Methodology For Predicting Fiber Quality And Developing An Intelligent Control System

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ABSTRACT

This article investigates, through a comprehensive approach, the issues of predicting fiber quality and developing an intelligent control system based on the initial technological parameters of raw cotton during primary processing. The experiments evaluated the influence of initial moisture content and contamination level of raw cotton, drying drum capacity, and drying agent temperature on fiber quality using a multivariate regression model. The model demonstrated a coefficient of determination of R^2 = 0.87, indicating high predictive accuracy.

According to the research findings, the considered factors play a significant role in forecasting and maintaining optimal fiber quality parameters, as well as in forming an effective control system. The proposed intelligent control system is based on sensor monitoring, a data processing module, a mathematical model, and an optimization algorithm, ensuring real-time process control during production. Practical implementation results confirmed a reduction in energy consumption.

These scientific findings contribute to accelerating digitalization processes in cotton ginning enterprises and increasing the share of export-oriented.

Keywords: Raw cotton, fiber, seed, quality, drying, moisture content, temperature, regression model, optimization, intelligent control, technological parameters, energy efficiency.

Introduction. Based on a theoretical analysis of efficient utilization options of the cotton drying drum, it is important to develop analytical relationships characterizing the heat exchange between the drying agent, raw cotton, and the drum surface. Using these relationships, the influence of the drying drum capacity on cotton moisture content and heating temperature can be determined. It is also necessary to consider the moisture content and temperature of both fiber and seed as key indicators characterizing cotton as an object of cleaning and ginning, to ensure that these parameters attain rational values during technological processes, and to develop mathematical models for their control. Furthermore, it is essential to substantiate that the application of multiple drying improves fiber quality, and to obtain mathematical models describing changes in fiber temperature during pneumatic conveying of dried raw cotton. On this basis, the state of fiber and seed moisture content and temperature during the cleaning process can be determined [1–4].

Considering the need for industrial implementation of the developed technological solutions, selecting the optimal drying regime according to the initial moisture content of raw cotton, developing mathematical models of drying drum operating modes enabling prediction of quality indicators of cotton components, and creating an intelligent control system that ensures efficient cleaning and ginning of raw cotton while fully preserving fiber quality represent urgent tasks for cotton ginning enterprises.

Research Method. Cotton fiber quality is one of the key indicators determining the economic efficiency and export potential of the textile industry. Variations in the quality of raw materials at the primary processing stage directly affect the quality of the final product. Currently, in addition to traditional mechanical methods aimed at improving quality, the cotton industry широко applies sensor-based monitoring, data analysis, mathematical modeling, and optimization algorithms [5].

Initial technological parameters of raw cotton—such as moisture content, impurity level, fiber content (lint percentage), intensity of mechanical impact, and fiber length—play a decisive role in determining fiber quality. At the same time, the use of an automated control system enables real-time optimization of the production process.

Problem Statement and Formulation. Modern research indicates that accurate measurement and control of raw material parameters lead to improved fiber strength, more efficient energy utilization, and greater stability of final product quality. Therefore, the implementation of an intelligent control system represents a relevant scientific and practical task aimed at increasing production efficiency and ensuring the manufacture of high-quality export-oriented products [5,6].

This article examines in detail the concept of an intelligent control system based on the initial parameters of raw materials, as well as methods for predicting and controlling fiber quality through a multivariate regression model and optimization algorithms. The results demonstrate the feasibility of industrial implementation and confirm the potential for enhancing production efficiency.

Experiment and analysis of results. To control and predict fiber quality, a multivariate mathematical model was developed [10,11]. The model considers the initial parameters of raw cotton—moisture content (W), impurity level (I), fiber content (T), intensity of mechanical impact (M), and average fiber length (L)—as input variables.

The resulting quality indicator (Q) is determined using the following multivariate regression equation:

$$Q = a_0 + a_1W + a_2I + a_3T + a_4M + a_5L.$$

$a_0, a_1, \dots, a_5$ – model coefficients determined through laboratory and industrial experiments.

Q – an integral fiber quality index, a single indicator that takes into account strength, length, cleanliness, and lint percentage.

The following methodological steps were applied in developing the model:

- Data collection and standardization.
- All raw material parameters were measured in real time using sensors and laboratory measurements.
- The data were normalized and cleaned from external noise and measurement errors.

Statistical analysis. The influence of each parameter on fiber quality was determined using correlation analysis. The model accuracy was evaluated using the coefficient of determination (R^2). The obtained value R^2 = 0.87 demonstrated a high level of predictive accuracy [6,7].

Optimization algorithm. Based on the model results, an algorithm was developed to adjust the parameters of mechanical impact, moisture content, and impurity level to optimal ranges in order to preserve fiber quality to the maximum extent. A real-time intelligent control system block diagram enabled automatic adjustment of equipment operating modes.

Testing and validation. The reliability of the model was tested under industrial conditions using several varieties of raw cotton. The results showed that fiber strength and length were maintained within optimal ranges, while energy consumption decreased by 10–12%.

Integration of the intelligent control system into the production process makes it possible to steadily improve cotton fiber quality and ensure efficient use of resources. At the same time, further development of the model may involve the application of neural networks, artificial intelligence algorithms, and real-time databases [8,9].

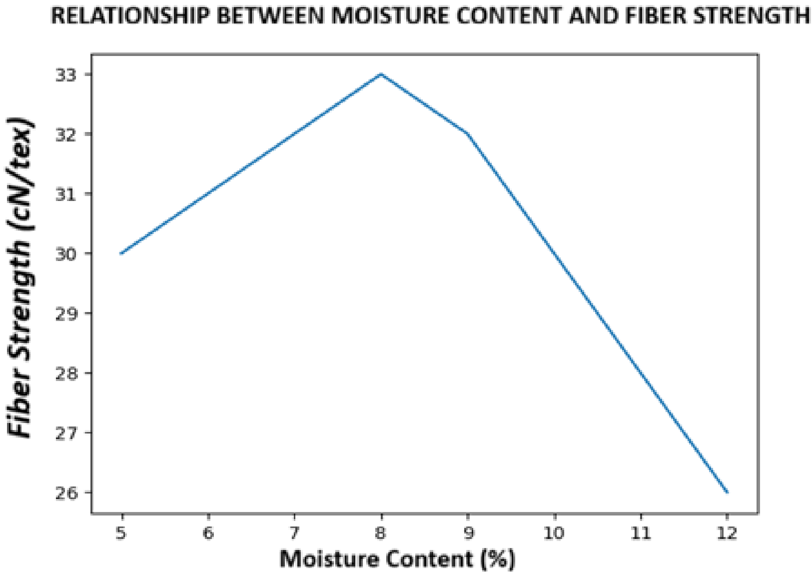


Figure 1. Relationship between Moisture Content and Fiber Strength

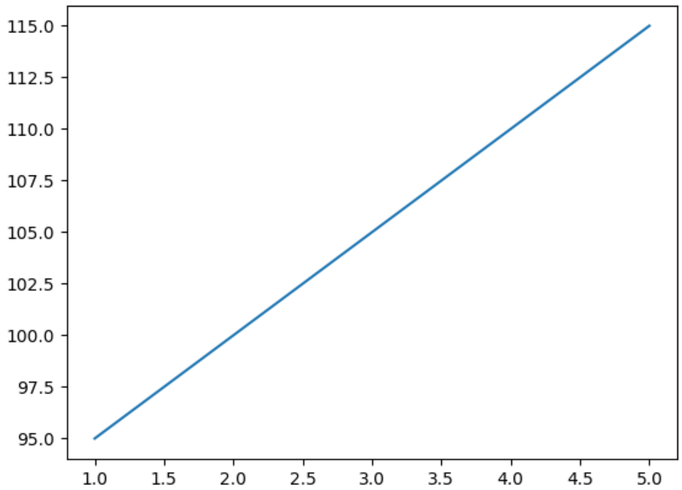
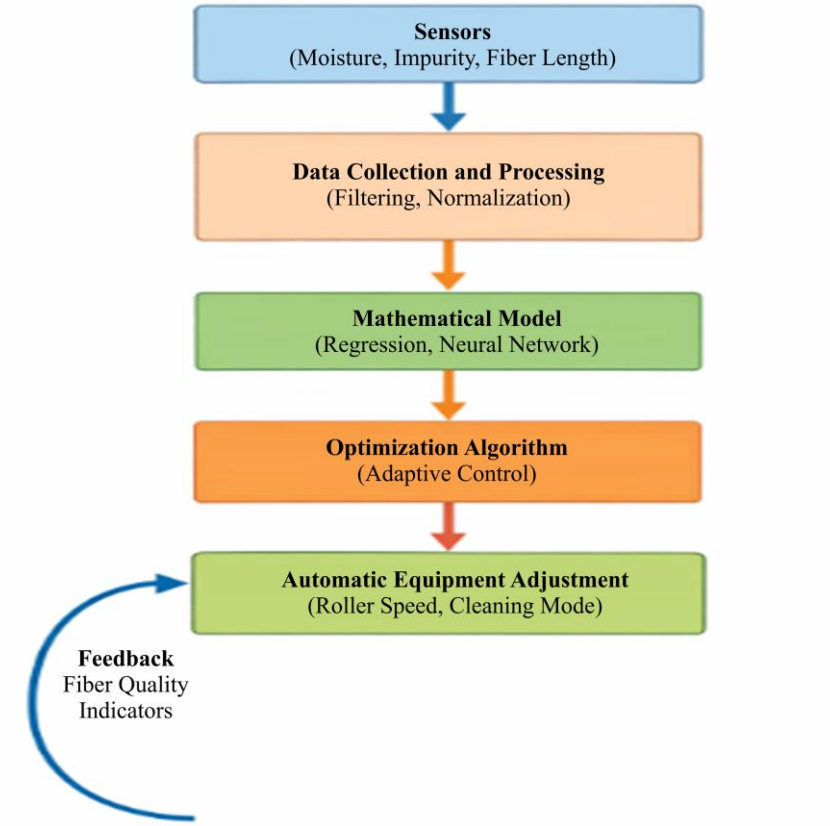


Figure 2. Relationship between Impurity Level and Energy Consumption

Block Diagram of the Intelligent Control System:

Sensors → Data Collection → Mathematical Model → Optimization Algorithm → Automatic Equipment Adjustment → Quality Control [12,13]



The system operates according to the following principle:

- Sensors measure the initial parameters of the raw cotton.
- Data are processed in real time.
- The mathematical model predicts fiber quality.
- The optimization algorithm calculates the optimal operating mode.
- Equipment is automatically adjusted.
- The resulting fiber quality is fed back to the system as feedback.

Conclusion. In summary, the research results demonstrate that scientifically controlling the initial parameters of raw cotton—moisture content, impurity level, fiber content, and intensity of mechanical impact—allows for accurate prediction and optimization of fiber quality.

The developed multivariate regression model shows high accuracy in determining the integral fiber quality index, with a coefficient of determination $R^2 = 0.87$, confirming the model's reliability. This enables real-time quality management during the production process.

The proposed intelligent control system integrates sensor monitoring, a data processing module, a mathematical model, and an optimization algorithm to automatically control production equipment. Using this system:

- Fiber strength and length are maintained at optimal levels;
- Residual impurities are reduced;
- Energy consumption decreases by 10–12%;
- Production efficiency is significantly improved.

This system enables real-time control in industrial enterprises, accelerates the digitalization of cotton cleaning and processing operations, and increases the share of export-oriented products.

For future development and enhanced efficiency of the model, it is possible to:

- Apply neural networks and artificial intelligence algorithms;
- Perform prediction and optimization based on Big Data;
- Integrate the production process into more advanced automated systems.

In conclusion, controlling the initial parameters of raw cotton and implementing an intelligent control system enables the cotton industry to improve quality stability, ensure energy efficiency, and significantly enhance production performance [14].

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