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# Chaotic particle filter for visual object tracking☆

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ABSTRACT

In this paper, a chaotic particle filter method is introduced to improve the performance of particle filter based on chaos theory. The methodology of the algorithm includes two steps. First, the global motion estimation is used to predict target position using dynamical information of object movement over frames. Then, the color-based particle filter method is employed in the local region obtained from global motion estimation to localize the target. The algorithm significantly reduces the number of particles, search space, and the filter divergence because of high-order estimation. To verify the efficiency of the tracker, the proposed method is applied to two datasets, consisting of particle filter-based methods under the Bonn Benchmark on Tracking (BoBoT), the large Tracking Benchmark (TB), and Visual Object Tracking (VOT2014). The results demonstrate that the chaotic particle filter method outperforms other state-of-the-art methods on the abrupt motion, occlusion, and out of view. The precision of the proposed method is about 10% higher than that of other particle filter algorithms with low computational cost.

## 1. Introduction

The main objective in a visual tracking is to localize a target in video sequences. Object tracking is an important topic in computer vision which has many real-world applications, including traffic management [1], robot localization [2], and human-computer interfaces [3]. A tracking system consists of two main components: visual representation [4] and motion estimation [5]. Designing a stable and accurate system is a challenging task because of fast motion, low frame rate, and uncertain motion in the real world problems. In the motion estimation step of tracking, uncertainty or nonlinearity of object dynamics is modeled to localize an object in video sequences. The tracking methods can be categorized into two groups; namely deterministic [6] and stochastic [7] methods for motion estimation. The mean shift algorithm is a deterministic tracker which exploits a region to maximize similarity measure iteratively. The algorithm may drift in the occlusions, similar color distribution of foreground and background, and long video sequences [8]. In contrast, stochastic trackers employ statistical to localize the target position for object tracking. The Kalman filter method is developed for linear and a Gaussian observational noise [9] as a sequential stochastic way, which cannot be applied to nonlinear movement.

The particle filter method keeps the nonlinearity and uncertainty of the model evaluation and analysis steps in visual tracking [10]. In particle filter, the target state $x_t$ and the observation $z_t$ at time $t$ are considered to find the target states. The observations from the first frame up to the $t$ -th frame is $z_{1:t}$. In the particle filter, the posterior distribution can be defined using approximation model of Chapman-Kolmogorov equation using the set of particles $\{x_1^t, x_2^t, \ldots, x_N^t\}$ and the weights $\{w_1^t, w_2^t, \ldots, w_N^t\}$ [11].

$$w_t^i = w_{t-1}^i \frac{p(z_t|x_t^i)p(x_t^i|x_{t-1}^i)}{q(x_t^i|x_{t-1}^i, z_t)} \tag{1}$$

where $q$ is the importance density function. The posterior distribution of the previous time is $p(x_{t-1}|z_{1:t-1}) \approx \sum_{i=1}^{N} w_t^i \delta(x_t - x_t^i)$, where $\delta(\cdot)$ is the Dirac delta function with condition $\sum_{i=1}^{N} w_t^i = 1$, and $1 \leqslant i \leqslant N$ at the previous time. In particle filter method, multimodal distribution may lead to noisy estimation of the target position [12]. Many extended particle filters have been proposed to improve the weaknesses of particle filter in object tracking, including Fuzzy based particle filter [13], iterative particle filter (IPF) [14], and particle filter based on human motion model [15]. Kalman and particle filters have main limitations in motion model and high-dimensional search for visual object tracking.

To improve the global search of particle filter, some algorithms have been introduced based on Kalman filter [16] or meanshift methods [17,18]. Hierarchical Kalman-particle filter (HKP) introduced the coarse-to-fine strategy for global and local motion using Kalman and particle filter respectively [19]. Mean shift algorithm is embedded into

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particle filter to reduce the number of particles [20]. These global motion estimation methods use the information of one previous frame for tracking, while the previous frame cannot provide enough information to track object. Also, these algorithms can track object based on stochastic process. To solve these weaknesses, we use chaos theory for high-order estimation.

Chaos theory is a field of mathematics, which focuses on the behavior of dynamical systems. The chaos theory is a random-like system, which has a deterministic attractor in the state space. The concept of deterministic chaos, with properties, including ergodicity, randomness, and sensitive to initial conditions, has an important impact on signal and image processing [21–23] and mathematics [24–28]. Abdechiri et al. [29] presented chaotic multi-instance learning (CMIL) as a tracking by detection method to balance local and global feature for object representation based on chaos theory. To handle different dimensions of each instance for online multi-instance learning (MIL) and to find a low-dimensional feature vector, Abdechiri et al. [30] introduced multiple chaotic instance learning (MCIL) for visual object tracking. The main drawback of the tracking by detection methods is the complexity cost of training phase in classifiers, which acquired with losing motion information.

Therefore, multi-step ahead prediction (MSP) method has been presented to handle the problems based on chaos theory [31]. The weaknesses of MSP are 2D object tracking (Ikeda map in chaotic system) for global search and ensemble members for local search. In this paper, we propose a chaos-based object tracking to improve the weaknesses of MSP. Therefore, we apply pseudo-orbit data assimilation (PDA) method [32] as 2D-global search for high-order estimation and particle filter as multi-dimensional local search to accurately track object.

In this paper, a new particle filter based tracker using chaotic motion estimation is introduced. The proposed algorithm overcomes motion uncertainty with a chaotic motion estimation. This tracker performs a global motion estimation based on the states predicted over past frames to obtain a local region for local motion estimation. Then, the particle filter is applied to a local region obtained from the global estimation step for state correction. The main contributions of this paper are as follows:

- The first contribution of this paper is the global-local estimation method for generating more informative samples, which reduces the number of particles in particle filter method.
- The second contribution of this paper is to improve high-order motion estimation in stochastic methods. Inspired by the success of chaos theory in object tracking [29–31], we propose a chaos-based object tracking to extract the motion dynamics of object for tracking based on PDA. The high-order estimation aids to reduce the tracking error using rich information of motion, while particle filter uses one-order motion estimation. Therefore, the chaotic particle filter method is a robust object tracking under occlusion and irregular motion, while the traditional particle filter cannot handle these challenges.
- The third contribution of this paper is to introduce a chaotic approach for tracking instead of stochastic methods, which reduces the complexity cost. The chaos-based methods are efficient to search space [25,26] which is an important tool for global search in real time tracking.
- The fourth contribution of this paper is to improve 2D chaotic tracker of MSP. The mains goal is to accurately estimate the states of object, while MSP is 2D object tracking. The paper introduces a new algorithm, which is suitable for multi-dimensional state estimation based on chaos.

The results indicated that the chaotic particle filter method increases the performance of the traditional particle filter in nonlinear movement and abrupt motion changes. The proposed algorithm decreases the number of particles and the filter divergence. The performance of the proposed method is better than the performance other particle filter methods under the Bonn Benchmark on Tracking (BoBoT) [33]. The proposed method can handle fast motion, occlusion, and out of view challenges on the large Tracking Benchmark (TB) [34] and Visual Object Tracking (VOT2014) challenges [35].

The paper is organized into several sections. The chaotic modeling and prediction of nonlinear dynamics is described in Section 2. Section 3 explains the architecture of the proposed method; the chaotic dynamics of object movement in video sequences are also explained. In Section 4, the effectiveness of the chaotic particle filter method is validated for different challenges. Finally, Section 5 concludes this paper with some suggestions for future research.

## 2. Chaotic modeling and prediction of nonlinear dynamics

There have been many methods to process nonlinear dynamics based on chaos theory [36,37]. In these methods, a chaotic system such as Lorenz or Logistic map can be used to map the observations onto the chaotic attractors. Pseudo-orbit data assimilation (PDA) is a state estimation method based on chaos [32,38]. In PDA method, an optimization function based on gradient of a chaotic map is applied to search the state space for finding a reference trajectory. The chaotic trajectory and the observations in state space as can be seen in Fig. 1.

The optimization method reduces the mismatches of observations and the points of model as can be seen in Fig. 2.

In PDA, Ikeda map is considered as the chaotic system $F$ [32]. The discrete system $F$ is

$$F = \begin{cases} x_{n+1} = \gamma + u(x_n\cos\phi - y_n sin\phi) \\ y_{n+1} = u(x_n\sin\phi - y_n\cos\phi) \end{cases} \tag{2}$$

where $\phi = \beta - \alpha/(1 + x_n^2 + y_n^2)$, $\alpha = 6$, $\beta = 0.4$, $\gamma = 1$, and $u = 0.83$. In optimization process, for each window with $m$ observations, some points $u_n$ are trajectory and some of them are not [31,32]. A pseudo orbit $U = \{u_{-m+1},...,u_{-1},u_0\}$ is considered as a point in the $m \times n$ dimensional state space for which $U_{n+1} \neq F(u_n)$. The gradient algorithm minimizes the errors

$$e_n = |F(u_n) - u_{n+1}|, n = -m+1,...,-1 \tag{3}$$

with the cost function

$$C(U) = \sum e_n^2. \tag{4}$$

The pseudo orbit $U$ is obtained by

$$\frac{\partial C(U)}{\partial u_n} = 2 \times \begin{cases} -[u_{n+1} - F(u_n)]d_nF(u_n) & n = -m+1 \\ [u_n - F(u_{n+1})] - [u_{n+1} - F(u_n)]d_nF(u_n) & -m+1 < n < 0 \\ u_n - F(u_{n-1}) & n = 0 \end{cases} \tag{5}$$

where $d_nF(u_n)$ is the Jacobian matrix of $F$. In each step, the pseudo

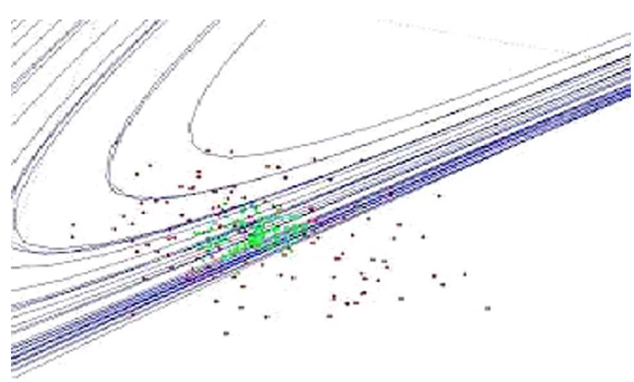

**Fig. 1.** Pseudo-orbit data assimilation framework [32].