## Kalman Filter

Rudolf E. Kalman first published Kalman Filter (KF) in 1960 [5] and this pioneering work deeply influence progress of science and technology so far. Kalman Filter is an optional estimation algorithm widely used in research and engineering applications such as robotic, navigation, and vehicle control.

In this thesis, KF is the method used to predict velocity as well as position of obstacles in front of vehicle, and concept of KF will have an introduction in this section.

* **Kalman Filter Introduction [6] :**

KF is a set of mathematical equations that provides efficient ways to estimate state of a process by minimizing mean of the squared error. To estimate the state, the non-linear stochastic difference equation (3.4.1) and measurement equation (3.4.2) should be clarified. Meaning of symbols are defined on Table 3-4-1.

is the measurement matrix.  and  are assumed to be independent of each other and with normal probability distributions.

 (3.4.1)

 (3.4.2)

 (3.4.3)

 (3.4.4)

KF estimates the state at a time and obtains feedback in the form of noisy measurements afterward. The overall system process is declares on Figure 3-4-1, and the procedure and equation will be explained below.

* **Time Update:**

The transition equation (3.4.5) is the process using transition matrix , which predicts the state from time step  to step  with process error . In addition, time update equation from (3.4.6) projects the covariance estimate with Q that is from (3.4.3).

 (3.4.5)

 (3.4.6)

* **Measurement Update :**

Kalman filter helps us to obtain reliable estimates from a sequence of observed measurements. First, Kalman gain  must be calculate (3.4.7), which is an important element of KF because it the weighting between estimate and measurement. The second step is to obtain  to generate posteriori-estimated state. A posteriori error covariance estimate is calculated via (3.4.9).

 (3.4.7)

 (3.4.8)

 (3.4.9)

KF is a recursive estimator; thus, it will repeat the process such as Figure 3-4-1 as long as time and measurement update. Typically, “Predict” process and “Correct” process will alternate, but it can still work when observation is unavailable in some situation.



**Figure 3-4-1. A complete picture of the operation of the Kalman filter [6]**

**Table 3-4-1 Symbols of Kalman Filter**

|  |  |
| --- | --- |
| Symbols | Meaning |
|  | True State |
|  | Posteriori Estimated State |
|  | Priori Estimated State |
|  | Measurement Vector |
|  | Posteriori Estimated Error Covariance |
|  | Priori Estimated Error Covariance |
|  | Control Vector |
|  | Control Matrix |
|  | State Transition Matrix |
|  | Measurement Noise |
|  | Process Noise |
|  | Measurement Matrix |
|  | Process Error Covariance |
|  | Measurement Error Covariance |
|  | Kalman Gain |

[5] R. E. Kalman, "A new approach to linear filtering and prediction problems," Trans. ASME J. Basic Eng., Vol. 82, pp. 34-45, Mar. 1960.

[6] An Introduction to the Kalman Filter