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Original article

A new EP-based α–β–γ–δ filter for target tracking

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Abstract

This study explores a new fourth-order target-tracking α–β–γ–δ filter using an evolutionary programming (EP) for numerical simulation in view that the current third-order α–β–γ filter system tracks only the target's position and velocity but not its acceleration. As demonstrated, the new α–β–γ–δ filter exhibits a significantly improved tracking accuracy over the conventional α–β–γ filter. Not unexpectedly, however, the new α–β–γ–δ filter takes more computation time in the optimization process. To overcome this weakness, an optimal simulation technique via EP is proposed. The developed EP-based α–β–γ–δ filter finds not only the optimal set of filter parameters to minimize position tracking errors but could also reduce the computation time by up to 95% in some time steps. The trajectory simulated by the EP-based α–β–γ–δ filter is compared with those by other filters to illustrate the efficiency of the former filter.

Keywords: Target tracker; Evolutionary programming; The α–β–γ–δ filter; The α–β–γ filter; The EP-based α–β–γ–δ filter

1. Introduction

Target tracking is an important tool used in modern societies to track fast-moving objects of interest, e.g., airplanes, missiles, submarines, and others. Many mathematical models have been formulated to manipulate the target tracking system. The basic model consists of an algorithm to process the discrete-time data to describe the kinematics of a dynamic object. In the mid 1950s, relatively simple α–β and α–β–γ filter trackers [11,17] were developed to deal with this problem. In the α–β filter system, as described in Sklansky [18], the target tracking was achieved utilizing a mathematic optimization process similar to that used in the radar system. Subsequently, various optimal target-tracking algorithms have been investigated [1,12]. Tenne and Singh [19] reported the optimal design of the third-order α–β–γ filter. Recently, Lee et al. [14] developed a real-coded genetic algorithm in the α–β–γ filter to search for the optimal parameter values. The proposed method effectively improved the maneuverability and performance of the α–β–γ filter while keeping the noise level within an acceptable range.

In perspective, the third-order filter is capable of predicting the target's next position and velocity based on the current and past positions and velocities. To further predict the acceleration and improve the tracking accuracy, an

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additional state variable called *jerk*, a time derivative of acceleration, must be inserted. The addition of *jerk*, however, increases greatly the computation time for the optimal filter parameters (i.e., α, β, and γ). A practical technique for optimal simulation via evolutionary programming (EP) is recommended to reduce the computation time. As a numerical optimization method, EP offers an efficient optimization for finding the optimal parameters (i.e., α, β, γ and δ) as the final output values. Fogel et al. [6] were the first to use the simulated evolution via EP as a learning process to generate artificial intelligence. Since then, the applicability of EP has been widely investigated [4,9,13,20].

In this paper, the fundamental mathematic formulations of the α–β–γ and α–β–γ–δ filters are introduced first, followed by their numerical simulations of tracking a highly nonlinear function. The EP algorithm is then introduced to the α–β–γ–δ filter; the associated tracking errors of the three filter systems (i.e. α–β–γ, α–β–γ–δ, and EP-based α–β–γ–δ filters) and the computation times of the α–β–γ–δ filter with/without EP are compared. The simulated results by use of the three filters are included for comparison to illustrate the modeling efficiency.

2. Mathematical model

The third-order α–β–γ filter identifies the object's next position and velocity based on the current and past positions and velocities. The following governing equations for the object's position and velocity are extracted from Tenne and Singh [19]:

$$x_p(k+1) = x_s(k) + Tv_s(k) + \frac{1}{2}T^2 a_s(k) \tag{1}$$

$$v_p(k+1) = v_s(k) + Ta_s(k) \tag{2}$$

where T is the time step or the time increment, x is the position, v is the velocity, and a is the acceleration; subscripts p and s denote the predicted and smoothed state values, respectively.

The parameters are derived with the previously predicted values and the weighted innovation described as follows:

$$x_s(k) = x_p + \alpha(x_o(k) - x_p(k)) \tag{3}$$

$$v_s(k) = v_p + \frac{\beta}{T}(x_o - x_p(k)) \tag{4}$$

$$a_s(k) = a_p(k-1) + \frac{\gamma}{2T^2}(x_o(k) - x_p(k)) \tag{5}$$

where subscript o denotes the exact value, in mathematics and signal processing, and the Z-transform converts a discrete time-domain signal, which is a sequence of real or complex numbers, into a complex frequency-domain representation. In essence, the Z-transform is a discrete equivalent of the Laplace transform. Just as the analog filters are designed using the Laplace transform, the recursive digital filters are developed with a parallel technique called the Z-transform.

From Eqs. (1)–(5), the ratio (x_p/x_o) is applied and solved by the Z-transform. The transfer function in the z-domain is given by;

$$G(z) = \frac{x_p}{x_o} = \frac{\alpha + (-2\alpha - \beta + (1/4)\gamma)z + (\alpha + \beta + (1/4)\gamma)Z^2}{Z^3 + (\alpha + \beta + (1/4)\gamma - 3)Z^2 + (-2\alpha - \beta + (1/4)\gamma + 3)z + \alpha - 1} \tag{6}$$

The Jury's stability test [16] yields the constraints on the α, β, and γ parameters for the α–β–γ filter, as shown below. This test is also used to find the stability domain for the characteristic polynomial (CP) of Eq. (6).

$$0 < \alpha < 2 \tag{7}$$

$$0 < \beta < 4 - 2\alpha \tag{8}$$

$$0 < \gamma < \frac{4\alpha\beta}{2 - \alpha} \tag{9}$$