A V2X-Assisted Intelligent Vehicle Target Tracking Method

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Abstract—In the target tracking scene of connected intelligent vehicles, besides onboard sensors, the V2X is an important approach to acquire target information. In this paper, a target tracking method which introduces the targets’ identity provided by V2X to improve the data association is proposed. The measurements are associated with targets according to conventional method firstly, and then the position data from V2X is used to update the association probability between tracks and measurements. The simulation results show that the proposed method can improve the performance of the target tracking.

1. INTRODUCTION

Accurate target tracking is important for intelligent connected cars, which can effectively improve the performance of vehicle decision-making and control. In the intelligent connected car target tracking method, data association is the core. In the classical data association algorithms, the target dynamics models and kinematic measurements are exploited to solve tracking problems. There are so many data association methods, such as NN[1](the Nearest Neighbor association), PDA[2](the Probabilistic Data Association), JPDA[3](the Joint Probability Data Association), MHT[4](the Multiple Hypothesis Tracking) and some corresponding improved algorithms[5]-[7].

Based on the development of intelligent connected cars, the paper defines the target tracking scene showed in Figure.1: the targets can transmit their own information (kinematic states and identities) to the tracking system. In the target tracking, traditionally data association methods only update the non-kinematic information as new measurements associated with tracks and exploit the probability score to make track association decisions. According to the assumption about this new scene, the conventional non-kinematic-aided data association methods are not suitable for this. This paper introduces the targets’ identity into the association process, the measurements are associated with targets according to conventional association method firstly, and then the position data of targets are used to update the association probability between tracks and measurements, make full use of the identity information provided by V2X.
This paper is organized as follows. In Section II, the target tracking models are proposed and the data association method exploited target’s position and identity algorithm is given in detail. Experiments is given to present the superiority of the method proposed in Section III. Conclusion is given in the last section.

2. V2X-ASSISTED TARGET TRACKING MODEL

2.1. The target tracking scene

As shown in Fig.1, the scene contains vehicles targets and pedestrians targets, the measurements obtained through the tracking system contain two kinds. One is directly from the sensors on the tracking system, the other is indirectly gained through V2X, which contains position information like general measurements, but also contains identity information.

2.2. Tracking model without V2X-assisted

The study of target tracking algorithm is to solve the problem of seeking the corresponding relationship between the target and the measurement, and to maintain the estimation of the current state of the target:

\[ \hat{X}_{k|k} = E(X_k | Z_k) \]  

Where \( Z_k \) represents the validation measurements, \( \hat{X}_{k|k} \) represents the estimate state of the targets. The classical data association algorithm JPDA is divided into the following three parts:

- Exploit Mahalanobis distance to establish the corresponding relationship between the measurement and the tracked target, and form the confirmation matrix \( \Omega \).
- Split the confirmation matrix \( \Omega \) to produce feasible matrices, and obtain the feasible events.
- Calculate the association probability between the measurements and the targets:

\[ \beta_{k,j}^{i,j} = \sum_j P(\theta_{k,j} | Z^j) \tilde{w}_j^i(\theta_{k,j}) \]  

So the state estimation of target \( t \) obtained through using the \( Z_k \) is:

\[ \hat{X}_{k|k}^t = E(x_k^t | Z_k) = \sum_{j=0}^{m_k} \beta_{k,j}^{i,j} \hat{X}_{k|k,j}^t \]
Where \( \hat{X}_{j,k} = E(X'_k | \theta_k^{j,i} Z^k) \), \( j = 0, 1, 2, \ldots, m_i \), represents the state estimate of the target \( t \) through using the measure \( j \), and \( \sum_{j=0}^{m_i} \beta_k^{j,i} = 1 \).

### 2.3. Tracking model with V2X-assisted

In the scene, the measurements not only contain the target position but also the target identity. The tracking model with V2X as follows:

\[
\hat{X}_{j,k} = E\{X_k | Z_k, (Z_c, C)\}
\]

(4)

Where \( Z_k \) represents the measurements from its own sensor system. \( \{Z_c, C\} \) represents the measurements from V2X, \( Z_c \) represents the target position, and \( C \) represents target identity.

Because measurements from V2X include positions and target identities, which is different from the traditional method. The modified JPDA algorithm is as follows:

- Exploit Mahalanobis distance to establish the corresponding relationship between two kinds of measurements, and form the confirmation matrix \( \Omega \).
- Split the confirmation matrix \( \Omega \) to produce feasible matrices, and obtain the feasible events.
- Calculate the association probability between the two kinds of measurements:

\[
\beta_k^{j,i} = \sum_i P(\theta_k^{j,i} | Z^i) \hat{w}^j_i(\theta_k^{j,i})
\]

(5)

And the association probability between the target and the measurements from V2X is \( \beta = 1 \).

Assume that the \( \beta' k \) represents the modified probability that the general measurement \( j \) originated from target \( t \), and the \( \beta_{c,t} k \) represents the modified probability that the measurements from V2X originated from target \( t \). According to the JPDA algorithm framework, the following relationship must be meet:

\[
\sum_{j=0}^{m_i} \beta_k' + \beta_{c,t} k = 1
\]

(6)

For the value of \( \beta_{c,t} k \) and \( \beta_k' \), qualitatively, when the accuracy of the measurements from V2X is higher than the accuracy of the general measurement, the higher weight should be given to the former and vice versa. The accuracy of the two kinds of measurements should be considered in the process of determining the value of \( \beta_{c,t} k \) and \( \beta_k' \). For the same target, assume the error of the general measurements and the measurements from V2X are \( P_{m, k} \), \( m = i, j \), this paper exploits following method to modify the value of association probability:

\[
\beta_k = P'(P_i + P_j)^{-1} \beta_k^{j,i}
\]

(7)

\[
\beta_k' = P'(P_i + P_j)^{-1} \beta
\]

(8)

So the estimation state is also presented as follow:

\[
\hat{X}_{j,k} = E\{X_k | Z_k, (Z_c, C)\}
\]

\[
= \sum_{j=0}^{m_i} \beta_k^{j,i} \hat{X}_{j,k} + \beta \hat{X}_{c,t} : P'(P_i + P_j)^{-1}
\]

(9)

and

\[
\sum_{j=0}^{m_i} \beta_k' + \beta_{c,t} k = \sum_{j=0}^{m_i} \beta_k^{j,i} \cdot P'(P_i + P_j)^{-1} + \beta \cdot P'(P_i + P_j)^{-1} = 1
\]

(10)

When the error of the target measurements from V2X is \( P_{j, k} \rightarrow \infty \), the equation (9) and (10) degenerate into equation (3) and (2), namely, the proposed method will degenerate into the conventional data association method. When the error of the cooperative target measurements \( P_{j, k} \rightarrow 0 \), the equation (9) will become equation (11), as follows:
\[ \hat{x}_{k|k} = E\{x_k^* | Z^k, (Z_c, C)\} = \hat{x}_{k|k,c} \]  
\hfill (11)

Namely, when the measurements from V2X are accurate absolutely, the state estimation of tracked targets are decided by the measurements from V2X completely.

3. EXPERIMENTS

To evaluate the performance of the proposed method, 3 scenes are designed as follow. Assume target tracking system track the targets \( T_j (j=1,2) \), the sampling period is \( T=1s \). The target state vector is \( x_k=[x, \dot{x}, y, \dot{y}] \), where \( x, y \) is the target position, and the \( \dot{x}, \dot{y} \) is the velocity in the direction of the X and Y axes. The process noise \( w_k \) and the measurement noise \( v_k \) are zero-mean mutually independent, white Gaussian noise sequences with known covariance matrices \( Q(k) \) and \( R(k) \). The initial state of the target \( T_j (j=1, 2) \) is \( x_1=[1500 \ 300 \ 500 \ 400]^T \), \( x_2=[500 \ 400 \ 1500 \ 300]^T \), and the corresponding initial error covariance matrices are \( P_1=\text{diag}[1 \ 0.001 \ 1 \ 0.001] \), \( P_2=\text{diag}[1 \ 0.001 \ 1 \ 0.001] \). For the measurements from V2X is \( \{Z_c, C\} \), when \( C=T (j=1, 2) \), the target position \( Z_c \) equals targets’ real position with a white Gaussian noise \( u_c \), and the covariance matrices is \( U(k) \).

Scene 1: \( U(k) \gg R(k) \). Let \( R(k)=\text{diag}[16 \ 16], U(k)=\text{diag}[900 \ 900] \), and the simulation results are shown as follows.

![Figure 2(a). the RMSE of Target A](image)

![Figure 2(b) the RMSE of Target B](image)

According to the experiment results, when the error of target measurements from V2X is far more than the error of general measurements, the position RMSE (Root Mean Square Error) of the proposed method is nearly same as the position RMSE of classical method, and the RMSE trend of the novel method is nearly identical to the RMSE trend of classical method, as shown in Figure 2.

Scene 2: \( U(k) \approx R(k) \). Let \( R(k)=\text{diag}[4 \ 4], U(k)=\text{diag}[4 \ 4] \), and the simulation results are shown in as follows.
Figure 3(a). the RMSE of Target A

Figure 3(b) the RMSE of Target B

From the experiment results, when the error of target measurements from V2X is same as the error of general measurements, compared to classical method, the proposed method has smaller RMSE, as shown in Figure 3.

Scene 3: $U(k) \ll R(k)$. Let $R(k) = diag[16, 16]$, $U(k) = diag[1.6, 1.6]$, and the simulation results are shown in Figure 4.

Figure 4(a). the RMSE of Target A

Figure 4(b) the RMSE of Target B

When the error of target measurements from V2X is far less than the error of general measurements, the RMSE of this paper proposed method has decreased significantly, as shown above.
The three scenes above indicate the tracking performance of the proposed method is significantly superior to the classical method when the error of target measurements from V2X is not more than the error of general measurements.

In order to evaluate the effect of the error of target measurements from V2X, this paper designed the Scene 4 experiment.

**Scene 4:** $U_1(k) << U_2(k) << U_3(k)$. Let $U_3(k)=\text{diag}[1600, 1600], U_2(k)=\text{diag}[16, 16], U_1(k)=\text{diag}[0.16, 0.16], R(k)=\text{diag}[16, 16]$, and the simulation results are shown in Figure 5.

![Figure 5(a). the RMSE of Target A](image1)

![Figure 5(b). the RMSE of Target B](image2)

As shown in Figure 5, the smaller the error of target measurements from V2X, the better performance of the proposed method.

**4. CONCLUSIONS**

Using the identity information of the measurements provided through V2X, this paper have proposed a novel target tracking method, which introduces the targets’ identity from V2X into the data association process. Unlike conventional feature-aided data association method, in this novel method, the measurements are associated with target tracks according to conventional data association method firstly, and then the position data of targets from V2X are used to update the association probability between tracks and measurements. Compared to the conventional method, the novel method have taken full advantage of the identity information provided by V2X. Besides the novel method have shown a better performance when the error of target measurements from V2X is not more than the error of general measurements. Meanwhile, the experiment results also show that the smaller error of target measurements from V2X, the better performance of the novel method. This work is supported by Chongqing Key Technology Innovation Project under Grant(cstc2020jjscx-dxwtB0003)

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