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Efficient jitter compensation using double exponential smoothing

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ABSTRACT

This paper proposes a new jitter reduction scheme based on double exponential smoothing (DES). We compare this DES-based method to jitter reduction methods based on the Kalman filter (KF) and extended Kalman filter (EKF), two well-known methods of jitter reduction. To evaluate the jitter reduction performance, we used a laser pointer interaction system with a known problem with jittery laser spot movements caused by natural hand tremors. We show that the DES-based scheme runs approximately 100 times faster than the EKF-based method and 19 times faster than the KF-based method. Furthermore, in terms of jitter reduction, the proposed DES-based method yields approximately 18% better results than the EKF-based method and 20% better results than the KF-based method.

1. Introduction

Laser pointer interaction is a camera-based system which tracks a laser spot on a projection screen to manipulate an application on the screen [3,4,12,14]. In this interactive system, the laser pointer is used as an input device to control the movement of the cursor in the application. One systemic problem, however, is that the user's natural hand tremors cause jitters in the laser spot, and it is therefore difficult to place the cursor precisely onto a small target on the screen. To reduce these jitters, Oh and Stuerzlinger [11] introduced a method utilizing a single Kalman filter (KF). Konig et al. [5] developed a method based on multiple KFs, and Matveyev et al. [9] adjusted the KF's measurement covariance matrix.

The KF and EKF (extended Kalman filter) [10,13,17,18] methods are among the best known for jitter reduction (these methods are also used to track a moving object with a sensor network [7] and to make predictions of sensory input in an artificial cognitive system [8]). However, the KF and EKF methods have a critical weakness: both require computationally expensive operations, such as matrix inversion, to work properly. In this paper, we propose a new jitter reduction scheme based on double exponential smoothing (DES) [16], a popular technique used in business and economics to predict a trend of time series data with simple linear equations. According to the results of our study, the DES jitter compensation method runs faster and performs better than the EKF and KF methods. In fact, the DES method runs approximately 100 times faster than the EKF method and 19 times faster than the KF method, while yielding results that are approximately 18% and 20% better in terms of jitter reduction than the EKF and KF methods, respectively.

To the authors' best knowledge, the method proposed in this paper is the first attempt to utilize the concept of DES for jitter compensation. Although LaViola [6] employed DES for predictive tracking of user position and orientation in a virtual environment, LaViolas DES and our DES are dissimilar for the following reasons: (a) different forms of linear equations are

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used to implement the DES, which is the most significant difference; (b) LaViola has one weighting parameter, while we have two; and (c) LaViola's parameter is static, but our parameters are dynamic and adaptive.

Understandably, the proposed DES method may be useful in many other areas of application, such as microsurgery [2,15], domotics (also known as home automation) for the disabled and elderly [1], and other fields. In microsurgery, for example, tremor reduction is extremely important because a surgeon's hand tremor affects the results of the microsurgical operations. In smart homes for disabled or elderly people, a laser pointer is used to interact with home devices and stabilize the jittery laser spot movements caused by the shaky hands of elderly or disabled people, which is essential for correct and safe control of the devices.

In Section 2, we describe the EKF method of jitter compensation for the sake of comparison before we set forth the details of our DES method of jitter compensation. The experimental results are shown and explained in Section 3, and brief concluding remarks are given in Section 4.

2. Two jitter compensation methods

2.1. EKF-based jitter compensation

Given a noisy measurement of the laser spot in a laser pointer interaction system, the goal of the EKF method of jitter compensation is to produce a smoothed cursor position with extended Kalman filter equations. Assume that at a time instant t_k, the cursor passes though a position $[x_k, y_k]^T$ with a velocity $[x'_k, y'_k]^T$ and that $\boldsymbol{x}_k = [x_k, y_k, x'_k, y'_k]^T$ is a state vector of our process. The process function $\boldsymbol{f}$ can then be modeled as follows to describe the evolution of this state vector over time:

$$\boldsymbol{x}_k = \boldsymbol{f}(\boldsymbol{x}_{k-1}, \boldsymbol{w}_{k-1}) = \begin{bmatrix} x_{k-1} + x'_{k-1}\Delta t + w_1 \\ y_{k-1} + y'_{k-1}\Delta t + w_2 \\ x'_{k-1} + w_3 \\ y'_{k-1} + w_4 \end{bmatrix}, \tag{1}$$

where $\Delta t = t_k - t_{k-1}$ is a constant for a time interval and the process noise vector $\boldsymbol{w}_k$ is normally distributed with $N(0, \boldsymbol{Q})$. Similarly, the measurement function $\boldsymbol{h}$ that relates the state vector $\boldsymbol{x}_k$ to the measured cursor position $\boldsymbol{z}_k$ can be defined as

$$\boldsymbol{z}_k = \boldsymbol{h}(\boldsymbol{x}_k, \boldsymbol{v}_k) = \begin{bmatrix} x_k + v_1 \\ y_k + v_2 \end{bmatrix}, \tag{2}$$

where the measurement noise vector $\boldsymbol{v}_k$ is also normally distributed with $N(0, \boldsymbol{R})$. Additional definitions are provided below in the description of the EKF equations.

- $\boldsymbol{A}$ is the Jacobian matrix of partial derivatives of $\boldsymbol{f}$ with respect to $\boldsymbol{x}$; $\boldsymbol{w}$ is the Jacobian matrix of partial derivatives of $\boldsymbol{f}$ with respect to $\boldsymbol{w}$; $\boldsymbol{H}$ is the Jacobian matrix of partial derivatives of $\boldsymbol{h}$ with respect to $\boldsymbol{x}$; and $\boldsymbol{V}$ is the Jacobian matrix of partial derivatives of $\boldsymbol{h}$ with respect to $\boldsymbol{v}$.

$$\boldsymbol{A} = \begin{bmatrix} 1 & 0 & \Delta t & 0 \\ 0 & 1 & 0 & \Delta t \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad \boldsymbol{W} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix},$$
$$\boldsymbol{H} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}, \quad \boldsymbol{V} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}.$$

- $\hat{\boldsymbol{x}}_k^-$ is the *a priori* state estimate, $\hat{\boldsymbol{x}}_k$ is the *a posteriori* state estimate, $\boldsymbol{P}_k^-$ is the *a priori* error covariance, and $\boldsymbol{P}_k$ is the *a posteriori* error covariance.

The EKF-based jitter compensation algorithm works as follows:

1. Initialize $\hat{\boldsymbol{x}}_0, \boldsymbol{P}_0$, $\boldsymbol{Q}$, and $\boldsymbol{R}$, and set $k = 1$.
2. (Prediction step) Compute both the *a priori* state estimate and the *a priori* error covariance estimate at the time t_k.

$$\hat{\boldsymbol{x}}_k^- = \boldsymbol{f}(\hat{\boldsymbol{x}}_{k-1}, 0),$$
$$\boldsymbol{P}_k^- = \boldsymbol{A}_k \boldsymbol{P}_{k-1} \boldsymbol{A}_k^T + \boldsymbol{W}_k \boldsymbol{Q}_{k-1} \boldsymbol{W}_k^T.$$

3. Compute the optimal Kalman gain $\boldsymbol{K}_k$.

$$\boldsymbol{K}_k = \boldsymbol{P}_k^- \boldsymbol{H}_k^T (\boldsymbol{H}_k \boldsymbol{P}_k^- \boldsymbol{H}_k^T + \boldsymbol{V}_k \boldsymbol{R}_k \boldsymbol{V}_k^T)^{-1}.$$

4. (Correction step) Obtain a measured 2D position $\boldsymbol{z}_k$ of the laser spot, and compute both the *a posteriori* state estimate and the *a posteriori* error covariance estimate.