Morphological description and statistical characteristic simulation of cocoon filament size curve

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Abstract. Computer simulation of silk reeling is an important means to understand structure and formation of raw silk, and simulation to generate cocoon filament size curve is the premise of computer simulation of reeling silk. In this paper, according to unique pattern of cocoon filament size curve that is "thin-thick-thin, the last part is the thinnest", a simulation and generation method of cocoon filament size curve with adjustable morphological is obtained by analyzing the characteristic point values and statistical data of cocoon filament size curve, such as head end size, maximum size and its position on cocoon filament, length of cocoon filament. Through a lot of simulation practice and analysis on statistical characteristics of cocoon filament size curve, it is considered that the proposed generation method has good applicability.

1. Introduction

The basis of raw silk formation is the merging of several cocoon filaments following certain rules, such as silk reeling with fixed number of cocoons is the merging of a definite number of cocoon filaments, and silk reeling with fixed size is the merging of different numbers of cocoon filaments that raw silk size within a restricted range [1]. Computer simulation of silk reeling can be used for understanding effectively the effect of different merging rules of cocoon filaments on raw silk forming structure, and the simulated "raw silk" can be used as data to study the morphological changes of raw silk between short term, which is beneficial to promote the research of electronic detection and classification theory of raw silk [2]. The morphological description and statistical simulation of the cocoon filament size curve is a prerequisite for computer simulation of silk reeling, and provides data characterization methods for silkworm breeding and development of silk reeling process, which has wide application prospects and scientific significance [3].

It is well known that cocoon filament size curve has a significant stable morphological pattern that is "thin-thick-thin, the last part is the thinnest". Various models have been proposed for the morphological description and statistical simulation of the cocoon filament size curve, including stage-autoregressive model [3,4], parabolic analytical model [5], trend component separated and finite-length non-stationary time series model [6,7], other empirical and regression models [8-10], these models have good applicability in their respective fields. Recently, we've realized that silkworm spinning goes through the process of the spinning mouth gradually opening and the silk fluid or
spinning force gradually decreasing, which to form the morphological pattern of cocoon filament size curve. According to these spinning behaviours of silkworm, we have proposed to adopt the compound function of logistic function and quadratic function to simulate cocoon filament size curve [11]. This paper discusses the statistical characteristics of the cocoon filament size curve based on the proposed model, and explains the meaning of model parameters corresponding to the cocoon filament size curve.

2. The morphology of cocoon filament size curve and its function model

Figure 1 (I) shows the average trend of cocoon filament size curve obtained from four cocoon lots in different region of China, which has same morphological pattern of "thin-thick-thin, the last part is the thinnest". Figure 1 (II) shows curve of formula (1), which is the proposed model based on the compound of logistic function and quadratic function for simulating the cocoon filament size curve.

\[
f(x) = a(x-b)^2 + d
\]  

(1)

As shown in figure 1 (II), some characteristic points on the cocoon filament size curve has been extracted:

1) Point A: the head end of cocoon filament, which corresponds to a size value, denoted as \( S_0 \).
2) Point B: the maximum point of cocoon filament size curve, which corresponds to a size value and its position, denoted respectively as \( S_{\text{max}} \) and \( x_{\text{max}} \).
3) Point C: the trailing end of the cocoon filament, which corresponds to a size value and the length of cocoon filament, denoted respectively as \( S_L \) and \( L \).

According to formula (1), the following formula can be obtained:

\[
S_0 = f(0) = \frac{ab^2}{1 + e^{-k(x-t)}} + d
\]

(2)

\[
S_{\text{max}} = f(x_{\text{max}}) = \frac{a(x_{\text{max}}-b)^2}{1 + e^{-k(x_{\text{max}}-t)}} + d
\]

(3)

\[
S_L = f(L) = \frac{a(L-b)^2}{1 + e^{-k(L-t)}} + d
\]

(4)

The formula (5) is derivative function of formula (1).

\[
f'(x) = \frac{ae^{k(x-t)}(b - x)(2e^{k(x-t)} - bk + kx)}{(1 + e^{k(x-t)})^2}
\]

(5)

As shown in figure 1 (II), there are two inflection points on the model of cocoon filament size curve:

1) \( x = b \rightarrow f'(x) = 0 \), corresponds to the point D shown in figure 1 (II), and \( f(b) = d \).
2) \( 2 + 2e^{k(x-t)} - bk + kx = 0 \rightarrow f'(x) = 0 \), corresponds to point B shown in figure 1 (II), which is the assumptive maximum point of the cocoon filament size curve, i.e., \( 2 + 2e^{k(x_{\text{max}}-t)} - \)
\[ bk + kx_{\text{max}} = 0. \]

The parameters \( a \) and \( k \) of formula (1) can be obtained:
\[
a = \frac{(S_0-d)(1+e^{kt})}{b^2} \quad (6)
\]
\[
k = \frac{4}{b-t} \quad (7)
\]

Furtherly, it is also necessary to figure out the parameters \( t, b \) and \( d \) of formula (1):

1) \( t \) is related to the position of the maximum value of cocoon filament size curve, which can be set \( t = x_{\text{max}} \).

2) \( b \) is related to the length of cocoon filament, which should be a value that greater than or equal to \( L \). A tuning parameter for morphology of cocoon filament size curve can be assumed, denoted as \( L' \), and let \( b = L + L' \).

3) \( d \) is a value on function curve on which change rate is 0, however, the value is usually non-existent on actual cocoon filament size curve, so it is also used as a tuning parameter for morphology of cocoon filament size curve.

Based on the above, all parameters of formula (1) were obtained:
\[
a = \frac{(S_0-d)(1+e^{kt})}{b^2} \quad (8)
\]
\[
b = L + L' \quad (9)
\]
\[
k = \frac{4}{b-x_{\text{max}}} \quad (10)
\]
\[
t = x_{\text{max}} \quad (11)
\]
\[
d = f(b) \quad (12)
\]

3. Simulation generation and morphological regulation of cocoon filament size curve

Figure 2 (I) and (II) shows the cocoon filament size curve with different morphological tuning parameter \( L' \) and \( d \). Figure 2 (III) shows the size curves of cocoon filaments simulated, which shows that exceptional maximum value of cocoon filament size curve that may be generated, to avoid this phenomenon, some limiting parameters have been proposed:

As shown in figure 1 (II), \( AB' = x_{\text{max}}, BB' = S_{\text{max}} - S_0 \), let \( \theta = \angle BAB' \), i.e. \( \tan \theta = (S_{\text{max}} - S_0)/x_{\text{max}} \). Furtherly, \( CC' = L - x_{\text{max}}, BC' = S_{\text{max}} - S_L \), let \( \varphi = \angle BCC' \), i.e. \( \tan \varphi = (S_{\text{max}} - S_L)/(L - x_{\text{max}}) \). Figure 2 (IV) shows size curves of cocoon filaments simulated with tuning parameter \( (\theta, \varphi) \). As shown in figure 2 (IV), the cocoon filament size curve with different morphological tuning parameter \( (\theta, \varphi) \), which exceptional maximum value of cocoon filament size curve was disappeared.
In summary, the statistical characteristics of cocoon filament size curve from a specific cocoon lots are obtained through a survey of cocoon filament size curve, based on data surveyed of statistical characteristics, the parameters $L'$ and $d$ can be adjusted to match the statistical characteristics of the cocoons lots surveyed. Finally, it is proved that the result is close to the actual situation.

4. Conclusions

This article aims to construct a suitable computer simulation method for the cocoon filament size curve. Based on the morphological pattern of cocoon filament size curve and the compound function of logistic function and quadratic function, the relationship between the parameters of compound function and head end size, trailing end size, the maximum size on cocoon filaments and length of cocoon filaments are analyzed. A simulation generation method of cocoon filament size curve with adjustable morphological is obtained. Through a lot of simulation practice and analysis on statistical characteristics of cocoon filament size curve, it is considered that the proposed generation method has good applicability.

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