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Square Root Cubature Kalman Filter-Kalman Filter Algorithm for Intelligent Vehicle Position Estimate

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Abstract

A new filtering algorithm, adaptive square root cubature Kalman filter-Kalman filter (SRCKF-KF) is proposed to reduce the problems of amount of calculation, complex formula-transform, low accuracy, poor convergence or even divergence. The method uses cubature Kalman filter (CKF) to estimate the nonlinear states of model while its linear states are estimated by the Kalman filter (KF). The simulation and practical experiment results show that, compared to the extended Kalman filter (EKF) and unscented Kalman filter (UKF).The modified filter not only enhances the numerical stability, guarantees positive definiteness of the state covariance, but also increases accuracy, which has high practicability.

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Keywords: square root cubature Kalman filter; Kalman filter; integrated filter; intelligent vehicle

1. Introduction

Research has shown that the fundamental causes of traffic accident occurring lie in the subjective judgment of driver, about 90% of traffic accidents from the driver's mistake (e.g., Fachinger et al. [1]). In order to improve traffic safety and transportation efficiency, intelligent vehicle receives much recognition in many developed countries, which brings it a rapid development. The premise of driving safety is proving precise navigation information for intelligent vehicle (e.g., Nobe et al. [2]). In short the research of vehicle navigation system is very important. Vehicle navigation is often referred as a nonlinear state estimation problem. The extended Kalman filter (EKF) plays a key role in nonlinear state estimation for decades (e.g., Nobe et al. [2]). However, one of the limitations of

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EKF is the calculation of Jacobian matrices [3], which are the first order approximations of nonlinear process and measurement models. Additionally, EKF has truncation errors, it works well only in which the linear approximation of the nonlinear dynamic system and observation model is valid, that narrows the range of EKF application in practical nonlinear systems [4]. In the past years, a few researchers have focused on advanced algorithms for nonlinear state estimation; for example, sigma-point filters such as unscented Kalman filter (UKF) in Julier and Uhlmann, and cubature Kalman filter (CKF) in Arasaratnam and Haykin, etc [2]. The UKF has attracted the most attention in this area, which the deterministic sampling approach is used to capture the mean and covariance [3]. It is shown that a UKF performs much better than EKF, but its run time is considerably longer [5], due to UKF use deterministic sigma-points to capture the mean and covariance, formative time lags [6]. Furthermore, the UKF needs an additional scaling parameter, for negative, when the number of states is more than 3, the UKF may halt its operation [5]. At the same time, parameters should accurate setup, it is inconvenient to operation from a practical point of view. Although CKF uses deterministic sigma-points as well, CKF only requires 2n cubature points [6]. Theoretically, CKF has better computational speed. Therefore, proposed algorithm fusion frame in CKF

During the real-time implementation of KFs, the propagated error covariance matrices may become ill conditioned. These types of ill-conditioned covariance matrix may cause numerical instability during the on-line implementation, even cause the filtering divergence [7]. To handle these difficulties, one can use square-root filters, which propagate and update square root of the error covariance with performing Cholesky decomposition at each step , and they are ensure positive semi-definiteness of the state estimation covariance matrix [8]. Some of the key properties of square-root filters are positive definite error covariance and improved numerical accuracy, etc [9].

2. Square root cubature kalman filter -kalman filter

In this subsection, the derivative square-root cubature Kalman filter-Kalman filter for nonlinear systems is derived. It means that, the proposed algorithm is derived from the square-root CKF and KF, the square-root CKF is used to complete nonlinear state estimation and the KF filter can deal with linear state estimation. The square-root cubature filter-Kalman filter has strong stability and high precision. Consider the following process and observation models [8].

$$\begin{cases} x_k = f(x_{k-1}) + w_{k-1} \\ z_k = h(x_k) + v_{k-1} \end{cases} \tag{1}$$

where x_k and z_k represent the state of the system and measurement at time instant k , respectively. $f(\bullet)$ and $h(\bullet)$ are known vector mappings, $w_k \sim N(0, Q_k)$ and $v_k \sim N(0, R_k)$ are the state and measurement white noises respectively and are mutually independent. The cubature rule to approximate an n-dimensional Gaussian weighted integral is：

$$I(f) = \int_{R^n} f(x)\exp(-x^T x)dx. \tag{2}$$

where $f(x)$ is the arbitrary function. R^n is domain of integration. x^T is the transposed of x .The integral equation is difficult to solve in the general condition. Approximation for a set of points with weight $(\omega_{i,}\xi_i)$ as follow

$$I(f) = \sum_{i=1}^{m} \omega_i f(\xi_i) \tag{3}$$

CKF select 2n cubature points based on spherical-radial criterion, n denote the dimensions of state.

where ξ_i is the i th cubature point located at the intersection of the unit sphere and its axes, ω_i is corresponding weight to cubature point. Thus it can be seen that CKF use $2n$ points which are equally likely to calculated by Gaussian integration directly.

Then, the square root cubature Kalman filter-Kalman filter for state estimation problem contains the following sections.