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Adaptive parameter identification tracking based on particle filter for airborne laser communication

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Abstract: Airborne laser communication has became the main way of large capacity space communication for the future, high precision dynamic tracking system of airborne platform has already been one of the most difficult problem. In order to resolve the diversity of maneuvering forms for airborne platform, adaptive parameter identification with particle filter was put forward in the paper, in the continuous time domain, parameter identification model based on three order linear differential equation was applied to describe the motion of airborne laser platform, which can cover a wide variety of motion modes, the particle filter can deal with nonlinear/non-Gaussian problems, it can be introduced into parameter identification model. The results show that this algorithm can improve the convergence precison, which have some significance in engineering application.

Key words: airborne laser communication;　tracking;　parameter identification;　particle filter

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粒子滤波的机载激光通信自适应参数辨识跟踪方法

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摘　要： 机载空间激光通信是实现未来超大容量空间通信的主要途径，机载空间激光通信终端的高精度实时动态跟踪一直是其研究的难点问题。为了解决机载空间激光通信终端的机动形式多样性的问题，提出了自适应参数辨识粒子滤波方法。在连续的时间域中，基于三阶线性微分方程的参数辨识模型描述机载空间激光通信终端运动，该模型能适应机载激光通信终端的多种运动模式，粒子滤波能处理非线性/线性高斯问题，因此可以引入到参数辨识模型中。实验结果表明：该算法能改善收敛精度，对工程应用也有重要意义。

关键词： 机载激光通信；　跟踪；　参数辨识；　粒子滤波

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0 Introduction

In recent years, free space laser communication based on airborne platforms has became a research hotspot, the main developed countries and organizations, such as the United States, Japan and ESA have carried out airborne laser communications[1-3]. Because of the typical nonlinear/non-Gaussian problems in the tracking of the airborne platform[4-5], it is a huge challenge for airborne platform communication terminals to establish stable optical communication link[6].

Nowadays, the classical tracking algorithm in space laser communication includes linear regression filtering, Wiener filtering, Weighted Minimum Mean Square filtering, $\alpha-\beta-\gamma$ filtering and Kalman filtering etc[7-9], but while the model changes, these methods will bring about the decline or divergence in tracking performance. The interacting multiple model (IMM) estimation algorithm attracts more and more attention in good estimation performance, considering the computational burden; it is difficult to realize real-time processing of observation data[10]. In view of the above problems, this paper combines online parameter identification and particle filter (PF)[11-12], by virtue of the recursive least square method, the algorithm can overcome the data saturation and estimate divergence effectively. Through simulation and comparison, the parameter identification method can adapt the mutative tracking multiple motion models, and has good dynamic tracking accuracy.

1 Tracking model based on parameter identification

1.1 Model description

In the continuous time domain, airborne laser communication terminal motion equation based on third-order differential equations can be expressed as[13]:

$$\dddot{x}=a\ddot{x}+b+n(t) \tag{1}$$

Where a, b are the parameter of identification model; $n(t)$ is white noise with zero mean value.

Model can be identified by the parameter estimate of a and b, the state equation can also be expressed as:

$$\begin{aligned}&\dot{x}_1=x_2(t)\\&\dot{x}_2=x_3(t)\\&\dot{x}_3=ax_3(t)+b+n(t)\\&x(t)=x_1(t)\end{aligned} \tag{2}$$

As can be seen from Eq. (2), the parameters a, b determine the change rate of acceleration in tracking model, a denotes the correlation coefficient, b denotes the constant of change rate, according to the different combinations of a,b, parameter identification model covering many kinds of motion modes for the airborne laser communication terminal.

1.2 Parameter identification

In order to simplify the above problems, the tracking condition is assumed in the one-dimensional case, by Euler algorithm in two-step format, Eq. (1) can be discretely expressed as[14-15]:

$$\begin{aligned}&x_1(k+1)=x_1(k-1)+2hx_2(k)\\&x_2(k)=x_2(k-2)+2hx_3(k-1)\\&x_3(k-1)=x_3(k-3)+2h[ax_3(k-2)b+e(k-2)]\end{aligned} \tag{3}$$

Where h denotes the selection step, $e(k)$ denotes the model residuals.

By the difference quotient differential quadrature formula, above formula can be further transformed as follows:

$$\begin{aligned}x_2(k-2)&=\frac{1}{2h}[x_1(k-1)-x_1(k-3)]\\x_3(k-2)&=\frac{1}{h}[x_2(k-1)-x_1(k-2)]\\&\frac{1}{h^2}[x_2(k-1)-2x_1(k-2)+x_1(k-3)]\\x_3(k-3)&=\frac{1}{h}[x_2(k-2)-x_1(k-3)]\\&\frac{1}{h^2}[x_2(k-2)-2x_1(k-3)+x_1(k-4)]\end{aligned} \tag{4}$$

According to above formulas, linear equation with a and b can be derived as follows:

$$\begin{aligned}&\Phi(k)=\lambda_1(k)a+\lambda_2(k)b+e_r(k)\\&\lambda_1(k)=8hx_1(k-1)-16hx_1(k-2)+8hx_1(k-3)\\&\lambda_2(k)=8h^3\end{aligned}$$

$$e_r(k)=8h^3e(k-2) \tag{5}$$

Eq.(5) also can be further transformed into matrix as follows:

$$\begin{bmatrix} \Phi(k) \\ \lambda_1(k) \\ \lambda_1(k) \end{bmatrix} = \begin{bmatrix} 1 & 0 & -2 & -4 & 9 & -4 & 0 \\ 0 & 0 & 8h & -16h & 8h & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x(k+1) \\ x(k) \\ x(k-1) \\ x(k-2) \\ x(k-3) \\ x(k-4) \\ 8h^3 \end{bmatrix} \tag{6}$$

By the sequence dynamic observation $X(k)$, vector equation can be built as follows :

$$\Phi(k)=\lambda v+E_r(k) \tag{7}$$

Where $\Phi(k)$、λ and $E_r(k)$ can be defined as follows :

$$\Phi=[\Phi(1)\ \ \Phi(2)\ \cdots\ \Phi(k)]^T$$

$$\lambda=\begin{bmatrix} \lambda_1(1) & \lambda_2(1) \\ \lambda_1(2) & \lambda_2(2) \\ \cdots & \cdots \\ \lambda_1(k) & \lambda_2(k) \end{bmatrix}$$

$$v=[a\quad b]^T \tag{8}$$

In order to fully pay attention to the new observation data, the observation data can be weighted to decay old data. The improved recursive least squares method can be expressed as follows:

$$J=\sum_{k=1}^{m} e_r^2 W(k)=E_r^T WE_r$$

$$W=\mathrm{dig}[w(1)\quad w(2)\quad \cdots\quad w(m)]$$

$$w(k)=ar^{N-k} \tag{9}$$

Where $\alpha>0$, $0<r<1$, the function J can be minimized to get optimal solution for parameter v, the solution can be expressed as follows:

$$\hat{v}=[\lambda^T W\lambda]^{-1}\lambda^T W\Phi \tag{10}$$

2 Particle filter

PF with important resampling strategy is summarized as follows:

(1) Particles initialize: Particle swarm $\{x_i^j(0)\}_{j=1}^N$ is generated by the priori probability; all particle weights are $1/N$;

(2) At time k, the particle weights are updated to

$$\omega_k^i \propto \omega_{k-1}^i \frac{p(zk/x_k^i)p(x_k^i/x_{k-1}^i)}{q(x_k^i/x_{k-1}^i,z_k)} \tag{11}$$

(3) Normalized particle weights are computed by

$$\tilde{\omega}_k^i=\omega_k^i/\sum_{i=1}^{N}\omega_k^i \tag{12}$$

(4) The predicted state is:

$$\hat{x}_i(k)\approx\sum_{j=1}^{N}\omega_k^i x_k^i \tag{13}$$

The above equation constitute the basic process of recursive PF algorithm, as can be known from derivation process, the particle filter is easy to nonlinear/non - Gaussian problems.

By recursive least squares and PF together, it is possible to realize the adaptive parameter estimation, the state transition matrix can be determined by parameter a, b. The algorithm process is shown in Fig.1.

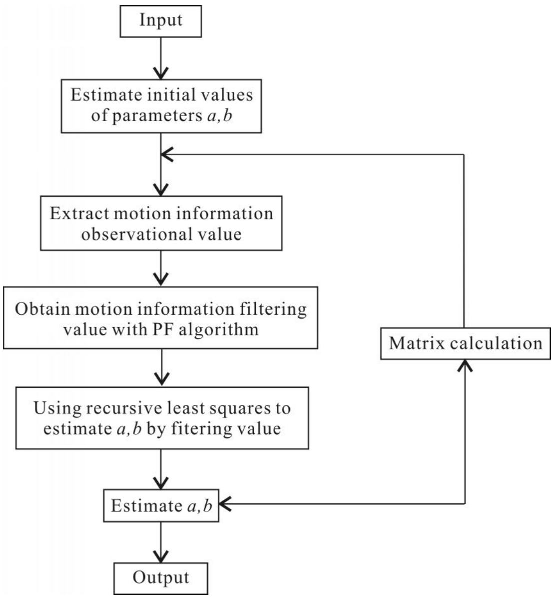

Fig.1 Flow chart of parameter identification

3 Simulation experiment

It is difficult to test tracking performance of airborne platform in real environment, so it is necessary to creatively build simulation test system, and verify the validity and reliability of the tracking theory. This paper presents a new method that use lase beam to simulate airborne platform motion, laser on two -dimensional turntable is emitted to form various motion modes of airborne laser communication terminal in wall, which include circular, linear uniform speed and acceleration etc, as shown in Fig.2.

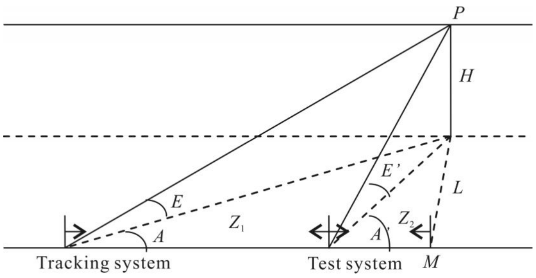

Fig.2 Simulation experimental system

In Fig.2, the triangular relationship can be deduced as follows:

$$A'=\arctan(\frac{L}{Z_2})$$
$$E'=\arctan(\frac{H}{\sqrt{L^2+Z_2^2}}) \quad (14)$$

Where L is the shortest level distance from wall to the laser turntable.

Similarly, angle equation in tracking system can be established as follows:

$$A=\arctan(\frac{L}{Z_1+Z_2})$$
$$E=\arctan(\frac{H}{\sqrt{L^2+(Z_1+Z_2)^2}}) \quad (15)$$

Through the above relationships, angle relationship can be built to test the dynamic tracking performance.

In order to simulate the high-speed, high mobility (acceleration and steering) characteristics for laser communication terminal, in lab, laser on two - dimensional turntable is driven to simulate terminal movement according to programming regular via the synthesis of velocity, which realize clockwise circular motion (6 (°)/s)-uniform linear (0.2 m/s) - Anti-clockwise circular motion (3 (°)/s) - clockwise circular motion (6 (°)/s) - uniformly accelerated rectilinear (0.2 m/s^2), the total duration of 120 s, the trajectory as shown in Fig.3.

Tracking error in azimuth and pitching angle is shown as

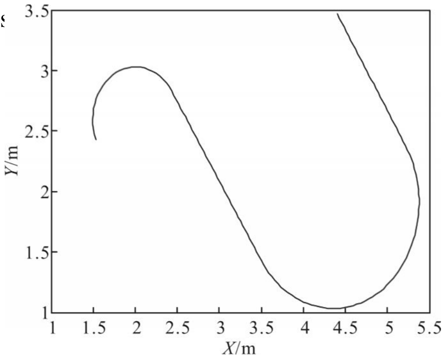

Fig.3 Simulation of airborne terminal trajectory

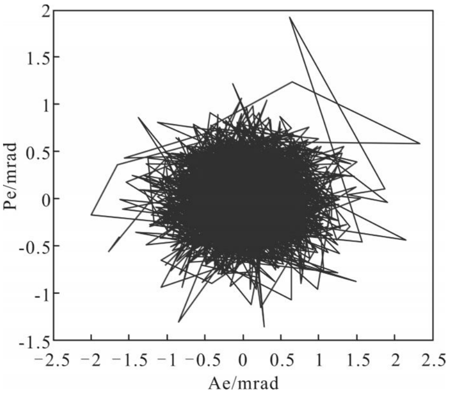

Fig.4 Tracking error with the parameter identification

With respect to the Fig.4, communication terminal keeps the stronger maneuverability, the tracking error is generally less than 2 mad, when the motion form changes, the tracking algorithm always keeps the better stability, the tracking error basically maintains within 3 mrad. Assume 3 mrad field of view in fine tracking, it is only 1.5 s for tracking system to cause lost lock phenomenon, which is mainly the result of program running reaction in initial stage of tracking.

Assume 3 mrad field of view in fine tracking, separately from four indicators to analysis tracking performance with different algorithms, which is shown as Tab.1.

Tab.1 Tracking effect

	Parameter identification with PF	Kalman
Error margin /mrad	2.8	5.2
RMSE/mrad	0.6	1.5
Response time/s	3.6	6.3
Lose tracking/s	1.5	13.7

4 Conclusion

Parameter identification with PF can overcome the limitations of the traditional single model tracking through effective automatic dynamic parameter adjustment. This paper presents a new method that adopt laser beam to simulate airborne laser communication terminal motion, at the same time, the experiments show that the algorithm has good tracking performance and strong robustness.

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