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A Survey of Maneuvering Target Tracking Using Kalman Filter

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Abstract. Maneuvering target tracking technology is widely used in both military and civilian fields. Kalman filtering technique is the key technology for maneuvering target tracking. However, due to the uncertainty of the environment and the diversity of the sensors, the defects of traditional Kalman filter are revealed. To solve these problems, a variety of new Kalman filters have been proposed. In this paper, we sum up the application of different Kalman filters for target tracking in various environments, including the adaptive Kalman filter, the extended Kalman filter(EKF), and the unscented Kalman filter(UKF), and analyze the key problems including the improvement of accuracy, real time performance and robustness.

Introduction

With the rapid development of science and technology, maneuvering target tracking technology has been widely used in various fields, especially since the Kalman filtering technology was successfully applied to maneuvering target tracking. Different filtering algorithms have different effects in different environments.

The traditional Kalman filtering algorithm use the state equation of a linear system and input and output data to make the optimal estimate of the system state. Use Kalman filter to track target can be divided into three steps:use past observations to predict the current state,obtain the current observation information and combine the predicted information to correct the current observation information. The traditional Kalman filter is only suitable for linear systems. For complex situation, it is easy to lead filter divergence and cannot meet the requirement of accuracy and robustness. In modern applications, most of the observation environments are complex and nonlinear, so a variety of new Kalman filtering algorithm have been proposed, adaptive Kalman filter, extended Kalman filter (EKF) and unscented Kalman filter(UKF) are commonly used.

Adaptive Kalman Filter

The adaptive Kalman filter is a kind of Kalman filter use predict and observe data from the Kalman filter to correct the error in the kinematic model and the noise variance automatically. The adaptive Kalman filter has better accuracy. In practical applications, the targets are generally not moving in accordance with the ideal uniform velocity(CV) model, uniform acceleration(CA) model or Signer model. In general, the kinematic models of the tracking objects are uncertain. When the actual kinematic model and the kinematic model used in calculation is not the same, the model error is generated. In addition, in the traditional Kalman filter, the noise is assumed to be white noise. But in practice, the complexity of the environment, the different light, the object be blocked and other unknown factors that affect noise is very common. This makes the noise of the system is not just white noise. Therefore, only consider white noise will produce errors, and even lead to filter divergence. The adaptive Kalman filter is proposed to solve these problems.

In summary, the adaptive Kalman filter can be divided into two categories:model adaptation and noise variance adaptation. For model adaptation,Blom, early in 1988, H.A.P. and Bar-Shalom, Y proposed an interactive multiple model (IMM) algorithm that can adaptively switch between three models by observing the process noise covariance matrix, in order to obtain a more suitable model [1]. But the disadvantage of this approach is that the algorithm is complexity and large amount of calculation. Zhao put forward an mean and variance of acceleration adaptive algorithm and an error covariance of acceleration adaptive algorithm, adjust kinematic model by acceleration feedback automatically [2], Gao et al. proposed a method that collect the first few moments of state matrix, use function estimation method to calculate the current state matrix and adjust the model [3]. For noise variance adaptation,Murat et al. tested the relationship between turn rate and process noise covariance of the target,proposed a real-time adaptive Kalman filtering algorithm based on the turn rate [4]. In addition, there is an adaptive Kalman filter consider both the model error and the noise error of the [5], reduce the computational work [6], as well as adaptive Kalman filter under the condition of occlusion [7].

Extended Kalman Filter

The traditional Kalman filtering algorithm has a good effect when the system is linear, but in actual application, the vast majority of cases are nonlinear. In this case, the traditional Kalman filtering cannot meet the requirements of the system. For the nonlinear model, we can use mathematical methods to make it approximate the linear model,then estimate it. Extended Kalman filter is a method to estimate the nonlinear model by using above mentioned method.The basic idea of the extended Kalman filter is using first order approximation of Taylor expansion to linearize nonlinear state equation and observation equation, then use traditional Kalman filter to estimate.

In 1971, Bucy et al. proposed an optimal nonlinear filter, called the extended Kalman filter [8]. In 1991, Cortina, Elsa et al. proposed a quasi extended Kalman filter in polar coordinates to track target [9], this filter has a certain effect in the short distance target tracking. In target tracking.Wrong initial value of the target position and velocity will cause a large deviation,even lead to filtering divergence. In order to solve this problem, Anders proposed a constrained extended Kalman filter and optimized the linear model [10]. In order to reduce the model error, adaptive extended Kalman filter [11] and an algorithm combine interacting multiple model filter and extended Kalman filter[12] had been proposed.In addition, there is high order truncated EKF to reduce the error of linear approximation[13], as well as fading memory extended Kalman filtering [14] to reduce the proportion of the prior data and enhance stability.

Unscented Kalman Filter

Extended Kalman filter is a traditional nonlinear filtering method, it has some defects. Because it uses first order truncation of Taylor expansion, ignore the higher-order terms and truncation error will be brought. Therefore,it is suitable for the approximately linear systems, when the target has great nonlinear, it will produce considerable error. Beyond that, extended Kalman filter has a large calculation. To solve the filtering problem in nonlinear system in a better way, Julier and Uhlmann proposed unscented Kalman filter [15] and applied it to target tracking [16]. Unscented transformation is the key of UKF. Unscented transformation use to handle the nonlinear transmission of mean and variance, approximate the probability density of nonlinear function to linear. It’s easier to approximate probability density than function,the calculation is relatively simple, and at least a second-order accuracy [17].

Because of unscented Kalman filter obtains good results in nonlinear filtering, it has been widely used in many fields, especially in the target tracking field, whether it is the radar target [18], infrared target [19] or high maneuvering target [20], using UKF can obtain better tracking effect. Depending on different environment and requirement, various improved UKF have been proposed. In order to reduce the error of the nonlinear model, people put forward interacting multiple model UKF [21], adaptive UKF [22] and UKF based on model error prediction [23]. To reduce the impact of historical data, fading memory UKF had been put forward [24]. In addition, there is augmented UKF to weaken the influence of noise [25], iterative UKF to improve the accuracy of the nonlinear approximation [26] and UKF based on Huber estimation to improve the robustness [27-28].

Key Problems

There are three criteria for determining the performance of a target tracking system: accuracy, real time and robustness.

Accuracy. In order to improve the accuracy of a tracking system, it is necessary to reduce errors caused by various reasons, such as kinematic model error, noise error, and linearization error. In the tracking system based on Kalman filter, the method of reduces kinematic model error is using interacting multiple model and model adaptive algorithm. Noise variance adaptive is commonly used to reduce noise error. The method of reducing linearization error is UKF and improved UKF.

Real time. The hardware structure and the complexity of the algorithm have a great impact on real time of a system. Using high-speed processor and reducing the complexity of the algorithm and computation will make real-time performance improved.

Robustness. At present, the commonly used method to improve the robustness of a system is Huber estimation. It is a robust processing method proposed by Huber to solve the problem symmetric interference in the vicinity of the Gauss distribution [29].

Generally, it is difficult to make the three properties optimally at the same time.

Summary

In this paper, we summarize the research status of maneuvering target tracking based on various Kalman filters and indicate the key problems including the improvement of accuracy, real time performance and robustness.

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