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A Study on Target-Tracking Algorithm using Fuzzy-Logic

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Abstract

Conventional target tracking techniques are primarily based on Kalman filtering or probabilistic data association(PDA). But it is difficult to perform well under a high cluttered tracking environment because of the difficulty of measurement, the problem of mathematical simplification and the difficulty of combined target detection for tracking association problem.

This paper deals with an analysis of target tracking problem using fuzzy-logic theory, and determines fuzzy rules used by a fuzzy tracker, and designs the fuzzy tracker by using fuzzy rules and Kalman filtering.

1. Introduction

Recently, many researches have been done about the target tracker using standard Kalman filter. Target tracking is the estimation of real value based on the target measurements given by sensors. In a real environment, these measurements have inaccuracy due to the measurement noise of sensors and uncertainty whether the measurement is from the target, i.e. clutter. Kalman filter shows a good tracking performance if the source of inaccuracy is random noise, but it has one fatal fault. It is the fact that it assumes the detection probability to be 100%. In a real environment, if we assume like that when using single Kalman filter, it shows a bad tracking performance due to the existence of clutters. The proposed algorithm in order to supplement such faults is probabilistic data association filter. This filter composed of several Kalman filters sets up a region around the estimated position generated by each Kalman filter(i.e. data association gate) and determines the weights of measurements included in that region. The weight given to each measurement is proportional to the probability likelihood that the measurement originates from the target. And a composite measurement is generated as a weighted sum of all the measurements inside the gate.

The problem of these conventional methods is that they are too restrictive to deal with the complexity of tracking problem in a real environment and it has too many simplifying assumptions. However, the biggest problem of PDAF is the bivalent nature that this algorithm fundamentally has. Among the target tracking process of PDAF, there exists a step that calculates the target likelihood and compares it with standard value. If the value exceeds the threshold, we declare the target is present, otherwise no target is declared. Obviously, there exists the bivalent nature. Such nature cannot be excluded also in the gate boundary. It is obvious that such classification method cannot reflect reality well. However, this problem can be solved by the level of membership function if we use fuzzy logic. Therefore, this paper designs fuzzy logic tracker based on Kalman filtering and compares the performance with the conventional PDAF.

2. The design of PDAF

Probabilistic data association filter(PDAF) is the algorithm that is proposed in order to support problems of conventional single Kalman filter. It is a suboptimal bayesian filter for the single target tracking in a cluttered environment similar to real situation. First of all, this algorithm pass through the validation process for each measurement given by several Kalman filters. After setting the data association gate whose origin is a measurement, if that measurement is included in that gate, we declare the data is from the target. Otherwise, we assume the probability that the measurement originates from the target to be very low and do not consider it when calculating final value. PDAF makes the weights of all validated measurements through this method, and generates final estimated value as bayesian sum of these measurements. This weight is defined as the probability that each measurement originates from the target. Therefore, the estimated value of target state from PDAF and error covariance matrix consider the uncertainty of measurements.

Kalman Filter

Kalman filter, which finds the state estimation vector $\hat{x}(t)$ estimating the state vector $x(t)$ in real-time and its input is the output $y(t)$ measured at probability dynamic system, is a linear time-invariant dynamic system whose order is same as the plant. In order to find an optimal state estimation vector $\hat{x}(t)$, we define state estimation error $\tilde{x}(t)$ as following [1].

$$\tilde{x}(t) \equiv x(t) - \hat{x}(t) \quad (1)$$

The average of state estimation error $\tilde{x}$ $E\{\tilde{x}(t)\}$ is 0 in steady-state, but the covariance matrix $P = E[\tilde{x}(t)\,\tilde{x}(t)^T]$ is not 0. Therefore, in order to find an optimal state estimation vector $\hat{x}(t)$, we must make the error covariance matrix P as small as possible Assume the linear system defined by following equations at time k.

$$x_{k+1} = A_k x_k + B_k u_k + \nu_k \quad (2)$$

$$y_k = C_k x_k + \omega_k \quad (3)$$

In this case, basic equations of Kalman filter are as following. And simple structure of Kalman filter is represented as block-diagram in Fig. 1.

$$\hat{x}_{k+1/k} = A_k\,\hat{x}_{k/k} + B_k u_k \quad (4)$$

$$\hat{x}_{k+1/k+1} = \hat{x}_{k+1/k} + H_{k+1}[y_{k+1} - C_{k+1}\,\hat{x}_{k+1/k}] \quad (5)$$

$$P_{k+1/k} = A_k P_{k/k} A_k^T + Q_k \quad (6)$$

$$P_{k+1/k+1} = P_{k+1/k} - H_{k+1} S_{k+1} H_{k+1}^T \quad (7)$$

$$H_{k+1} = P_{k+1/k} C_{k+1}^T S_{k+1}^{-1} \quad (8)$$

$$S_{k+1} = C_{k+1} P_{k+1/k} C_{k+1}^T + R_{k+1} \quad (9)$$

The meaning of each variable and matrix is as following [2].

x_k	: target state vector
u_k	: system input vector
y_k	: measurement vector
A_k	: state transition matrix
B_k	: input matrix
C_k	: measurement matrix
ν_k	: plant noise vector
ω_k	: measurement noise vector

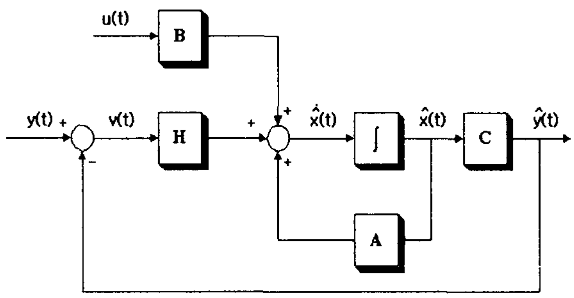

Fig. 1 The structure of Kalman Filter

Kalman filter assumes that there is not an ambiguity at the measurement center. That is to say, when detecting, the probability that it is from the target is 100%. However, in the real tracking environment, the disturbance of non-target exists. And target signals are vanished by the background noise, so they cannot be detected perfectly. Because of these faults, a single Kalman filter cannot show satisfactory tracking performance in a real situation.

Probabilistic data association filter(PDAF)

The real value estimation of PDAF can be divided as 3 steps. First step is the measurement validation process. Data association in cluttered environment begins at determining the validated measurement through the measurement validation process for a measurement from the sensor. Real target data and measurements from the sensor, the association probability between these two values is calculated by using probabilistic distance between predicted target data at next scan and measurements. We assume that the measurements that this distance is very far are associated with real data with very low probability. So, although we neglect these, the whole performance does not be changed much and we can decrease calculation load of tracking system.
Second step is the calculation of each association probability with validated measurements. The measurements accepted to the sensor include not only measurements from the target but also clutters due to sensor environment, so a proper determination of measurement using prior state information is needed.
Fig. 2 shows the block diagram of PDAF.

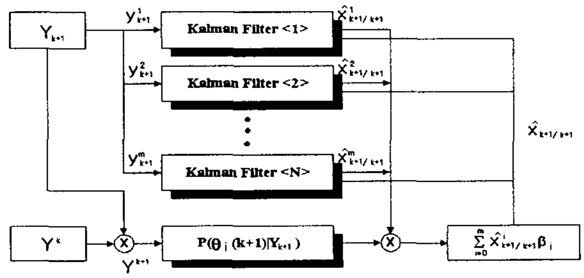

Fig. 2 Probabilistic Data Association Filter

At any given time k, there may be m measurements with the signal strength exceeding the detection threshold. We refer to the set of detected data as Y_k and the set of cumulative measurements from the start of the tracking period to the time k as Y^k. And we define the following event.

$$\{\ \theta_i(k)\ ,\ i=1,\cdots,m\ \} \tag{10}$$

: The event that ith measurement is correlated with the target

$$\theta_0(k) \tag{11}$$

: The event that no detection is from the target

The probability of these events conditional on the set of cumulative measurements is as following.

$$\beta_i(k) \equiv P(\theta_i(k) \mid Y^k)\ ,\ i=0,\cdots,m \tag{12}$$

$$\sum_{i=0}^{m}\beta_i(k)=1 \tag{13}$$

Then, the presentation of Kalman filter based on the basic assumption of PDAF is as following [3].

$$\hat{x}_{k+1/k}=A_k\,\hat{x}_{k/k}+B_k u_k \tag{14}$$

$$\hat{x}_{k+1/k+1}{}^{i}=\hat{x}_{k+1/k}+H_{k+1}[y^i_{k+1}-C_{k+1}\,\hat{x}_{k+1/k}] \tag{15}$$

Filter gain equation is,

$$H_{k+1}=P_{k+1/k}C^T_{k+1}S^{-1}_{k+1} \tag{16}$$

$$S_{k+1}=C_{k+1}P_{k+1/k}C^T_{k+1}+R_{k+1} \tag{17}$$

Covariance of error about the state estimation value is,

$$P_{k+1/k+1}=P_{k+1/k}-W_{k+1}S_{k+1}W^T_{k+1} \tag{18}$$

$$P_{k+1/k}=A_kP_{k/k}A_k^{T}+Q_k \tag{19}$$

The posterior probability that the measurement is from the target, $\beta_i(k)$ is as following and each equation can be calculated in regular order [4].

$$\beta_i(k) \equiv P(\theta_i(k) \mid Y^k)\ ,\ i=0,\cdots,m_k \tag{20}$$

$$\beta_i(k)=\frac{\exp\{-r_i(k)^T S(k)^{-1} r_i(k)/2\}}{b(k)+\sum_{i=1}^{m}\exp\{-r_i(k)^T S(k)^{-1} r_i(k)/2\}} \tag{21}$$

$$\beta_0(k)=\frac{b(k)}{b(k)+\sum_{i=1}^{m}\exp\{-r_i(k)^T S(k)^{-1} r_i(k)/2\}} \tag{22}$$

$$b(k)=(2\pi)^{M/2}(CV(k)/c_M\eta^M)(1-P_D)/P_D \tag{23}$$

Final step is the generation of final estimation value as weighted sum of measurements with association probability.

$$\hat{x}_{k+1/k+1}=\sum_{i=1}^{m_{k+1}}\hat{x}_{k+1/k+1}{}^{i}\beta_i(k) \tag{24}$$

3. The design of fuzzy-logic tracker

The purpose of designing fuzzy-logic tracker is to make the tracker that shows better performance in a real environment. Clutter in a real environment is related to plant noise, sensor noise, disturbance of non-target, etc. And generally, noise is not distributed uniformly and not constant with time. Such property infers that the tracker must be adaptive in order to perform well at a given environment. In this case, fuzzy-logic can show acceptable performance.

The target tracker using fuzzy-logic can exclude bivalent nature of PDAF, determine fuzzy rules by using expert's experience, implement practically because of weak restraint about mathematical assumption. Similarly like PDA tracker, fuzzy-logic tracker uses Kalman filter in order to update the trajectory by measurements. The only difference is that the association likelihood between measurement and real trajectory is generated by using fuzzy-logic.

Fig. 3 shows the structure of fuzzy-logic tracker.

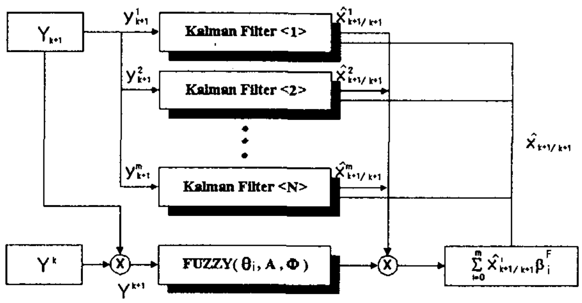

Fig. 3 Fuzzy-Logic Tracker

Fuzzy-logic tracker of this paper is concerned with the strength of signal and residual of Kalman filter. Fuzzy rule and membership function is determined by taking these two values as input and association likelihood as output.

Fuzzy rules are as following.

Residual \ SNR	high	high moderate	moderate	low moderate	low
far	moderate	moderate	low moderate	low	low
middle far	moderate	moderate	low moderate	low	low
middle	high moderate	moderate	low moderate	low	low
middle close	high	high moderate	moderate	low moderate	low
close	high	high moderate	moderate	low moderate	low

Table 1 Fuzzy Rules

Fig. 4 shows the membership function surface.

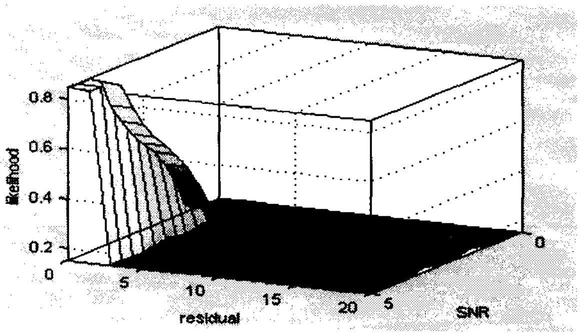

Fig. 4 Membership Function Surface

4. Simulation

This paper deals with the tracking problem of the target which moves on the first dimension space and has maneuvering period. The maneuvering point of the target is 60 and 140 second and it shows uniform motion elsewhere. As uniform noise and clutter are added to real trajectory, a simulated environment similar to a real environment is made. And the matrix A, C, Q, R used to state equation, covariance matrix of state estimation error, gain equation of Kalman filter are assumed as following.

$$A=1\ ,\ \ C=1\ ,\ \ Q=(bet*\sigma)^2 \qquad (25)$$

σ is the maximum value of autocorrelation function and bet is assumed to be 0.02 by experience.

$$bet=0.02\ ,\ \ R=0.007 \qquad (26)$$

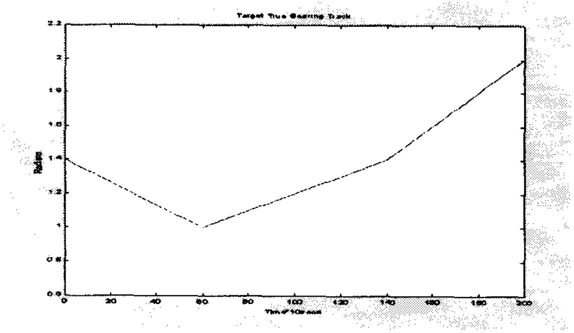

Fig. 5 True bearing of the target

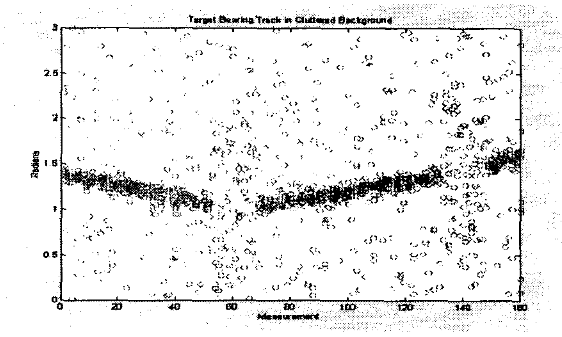

Fig. 6 Trajectory corrupted by noise and clutter

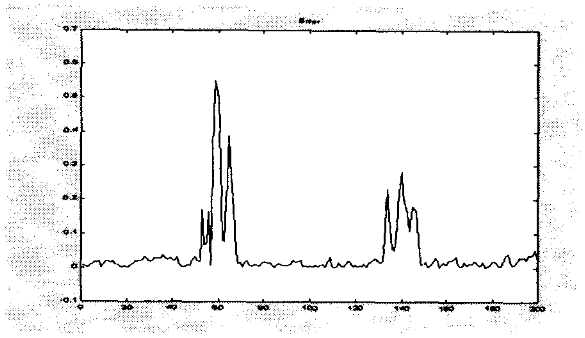

Fig. 7 RMS error of bearing(PDAF)

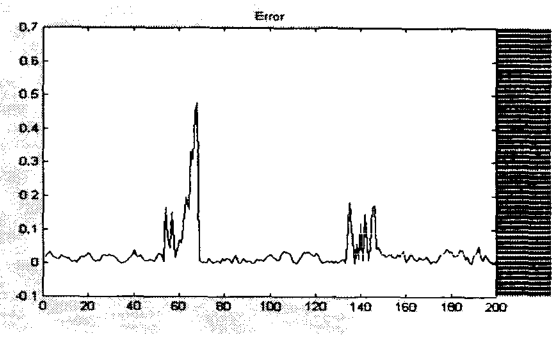

Fig. 8 RMS error of bearing(FLT)

According to simulation results, RMS error of fuzzy-logic tracker tends to be smaller than that of PDA tracker at the point of maneuvering(near the time 60 and 140). Thus, we can know the fact that the fuzzy-logic tracker shows better performance in that case. But at the non-maneuvering points, RMS error of fuzzy-logic tracker is a little bigger than that of PDA tracker.

5. Conclusion

In this paper, we designed the fuzzy-logic tracker that shows better performance in a real situation in order to overcome the faults of target trackers using conventional PDAF and saw their characteristics and performances. As referred before, fuzzy-logic tracker shows better performance when maneuvering.

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