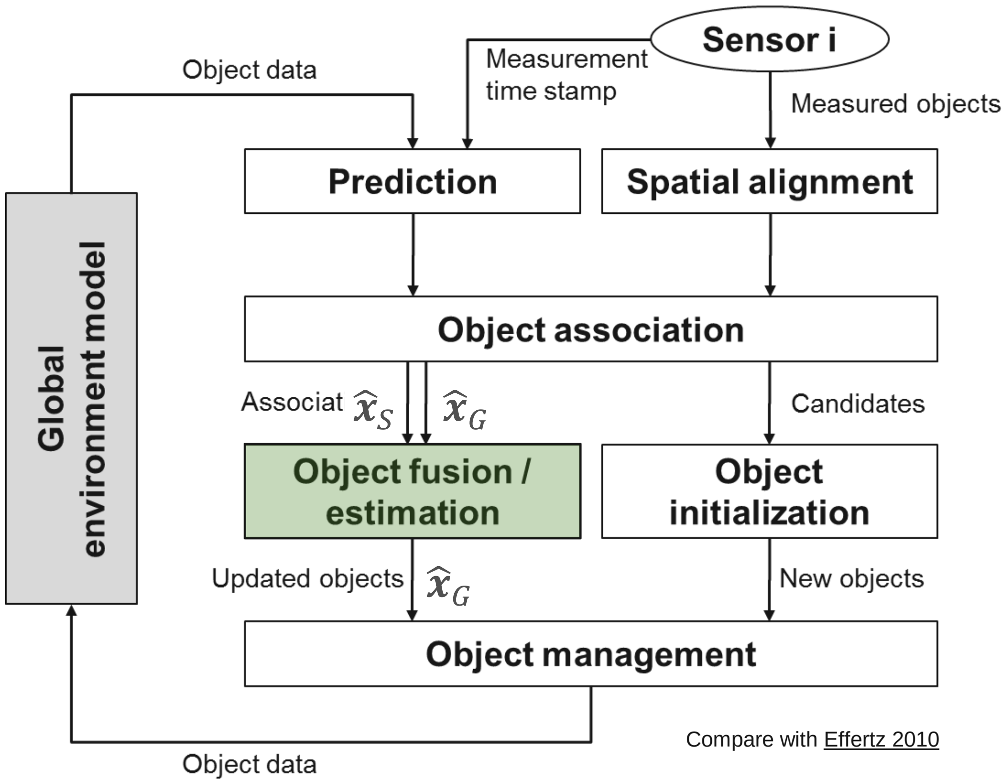
Institute for Automotive Engineering

Object Fusion and Tracking

Object Fusion



- Fuse the recently measured $\hat{x}_S$ into the predicted existing global object $\hat{x}_G$ to get an updated estimate $\hat{x}_G$
- Weigh measurement $\hat{x}_S$ and prediction of $\hat{x}_G$ according to their error covariances
  - Large error covariance → less weight in estimation



Compare with Effertz 2010

Object Fusion and Tracking

Object Fusion

Kalman Filter update step summary:

Fuse $\hat{\boldsymbol{x}}_S$ into $\hat{\boldsymbol{x}}_G$, taking into account their uncertainties $\boldsymbol{P}_S$ and $\boldsymbol{P}_G$

$\boldsymbol{z} = \boldsymbol{C}\hat{\boldsymbol{x}}_S$ (measurement: obtain only these variables that are actually measured. $\boldsymbol{C}$ maps full state space to measured state space)

$\boldsymbol{R} = \boldsymbol{C}\boldsymbol{P}_S\boldsymbol{C}^T$ (measurement error covariance; in measurement space)

$$\begin{array}{c}
\begin{array}{cccccccccc} x & y & z & v_x & v_y & a_x & a_y & l & w & h \end{array} \\
\boldsymbol{C} = \begin{bmatrix}
1 & & & & & & & & & \\
 & 1 & & & & & & & & \\
 & & & 1 & & & & & & \\
 & & & & 1 & & & & & \\
 & & & & & & & 1 & & \\
 & & & & & & & & 1 &
\end{bmatrix}
\end{array}$$

"Measurement matrix $\boldsymbol{C}$": in this example, the input sensor system provides measurements for all state variables except z, a_x, a_y, and h

Object Fusion and Tracking

Object Fusion

Kalman Filter update step summary:

Fuse $\hat{\boldsymbol{x}}_S$ into $\hat{\boldsymbol{x}}_G$, taking into account their uncertainties $\boldsymbol{P}_S$ and $\boldsymbol{P}_G$

$\boldsymbol{z} = \boldsymbol{C}\hat{\boldsymbol{x}}_S$ (measurement: obtain only these variables that are actually measured. $\boldsymbol{C}$ maps full state space to measured state space)

$\boldsymbol{R} = \boldsymbol{C}\boldsymbol{P}_S\boldsymbol{C}^T$ (measurement error covariance; in measurement space)

$\tilde{\boldsymbol{y}} = \boldsymbol{z} - \boldsymbol{C}\hat{\boldsymbol{x}}_G$ (innovation: direction from G (“global”) to S (“sensor”))

$\boldsymbol{S} = \boldsymbol{R} + \boldsymbol{C}\boldsymbol{P}_G\boldsymbol{C}^T$ (innovation error covariance: uncertainty of going into that direction)

$$\boldsymbol{C} = \begin{array}{c} \begin{array}{cccccccccc} x & y & z & v_x & v_y & a_x & a_y & l & w & h \end{array} \\ \begin{bmatrix} 1 & & & & & & & & & \\ & 1 & & & & & & & & \\ & & & 1 & & & & & & \\ & & & & 1 & & & & & \\ & & & & & & & 1 & & \\ & & & & & & & & 1 & \end{bmatrix} \end{array}$$

“Measurement matrix $\boldsymbol{C}$”: in this example, the input sensor system provides measurements for all state variables except z, a_x, a_y, and h

Object Fusion and Tracking

Object Fusion

Kalman Filter update step summary:

Fuse $\hat{\boldsymbol{x}}_S$ into $\hat{\boldsymbol{x}}_G$, taking into account their uncertainties $\boldsymbol{P}_S$ and $\boldsymbol{P}_G$

$\boldsymbol{z} = \boldsymbol{C}\hat{\boldsymbol{x}}_S$	(measurement: obtain only these variables that are actually measured. $\boldsymbol{C}$ maps full state space to measured state space)
$\boldsymbol{R} = \boldsymbol{C}\boldsymbol{P}_S\boldsymbol{C}^T$	(measurement error covariance; in measurement space)
$\tilde{\boldsymbol{y}} = \boldsymbol{z} - \boldsymbol{C}\hat{\boldsymbol{x}}_G$	(innovation: direction from G (“global”) to S (“sensor”))
$\boldsymbol{S} = \boldsymbol{R} + \boldsymbol{C}\boldsymbol{P}_G\boldsymbol{C}^T$	(innovation error covariance: uncertainty of going into that direction)
$\boldsymbol{K} = \boldsymbol{P}_G\boldsymbol{C}^T\boldsymbol{S}^{-1}$	(Kalman gain: weight factor between staying at $\hat{\boldsymbol{x}}_G$ (K=0) or going to measurement $\boldsymbol{z}$ (K=1))
$\hat{\boldsymbol{x}}_G \coloneqq \hat{\boldsymbol{x}}_G + \boldsymbol{K}\,\tilde{\boldsymbol{y}}$	(fused state estimate: go along innovation direction according to Kalman gain)

$$\boldsymbol{C} = \begin{array}{c} \begin{matrix} x & y & z & v_x & v_y & a_x & a_y & l & w & h \end{matrix} \\ \begin{bmatrix} 1 & & & & & & & & & \\ & 1 & & & & & & & & \\ & & & 1 & & & & & & \\ & & & & 1 & & & & & \\ & & & & & & & 1 & & \\ & & & & & & & & 1 & \end{bmatrix} \end{array}$$

“Measurement matrix $\boldsymbol{C}$”: in this example, the input sensor system provides measurements for all state variables except z, a_x, a_y, and h

Object Fusion and Tracking

Object Fusion

Kalman Filter update step summary:

Fuse $\hat{\boldsymbol{x}}_S$ into $\hat{\boldsymbol{x}}_G$, taking into account their uncertainties $\boldsymbol{P}_S$ and $\boldsymbol{P}_G$

$$\boldsymbol{z} = \boldsymbol{C}\hat{\boldsymbol{x}}_S$$
(measurement: obtain only these variables that are actually measured. $\boldsymbol{C}$ maps full state space to measured state space)

$$\boldsymbol{R} = \boldsymbol{C}\boldsymbol{P}_S\boldsymbol{C}^T$$
(measurement error covariance; in measurement space)

$$\tilde{\boldsymbol{y}} = \boldsymbol{z} - \boldsymbol{C}\hat{\boldsymbol{x}}_G$$
(innovation: direction from G (“global”) to S (“sensor”))

$$\boldsymbol{S} = \boldsymbol{R} + \boldsymbol{C}\boldsymbol{P}_G\boldsymbol{C}^T$$
(innovation error covariance: uncertainty of going into that direction)

$$\boldsymbol{K} = \boldsymbol{P}_G\boldsymbol{C}^T\boldsymbol{S}^{-1}$$
(Kalman gain: weight factor between staying at $\hat{\boldsymbol{x}}_G$ (K=0) or going to measurement $\boldsymbol{z}$ (K=1))

$$\hat{\boldsymbol{x}}_G \coloneqq \hat{\boldsymbol{x}}_G + \boldsymbol{K}\,\tilde{\boldsymbol{y}}$$
(fused state estimate: go along innovation direction according to Kalman gain)

$$\boldsymbol{P}_G \coloneqq (\boldsymbol{I} - \boldsymbol{K}\boldsymbol{C})\boldsymbol{P}_G$$
(fused state uncertainty; required for next time step)

$$\boldsymbol{C} = \begin{array}{c} \begin{array}{cccccccccc} x & y & z & v_x & v_y & a_x & a_y & l & w & h \end{array} \\ \begin{bmatrix} 1 & & & & & & & & & \\ & 1 & & & & & & & & \\ & & & 1 & & & & & & \\ & & & & 1 & & & & & \\ & & & & & & & 1 & & \\ & & & & & & & & 1 & \end{bmatrix} \end{array}$$

“Measurement matrix $\boldsymbol{C}$”: in this example, the input sensor system provides measurements for all state variables except z, a_x, a_y, and h

Object Fusion and Tracking

Object Fusion

Kalman Filter update step summary:

Fuse $\hat{\boldsymbol{x}}_S$ into $\hat{\boldsymbol{x}}_G$, taking into account their uncertainties $\boldsymbol{P}_S$ and $\boldsymbol{P}_G$

$\boldsymbol{z} = \boldsymbol{C}\hat{\boldsymbol{x}}_S$	(measurement: obtain only these variables that are actually measured. $\boldsymbol{C}$ maps full state space to measured state space)
$\boldsymbol{R} = \boldsymbol{C}\boldsymbol{P}_S\boldsymbol{C}^T$	(measurement error covariance; in measurement space)
$\tilde{\boldsymbol{y}} = \boldsymbol{z} - \boldsymbol{C}\hat{\boldsymbol{x}}_G$	(innovation: direction from G (“global”) to S (“sensor”))
$\boldsymbol{S} = \boldsymbol{R} + \boldsymbol{C}\boldsymbol{P}_G\boldsymbol{C}^T$	(innovation error covariance: uncertainty of going into that direction)
$\boldsymbol{K} = \boldsymbol{P}_G\boldsymbol{C}^T\boldsymbol{S}^{-1}$	(Kalman gain: weight factor between staying at $\hat{\boldsymbol{x}}_G$ (K=0) or going to measurement $\boldsymbol{z}$ (K=1))
$\hat{\boldsymbol{x}}_G \coloneqq \hat{\boldsymbol{x}}_G + \boldsymbol{K}\,\tilde{\boldsymbol{y}}$	(fused state estimate: go along innovation direction according to Kalman gain)
$\boldsymbol{P}_G \coloneqq (\boldsymbol{I} - \boldsymbol{K}\boldsymbol{C})\boldsymbol{P}_G$	(fused state uncertainty; required for next time step)

$$\boldsymbol{C} = \begin{array}{c} \begin{array}{cccccccccc} x & y & z & v_x & v_y & a_x & a_y & l & w & h \end{array} \\ \begin{bmatrix} 1 & & & & & & & & & \\ & 1 & & & & & & & & \\ & & & 1 & & & & & & \\ & & & & 1 & & & & & \\ & & & & & & & 1 & & \\ & & & & & & & & 1 & \end{bmatrix} \end{array}$$

“Measurement matrix $\boldsymbol{C}$”: in this example, the input sensor system provides measurements for all state variables except z, a_x, a_y, and h