The Data Processing of Single-yarn Strength Testing Based on the Particle Filter Algorithm

Honghai Li, Yujiao Liu

1 HuaiYin Institute of Technology, HuaiAn, China, honghaili@gmail.com
2 Nanjing University of Aeronautics and Astronautics, Nanjing, China, liuyujiao2005@126.com

Abstract

Aiming at a nonlinear/non-Gaussian filter problem, the data processing of a single-yarn strength testing system, a filtering method based on the particle filter algorithm is put forward. This paper expounds the principle, and the working process and the procedures of particle filter. It discusses in detail the application of particle filter in the single-yarn strength testing, the modeling of testing system state equation, and the implementation of this algorithm in a project. It also indicates that particle filter algorithm used to process single-yarn strength test data achieves a good effect and satisfactory filtering precision by simulated tests. Finally, this paper predicts that particle filter will play an important role in general data processing and analyzing.

Keywords: Particle Filter; Single-Yarn Strength; State Equations; Data Processing

1. Introduction

The detection of the yarn quality is very important for cotton production. Yarn strength is the reflection of inner quality of yarn and is the necessary condition of yarn’s processing performance and end-use. The unit of single-yarn strength is Newton (N) per centimeter (CN). By stretching testing with a single-yarn strength tester, the yarn’s characteristic parameters will be obtained, and the physical index of breaking strength, breaking elongation, fracture strength, fracture time and strength tensile curves can be determined, so the quality of yarn will be ascertained [1]. This paper majors in the research of the parameter of the single-yarn strength of yarn.

The strength of yarn will increase with increasing within a certain twist; however the strength of yarn will decrease when the twist exceeds the critical value. The relationship between yarn elongation and tension is often nonlinear. When the yarn quality is tested by single-yarn strength tester, the interference noise of test environment in the industrial field is non-Gaussian. So the processing of single-yarn strength testing data is a typical nonlinear and non-Gaussian filtering problem. The traditional digital filtering methods normally only filter out the caused by single reason and can’t achieve satisfactory results for complex noise. In order to solve this problem, a large number of nonlinear recursive filtering algorithm such as extended Kalman filtering (EKF), the modified gain Kalman filter (MGEKF), U Kalman filter (UKF) algorithm come forth in recent years, and these filters are based on particular assumption to ensure the optimality. The actual data is usually very complex, and contains many factors such as non-Gaussian, nonlinear, high dimensional and noise; in this case, the Kalman filter generally can’t get the analytical solution. This is a common problem and appears in many different kinds of fields [2-11].

Now, a new sequential Monte Carlo particle filter algorithm based on Bayesian principles has been paid more attention. The particle filter technology realize the recursive Bayesian filter with non-parametric Monte Carlo simulation method, which can fit to any state space model and the nonlinear systems which can’t be expressed by traditional Kalman filter, and its accuracy approach the accuracy of optimal estimation [12].

This paper places emphasis on introducing the principle and method of the particle filter, and the application of the nonlinear data processing.
2. The principle of particle filter

The mathematics description of testing system: let \( k \) represents the time, \( x_{0:k} \) represents the unknown variables column, that is \( x_{0:k} = \{x_i, i = 0, \cdots, k \} \). \( y_{1:k} \) represents representative the observation variable columns, that is \( y_{1:k} = \{y_i, i = 1, \cdots, k \} \). The system transition model and observation model can be defined as:

\[
x_k = f(x_{k-1}, u_{k-1})
\]

\[
y_k = h(x_k, v_k)
\]

Where \( f(\cdot) \) and \( h(\cdot) \) are the known function, the system noise and observation noise are random variables whose probability density has known, \( x_k \) represents the system state variables at the moment \( k \), \( y_k \) represents the observation of \( x_k \), \( u_k \) and \( v_k \) are independent and independent of the system state. The probability of system transition model and observation model can translate into \( p(x_k | x_{k-1}) \) and \( p(y_k | x_k) \), then state estimation problem will translate into computing posterior probability \( p(x_k | y_{1:k}) \).

If the posterior probability and observation probability are nonlinear and non-Gaussian, then particle filter is the effective method to solve this problem. The core idea of particle filter is using a set of weighted random sample \( \{x_i, w_i\}_{i=0}^N \) to represent appreciatively the posteriori probability density, the system dynamic solving can be done by Bayesian iterative reasoning process \([13,14]\). According to the principle of particle filter, the sample weight values \( w_i(i) \) may be defined as:

\[
w_i(i) = p(y_{1:k} | x_{0:k}^{(i)})
\]

\[
\sum_{i=1}^N w_i(i) = 1
\]

Where \( p(y_{1:k} | x_{0:k}^{(i)}) \) represents the observation probability of the sample \( x_{0:k}^{(i)} \), then the estimate of the moment \( k \) system is as followed:

\[
\hat{x}_k = E(x_k | y_{1:k}) = \sum_{i=1}^N w_i(i)x_k^{(i)}
\]

The specific working process of particle filter: a group of samples of state space can be extracted through the prior distribution to represent estimate distribution, then according to the measurement data the likelihood score of each model can be calculated and looked on as the probability. a certain number (often is constant) same weighted sample was sampled from the original sample set will be acted on as the approximation of estimate’s posterior distribution, thus leaving promising samples repeatedly, so the samples come closer to true state. In the framework of particle filter, the basic steps of algorithm are: initialization, re-sampling, the state transition and observation model (i.e. samples weights) calculation.

(1) Initialization: extracting samples \( x_0^i \) randomly from prior probability density \( p(x_0) \), and giving the weight \( w_0^{(i)} = 1/N \).
(2) Time update (the state transition): according to Monte Carlo simulation principle, sampling \( \tilde{x}_k^{(i)} \sim q(x_k^{(i)} | x_{k-1}^{(i)}, y_{0:k}) \) or \( \hat{x}_k^{(i)} \sim q(x_k^{(i)} | x_{k-1}^{(i)}) \) from the importance probability density \( q(x_k | y_{1:k}) \), and updating the particles \( x_{0:k}^{(i)} = (\hat{x}_k^{(i)}, x_{0:k-1}^{(i)}) \);

(3) Observation update: in the case of having got the observation of moment \( k \), using

\[
W_k^{(i)} = \frac{p(y_k | x_k^{(i)})p(x_k^{(i)} | x_{0:k-1}^{(i)})}{q(x_k^{(i)} | x_{0:k-1}^{(i)}, y_{1:k})}
\]

\( \tilde{w}_k^{(i)} = \frac{W_k^{(i)}}{\sum_{j=1}^{N} W_k^{(j)}} \);

(4) Re-sampling: according to the weight \( \tilde{w}_k^{(i)} \), copying the particles with high weight and abandoning the particles with low weight, then getting \( N \) new particles \( x_k^{(i)} \); normalizing the weights \( w_k^{(i)} = \tilde{w}_k^{(i)} = 1/N \);

(5) Let \( k = k + 1 \), turn to (2).

The particle filter algorithm finally got the updated particles (a sample set), namely which represents the posterior probability, the estimate of particle used to represent filter results.

3. Single yarn-strength testing system modeling based on the particle filter

Particle filter is based on state space model of the system to design. The modeling of single-yarn strength testing system needs two aspects: (1) the establishment of system model, which is used to describe the system with time evolution of the state, that is the single-yarn strength conversion relationship between previous time and present moment, and the degree of influence by system noise; (2) the establishment of observation model, which is used to connect the system output and the system state at some time, that is the corresponding relations between the data acquisition system output, the single-yarn strength and the measurement noise.

3.1. State transition model

In single yarn-strength testing, drawing force is sampled in same space; the state transition model depicts the dynamic characteristics of the yarn drawing force value in unit elongation between pre-and post moment. Obviously, the more precise state transition model will be more in favor of the accurate estimate of system state, and to create a precise state transition model is very difficult. Aiming at cotton yarn such testing object, the effect of the performance of a single sample caused by material, manufacturing process is very big, and the testing parameters are accord with certain statistical law of the random variables, so the practical significance of establishing precise state transition model is not big. Because of the Monte Carlo particle filter stochastic simulation mechanism, the forecast of drawing force can be estimated steady by the multiple hypothesis samples. Therefore, the robustness of drawing force estimate based on the particle filter is not overly dependent on the state of the accuracy of the state transition model, this paper adopts approximate state transition model.

Establishing state transition model has two common methods: The first is to choose a particular type yarn to do tensile test, and statistical model can be learned and choosed from training data sequence. However, it is difficult for the learning state transition model to have stronger adaptability. The second is to choose the general mathematics model, which certainly has not the best filtering effect for a single sample, but which can be used to data processing of same type yarns, and data filtering results of whole sample sets can achieve a more satisfactory results. This paper chooses first-order autoregressive model as state transition model of single yarn-strength testing, and the formula (6) is as follows:

\[
x_k = ax_{k-1} + b + u_{k-1}
\]
3.2. Observation probability model

The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations.

In this paper, the research of single-yarn strength testing is based on a single-yarn strength tester made by some factory in Suzhou, and the stretching mode is constant velocity elongation, namely the change of the sample’s elongation is uniform. The transmission channels of testing system pressure value are: fixture—sensor—signal acquisition—data processing. The main factors that testing data include noise are: (1) the system error: the migration of testing mechanism concentric line, sample slippage caused by the shortage of fixture’s clamping force, the pretension applied and matching inconsistent of yarn tested, vibration interference added to the equipment caused by motor rotation, etc.; (2) random error: the randomness of the yarn structure result in the random fluctuation of test parameters, the workshop spot external vibration interference, etc. These noises added together and looked as interference signal with unknown performance in filtering processing. The actual measuring data can be considered the superposition of yarn tension necessary force and noise, so the system observation model can be expressed as follows:

\[ y_k = cx_k + v_k \]  

(7)

In previous paper, the spread of the system state was hypothesized, that is after the establishment of the system state transition equation, which was proved by the observation \( y_k \), and this step is system observation. Using the observation \( y_k \) to confirm the result of the system state transition is actually a process of similarity measure. Because every particle stands for a possibility of target state, then the purpose of system observation is to make the particles which are near to the actual situation acquire some lager weights and the particles which are far to the actual situation acquire some smaller weights.

At the moment \( k \), the corresponding estimate of the ith sampling of yarn tension value \( x_k \), the similarity measures of observation and estimated values can be expressed as \( \Delta = y_k - x_k \). Reference to Bhattacharyya coefficient, observation model probability can be defined as:

\[ p(y_k | x_{oi}) = w_k (i) = \frac{1}{\sqrt{2 \pi \sigma}} e^{-\frac{x^2}{2 \sigma}} \]  

(8)

Where \( \sigma \) is observation noise \( v_k \) variance. Obviously, the smaller the similarity measures are, the greater the sample weight values are and the more reliable sample is.

4. The simulation results and analysis

In the single-yarn strength testing experiment, the purpose of filter particle is to adopt particle filter algorithm based on observed values and obtain the optimal estimation of single-yarn strength. Comparing the particle filter results with the Fourier3 Fitting of Curve Fitting Tool of Matlab, its accuracy can be analyzed. Comparing the particle filter results with the effect of the traditional digital filtering methods subconscious comparison, the improved effect will be analyzed.

4.1. Simulation experiment

According to the above analysis, single-yarn strength testing system state equation can be expressed as:
\[ x_k = ax_{k-1} + b + u_{k-1} \]
\[ y_k = cx_k + v_k \]

(9)

The yarn model for 120 of a factory is used in single-yarn testing experiment, where \( a = 1 \), \( b = 0.15 \), \( c = 1 \). The system noise \( u_k \) and observation noise \( v_k \) are Gaussian noise with variance for \( Q = 0.06 \), \( R = 1 \) respectively. The simulation and analysis are conducted with Matlab R2009a engineering software.

4.2. The simulation results of the particle filter

In order to validate the filtering effect of single-yarn strength testing data for the particle filter, where the number of particles \( N = 100 \), and a group of any type 120 yarn experimental data are processed, the effect as shown in Fig.1.

![Particle Filter](image)

**Figure 1.** Effect of Particle Filtering

As can be seen from the graph, particle filter method can filter various kinds of clutters contained in original data such as peak pulse, big cycle noise superimposed in experimental data etc. The filtering curve can well reflect the changing trends of the data and easily extract the yarn quality parameters; Filtering results retain the part details of information and provide the basic for the yarn defects analysis and testing equipment fault diagnosis.

4.3. Precision Analysis

This paper uses the residual and the RMS of residual to analyze the filtering precision.

The residual
\[ e_k = y_k - f(x_k, c) \]

The variance
\[ SSE = \sum_{k=1}^{N} (e_k)^2 \]

The RMS of residual
\[ RMSE = \sqrt{\frac{1}{N} \sum_{k=1}^{N} (e_k)^2} = \sqrt{\frac{1}{N} \sum_{k=1}^{N} (y_k - f(x_k, c))^2} \]

Using the Fourier3 of Matlab own Curve Fitting Tool to fit the original data in Fig. 1, the comparison between Fitting residual and estimates residual of the particle filter can be shown in Fig. 2.
From Fig. 2 qualitative analysis showed that the residual distribution of the particle filter and Fourier third-order fitting results is roughly same, thus it can be seen the filtering precision approximately same. With the simulation of 10 experimental data, the SSE and RMSE of each group data can be calculated and shown in table 1.

<table>
<thead>
<tr>
<th></th>
<th>RMSE</th>
<th>SSE</th>
<th>RMSE</th>
<th>SSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6.713</td>
<td>1.9328E+04</td>
<td>6.507</td>
<td>1.8710E+04</td>
</tr>
<tr>
<td>2</td>
<td>5.297</td>
<td>1.1221E+04</td>
<td>5.220</td>
<td>1.0680E+04</td>
</tr>
<tr>
<td>3</td>
<td>4.465</td>
<td>9.9673E+03</td>
<td>4.539</td>
<td>1.0140E+04</td>
</tr>
<tr>
<td>4</td>
<td>4.497</td>
<td>1.0112E+04</td>
<td>4.519</td>
<td>1.0050E+04</td>
</tr>
<tr>
<td>5</td>
<td>4.899</td>
<td>1.2001E+04</td>
<td>4.882</td>
<td>1.1730E+04</td>
</tr>
<tr>
<td>6</td>
<td>4.369</td>
<td>9.5460E+03</td>
<td>4.419</td>
<td>9.6060E+03</td>
</tr>
<tr>
<td>7</td>
<td>4.556</td>
<td>1.0378E+04</td>
<td>4.677</td>
<td>1.0760E+04</td>
</tr>
<tr>
<td>8</td>
<td>4.454</td>
<td>8.9280E+03</td>
<td>4.674</td>
<td>9.6550E+03</td>
</tr>
<tr>
<td>9</td>
<td>5.411</td>
<td>1.0249E+04</td>
<td>5.310</td>
<td>9.6450E+03</td>
</tr>
<tr>
<td>10</td>
<td>4.923</td>
<td>1.2115E+04</td>
<td>5.070</td>
<td>1.2650E+04</td>
</tr>
</tbody>
</table>

From table I it can be referred that the results of the particle filter can reach the precision of third-order Fourier fitting, which can meet filter accuracy requirement of actual single-yarn strength testing.

**4.4. Comparison with traditional method**

The comparison between particle filter and traditional filtering method is shown in Fig. 3. From Fig. 3 it can be referred that particle filter method can better remove the noise interference of big cycle, namely the filter curve of particle filter in the initial stage in Fig. 3 betters than that of the traditional filter, which is very important in single-yarn strength testing; because at the initial stage of testing, the testing data often contains serious big cycle noise on account of the influence of motor starting, the particle filter can solve this problem well.
5. Summary and forecast

This paper expounds the basic principle and the specific application in of the particle filter, and the simulation experiments can illustrate the good filtering effect and precision of particle filter. The particle filter which is very flexible, easy to implement, strong practicality will be paid more attention to its research and application. At present, the particle filter technology is widely used in the target tracking, financial field data analysis, computer vision, state monitoring and fault diagnosis, etc. But the application of the particle filter in general data processing is not much, this paper gives the specific application example in single-yarn strength testing. The Extension in general data processing and further study of particle filter will promote the development of the theory and the application and follow the world development trend in the non-Gaussian, nonlinear system data analysis and processing fields.

6. References


7. Author introduction:

LiHongHai(1976-),male, received M. Sc. From Nanjing University of Aeronautics and Astronautics in 2007. Now he is a lecturer in Huaiyin Institute of Technology. His major research interests include computer measurement and control technique, and computer vision.
Address: MeiCheng east road no.1 Faculty of Electronic and Electrical Engineering, huaian, Jiangsu province, China, zip code: 223003; The telephone number: +86-13852398185.