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Vehicle Target Tracking Method for Crooked Roads Based on UKF and Sensor Fusion

Vehicle Target Tracking Method for Crooked Roads Based on UKF and Sensor Fusion

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Abstract. Aiming at the problem that mm-wave radar tracking target is easy to lose when in crooked roads, a vehicle target tracking method based on Unscented Kalman Filter (UKF) and sensor fusion is proposed. This method uses mm-wave radar and camera to obtain vehicle targets' information in crooked roads at the same time. Then, according to whether mm-wave radar tracking target is lost or not, different tracking methods based on UKF are adopted. When the mm-wave radar tracking target is not lost, the historical and current data information of mm-wave radar are taken as the state information and measurement information, directly calculating the tracking vehicle parameters such as position, distance and speed; When the mm-wave radar tracking target is lost, a sensor fusion strategy is adopted. The historical data information of mm-wave radar is still the state information, and the camera vision image information of the tracking target becomes the measurement information, integrating the two sensors' information to get the tracking vehicle parameters. And the result will serve as next moment's state information for continuous tracking to solve the mm-wave radar tracking target loss problem in crooked roads. Finally, the validity of this method is verified by real road experiments.

1. Introduction

As an important part of Advanced Driving Assistant System (ADAS) and unmanned driving system, the performance of front vehicle detection directly affects the realization of corresponding functions. At present, millimetre wave radar (mm-wave radar) is often used to detect the state of front vehicles. However, due to the fixed detection angle and small detection range of mm-wave radar, it is easy for mm-wave radar to lose tracking targets when in crooked roads, resulting in the acceleration when turning, the discomfort of passengers and even the rear-end collision caused by emergency braking.

In the research on detection and tracking of crooked roads' vehicles at home and abroad, some scholars calculated the host vehicles' lane radius by combining the front or rear wheel steering parameters and vehicle structural parameters, then calculated the front vehicles' lane radius according to the real-time detection data of anti-collision radar, and finally judged whether the host vehicle and front vehicles were in the same lane [1-4]. Other scholars used Kalman filter theory to study the identification method of key front vehicle target in crooked roads, and established the extended Kalman filter of yaw angular velocity through three-degree-of-freedom vehicle model to realize on-line estimation of road curvature, constructing the judgment basis of key target recognition model in crooked roads [5-6]. But these methods are based on the premise that the mm-wave radar can track the vehicle all the way, failing to analyse the situation of mm-wave radar's tracking target losing in crooked roads.

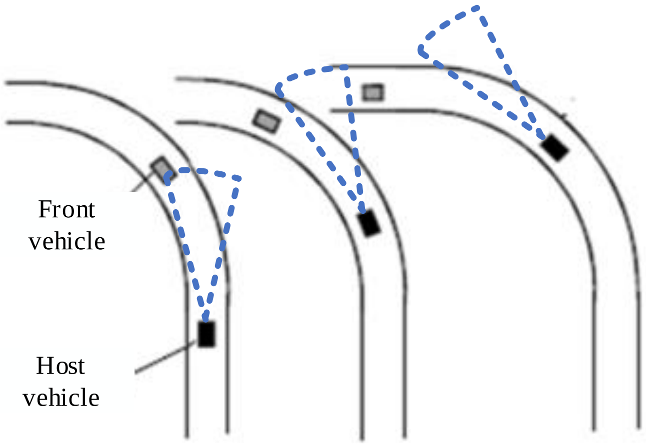

Figure 1. A schematic diagram of mm-wave radar's tracking target losing in crooked roads

In summary, there are few studies on vehicle detection target losing at home and abroad, and also a lack of research on tracking algorithm after target losing in crooked roads. So in this paper, a vehicle target tracking method based on Unscented Kalman Filter (UKF) and sensor fusion is studied by using the perception information of mm-wave radar and camera.

2. Principle

Aiming at the problem that mm-wave radar tracking target is easy to lose when in crooked roads, a vehicle target tracking method based on UKF and sensor fusion is proposed in this paper. The method synthesizes the perception information of mm-wave radar and camera. Firstly, the vehicle targets' information in crooked roads is obtained by mm-wave radar and camera at the same time. Then, according to whether the mm-wave radar tracking target is lost or not, different tracking methods based on UKF are adopted to solve the problem by UKF and sensor fusion. The specific principles and steps are as follows:

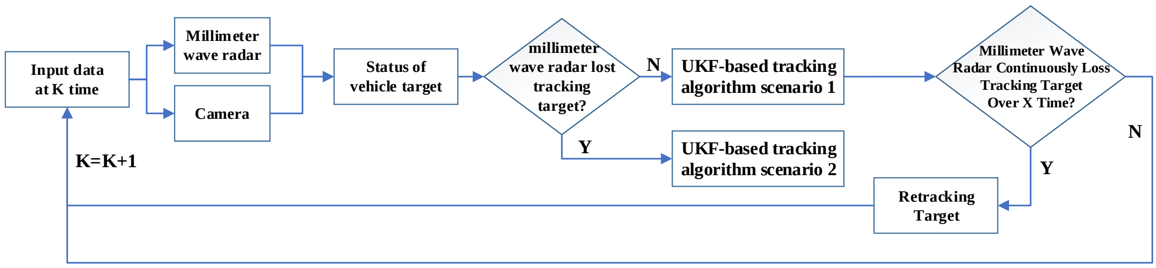

Figure 2. A tracking method based on UKF for vehicle target losing in crooked roads

1) Inputting the K-time data. The mm-wave radar obtains vehicle targets information in crooked roads through radar signal data acquisition, data processing and vehicle target maintenance [7-8]. At the same time, under the machine vision algorithm, the camera can also detect and obtain the vehicle targets' information by generating the vehicle target hypothesis and verifying the vehicle target hypothesis [9-11].

2) Judging whether the tracking target of mm-wave radar is lost or not. If it is not lost, UKF-based tracking algorithm scenario 1 is adopted; if it is lost, UKF-based tracking algorithm scenario 2 is adopted;

3) UKF-based tracking algorithm scenario 1: When the mm-wave radar tracking target is not lost, the mm-wave radar data with high measurement accuracy is given priority to use. So the historical mm-wave radar data of tracking target is taken as the state information, the current time mm-wave radar data

of tracking target is taken as the measurement information. And the tracking vehicle parameters such as position, distance and speed are directly calculated by UKF, then the result will be used as next moment's state information for continuous tracking.

4) UKF-based tracking algorithm scenario 2: When the mm-wave radar loses tracking target, a sensor fusion strategy is adopted. The historical mm-wave radar data of tracking target is still taken as the state information, and the camera vision image information of tracking target becomes the measurement information, integrating the two sensors' information and UKF to get the tracking vehicle parameters. The result can also be used as next moment's state information for continuous tracking.

5) Judging whether the tracking target of mm-wave radar is lost continuously over X time. If it exceeds X time, it is considered that the tracking target is out of the mm-wave radar's interested range and needs to be re-tracked. If it does not exceed X time, the above steps are continued to the inputting data at K+1 time.

3. Vehicle target tracking method based on UKF

The classical Kalman filtering algorithm [12] is suitable for the processing and prediction of linear problems, but can not achieve the optimal estimation effect in the non-linear scene. In the real driving environment, the front vehicles are always in the dynamic process of deceleration, acceleration and turning. These states can not be described by simple linear system. Unscented Kalman Filter (UKF) [13] is often used in describing nonlinear systems. The basis of UKF is the unscented transformation (UT) and classical Kalman filter. UKF's framework uses classical Kalman linear filter, but the non-linear transfer of mean and covariance is achieved by the unscented transformation. Finally, the state transition matrix is also used to complete the prediction of the next point [14] [15].

3.1. Scenario 1

When the mm-wave radar tracking target is not lost, the mm-wave radar data with high measurement accuracy is first used. So the historical mm-wave radar data of tracking target is taken as the state information, the current time mm-wave radar data of tracking target is taken as the measurement information. The tracking vehicle parameters such as position, distance and speed are directly calculated by UKF, and the result will be used as next moment's state information for continuous tracking.

1) Equation of State

For a moving vehicle, the motion state of its simplified two-degree-of-freedom model can be described as [16]:

$$X(t) = \begin{pmatrix} x & \mathrm{y} & \mathrm{v}_r & \omega_r \end{pmatrix}^T \tag{1}$$

In the upper formula, x is the longitudinal distance between the host vehicle and the tracking target, *m*; y is the lateral distance between the host vehicle and the tracking target, *m*; V_r is the speed of tracking target, *m/s*; ω_r is its yaw angular speed, *rad/s*; Since the change of vehicle state in each frame is very small, it can be assumed that the yaw angular velocity of the tracking target is a fixed value, then its state can be expressed as:

$$x_{k+1}(t) = \begin{pmatrix} r\sin(\omega_r t + \theta) - r\sin(\theta) + x_k(t) \\ -r\cos(\omega_r t + \theta) + r\cos(\theta) + y_k(t) \\ v_r \\ \omega_r \end{pmatrix} \tag{2}$$

where $r = \dfrac{v_r}{\omega_r}$ is the turning radius of tracking target, *m*. And when the tracking vehicle is moving in a straight line, $\omega_r = 0$, the upper formula can be simplified as follows:

$$x_{k+1}(t)=\begin{pmatrix} v_r\cos\theta t+x_k(t) \\ v_r\sin\theta t+y_k(t) \\ v_r \\ 0 \end{pmatrix} \quad (3)$$

2) Covariance of prediction

In order to estimate the state of the nonlinear model using the classical Kalman filter method, UKF satisfies the requirements of Kalman filter algorithm by finding an approximate Gauss distribution with the same mean and covariance as the real distribution. The method calculates a Gauss distribution by sampling 2n+1 sigma point at k-time, and then obtains the covariance formula for predicting the tracking state of the target at k+1-time.

$$\begin{aligned} &P(k+1|k)=\sum_{i=1}^{2n+1} w^{[i]}\left(x_{k+1}^{[i]}-\mu\right)\left(x_{k+1}^{[i]}-\mu\right)^T \\ &\mu=\sum_{i=1}^{2n+1} w^{[i]}x_{k+1}^{[i]} \\ &w^{[i]}=\frac{1}{2(\lambda+n)}, \quad i=2,\ldots,2n+1 \end{aligned} \quad (4)$$

where μ is the weighted sum of every point's each state quantity in the set of sigma points, according to the mean value $x_{k+1}|_k$ obtained by the state distribution of the tracking target; $w^{[i]}$ is the weight of sigma points; *n* is the number of tracking target state points; λ is the super-parameters, the larger the λ is, the farther the sigma point is from the state mean value, and here we take 2.

3) Kalman filter gain

Calculate the Kalman filter gain according to the calculation process of Kalman filter：

$$\begin{aligned} &K_g(k+1|k)=T_{k+1|k}\cdot S_{k+1|k}^{-1} \\ &z_{k+1|k}=\sum_{i=1}^{2n+1} w^{[i]}z_{k+1|k}^{[i]} \\ &T_{k+1|k}=\sum_{i=1}^{2n+1} w^{[i]}\left(x_{k+1|k}^{[i]}-x_{k+1|k}\right)\left(z_{k+1|k}^{[i]}-z_{k+1|k}\right)^T \\ &S_{k+1|k}=\sum_{i=1}^{2n+1} w^{[i]}\left(z_{k+1|k}^{[i]}-z_{k+1|k}\right)\left(z_{k+1|k}^{[i]}-z_{k+1|k}\right)^T+R \\ &R=E[\omega\omega^T]=\begin{pmatrix} \sigma_x^2 & 0 & 0 & 0 \\ 0 & \sigma_y^2 & 0 & 0 \\ 0 & 0 & \sigma_v^2 & 0 \\ 0 & 0 & 0 & \sigma_\omega^2 \end{pmatrix} \end{aligned} \quad (5)$$

where $z_{k+1|k}$ is the measurement state value; $T_{k+1|k}$ is the state function of the sigma point set; $S_{k+1|k}$ is the measurement space function and R is the measurement noise.

4) State Estimation

Use the above Kalman filter gain, the estimated value of tracking target state at k+1 time can be calculated.

$$\hat{x}_{k+1} = x_{k+1|k} + K_{g(k+1|k)}\left(z_{k+1|k} - x_{k+1|k}\right) \quad (6)$$

5) Estimated covariance

Finally, based on the above formulas, the covariance can be estimated:

$$\hat{P}_{k+1} = P_{k+1|k} - K_{g(k+1|k)} S_{k+1|k} K^{T}_{g(k+1|k)} \quad (7)$$

According to the formulas mentioned above, the state prediction of the tracking vehicle target can be carried out by the UKF-based tracking algorithm.

3.2. Scenario 2

When the mm-wave radar loses tracking target, a sensor fusion strategy is adopted. The historical mm-wave radar data of tracking target is still taken as the state information, and the camera vision image information of tracking target becomes the measurement information, integrating the two sensors' information and UKF to get the tracking vehicle parameters. The result can also be used as next moment's state information for continuous tracking.

According to the UKF's calculation process of tracking target state, the measured value of mm-wave radar $z_{k+1|k}=0$, the Kalman filter gain $K_{g(k+1|k)}=0$, so the tracking target state estimation equation can be expressed as follows:

$$\hat{x}_{k+1} = x_{k+1|k} \quad (8)$$

In the above formula, $x_{k+1|k}$ is the tracking target state value detected by camera. And when the tracking target is running in crooked roads, its value can be obtained by the method described in reference [17 [18]. After calculating the projection point of crooked roads through the perspective transformation and Hough transformation, the crooked roads fitting curve and its curvature radius R also can be obtained. Then the velocity and angular velocity of the tracking target can be expressed as:

$$v_r = \sqrt{\dot{x}_c^2 + \dot{y}_c^2} \quad (9)$$

$$\omega_r = \frac{v_r}{R} \quad (10)$$

where x_c, y_c are the longitudinal and lateral distance of the tracking target detected by the camera, *m*. Therefore, the state value of the tracking target at this time is:

$$\hat{x}_{k+1} = \left(x_c \ \ y_c \ \ v_r \ \ \omega_r\right)^T \quad (11)$$

According to the above formula, when the mm-wave radar tracking target is lost in crooked roads, the position information of tracking target detected by the camera is used to estimate the state of the tracking target. And the UKF-based tracking algorithm is used to predict the trajectory of the tracking target until the mm-wave radar detects the tracking target again.

4. Validation

The main parameters of mm-wave radar and camera selected in the experiment are shown in Table 1.

Table 1. Main parameters of mm-wave radar and camera

Main parameters of mm-wave radar					
Maximum detection distance	170 *m*	Detection velocity range	-110~+55 *m/s*	Detection azimuth	60 °
Detection Accuracy-Range	0.11 *m*	Detection accuracy-velocity	0.05 *m/s*	Detection Accuracy-Angle	0.1 °

Main parameters of camera					
Principal point coordinates	(307,199)	focal length	(1242,1245)	Resolving power	640×480

The experiment chooses three situations to verify the lost target tracking algorithm in crooked roads. Situation 1, the host vehicle is in the straight road, the vehicle is in the crooked roads; Situation 2, both the host vehicle and the front vehicle are in the crooked roads; Situation 3, the host vehicle is in the crooked roads, and the front vehicle is in the straight road.

In Situation 1, the front vehicle enters the crooked roads first and the host vehicle loses its target before entering the crooked roads. The output data of the millimetre wave radar is shown in Fig. 3. And the target is lost three times, the first duration is 1.5s, from 4.5s to 6s; the second duration is 1s, from 6.5s to 7.5s; the third duration is 2.5s, from 12s to 14.5s. And after using the UKF-based tracking algorithm, the detection results of the front vehicle are output as shown in Fig. 3. For the loss within 2 seconds, the state estimation of the front vehicle target can be output by the UKF-based tracking algorithm and maintains the front vehicle tracking. When the target loss is over 2 seconds, the front vehicle is considered to be out of millimetre wave radar's interested range, and will be abandoned until the target reappears.

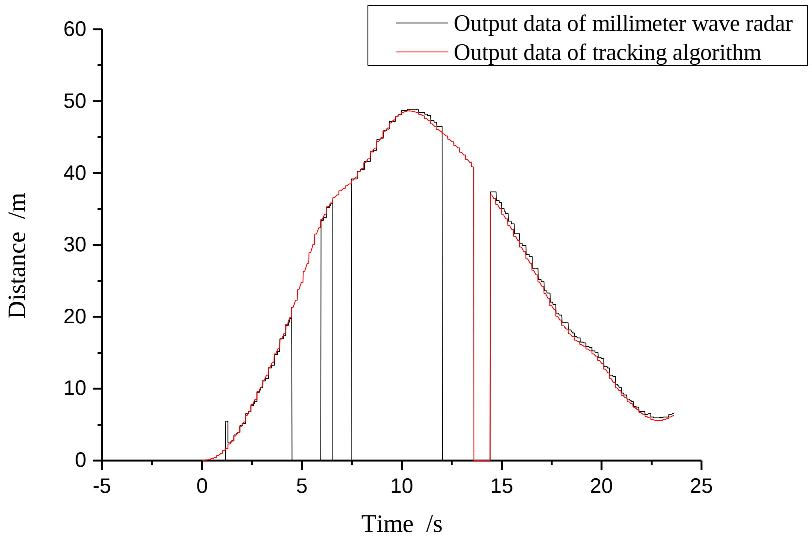

Figure 3. the UKF-based tracking algorithm's output data of Situation 1

In Situation 2, the tracking target is lost when both the front vehicle and the host vehicle are driving in crooked roads. The output data of millimetre radar are shown in Fig. 4, the front vehicle is lost at 8s and lasts for 1.8 seconds. After using the UKF-based tracking algorithm, the state of front vehicle is output as shown in Fig. 4. And the tracking algorithm can effectively solve the problem of target loss when both vehicles are in crooked roads.

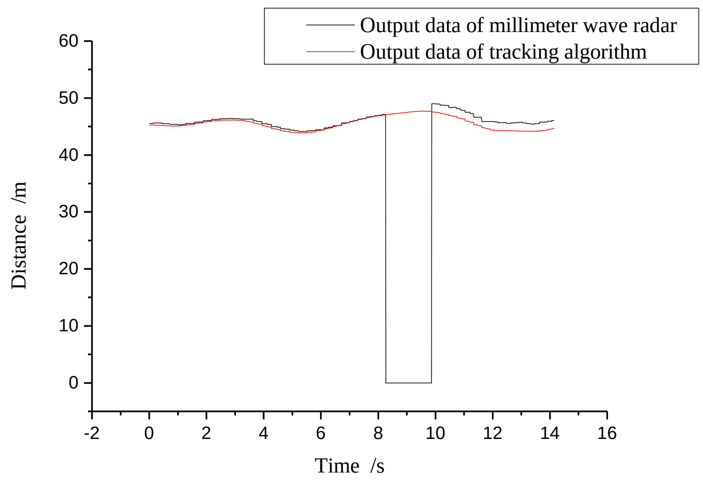

Figure 4. the UKF-based tracking algorithm's output data of Situation 2

In Situation 3, the front vehicle has already left the crooked roads and has been lost before the host vehicle leaves the crooked roads. The output data of millimetre radar is shown in Fig. 5, the front vehicle is lost at 6s and lasts for 1.7 seconds. After using the UKF-based tracking algorithm, the state of front vehicle is output as shown in Fig. 5. The tracking algorithm can also effectively solve the problem of tracking target loss when the host vehicle is in crooked roads and the front vehicle is running in a straight line.

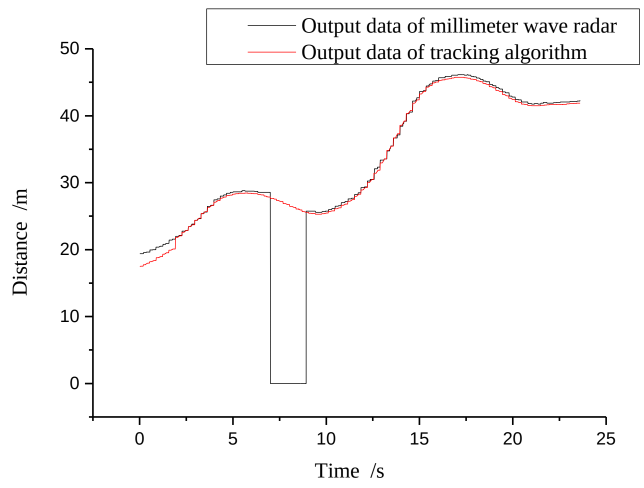

Figure 5. the UKF-based tracking algorithm's output data of Situation 3

5. Conclusion

Aiming at the problem that mm-wave radar is easy to lose tracking target in crooked roads, a vehicle target tracking method based on UKF and sensor fusion is proposed in this paper. The method synthesizes the perception information of mm-wave radar and camera. Firstly, the vehicle targets' information in crooked roads is obtained by mm-wave radar and camera at the same time. Secondly, according to whether mm-wave radar tracking target is lost or not, different tracking methods based on UKF and sensor fusion are adopted to solve the tracking target loss problem. And experiments on different crooked roads verified the validity of this method.

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