Prediction and optimization of yarn properties using genetic algorithm/artificial neural network

S N Subramanian\textsuperscript{a}
Textile Technology Department, SNS College of Technology, Coimbatore 641 035, India
A Venkatachalam
Textile Technology Department, P S G College of Technology, Coimbatore 641 004, India

and
V Subramaniyan
Jaya Engineering College, Thiruninravur 602 024, India

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Relative performance of the back propagation neural network (BPN) algorithm combined with genetic algorithm (GA) approach for the prediction/optimization of the properties of yarn produced on jet ring spinning system has been studied. Yarn samples of various linear densities have been produced on ring spinning machines using air-jet nozzles as retrofit by varying the nozzle parameter and the yarn properties studied. The hybrid application is used to predict selected yarn properties based on the effect of certain nozzle parameters. The network trained for a set of training vectors is found to predict the yarn properties for a compacting method with minimum error percentage. The proposed GA/BPN model could be extended to suggest a suitable compacting method for the desired yarn properties.

Keywords: Air-jet nozzles, Artificial neural network, Back propagation network, Genetic algorithm, Hybrid technique, Jet ring-spun yarns

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1 Introduction

Spinning process is one of the important production processes in the textile industry. The quality of the yarns produced is very important in determining their applications further. The characteristics of yarn considered as most important are tensile, evenness and hairiness properties. These properties need to be simultaneously optimized. Two problems arise while searching for an objective optimization of a process. The first problem is the choice of input parameters. The second problem is concerned with simulating the production function and its optimization.

Several studies have dealt with the effects of fibre properties and spinning parameters on yarn hairiness.\textsuperscript{1-2} Researchers have developed several mathematical,\textsuperscript{3-6} statistical,\textsuperscript{7,9} and artificial neural network\textsuperscript{10-13} models to predict the yarn properties from the characteristics of constituent fibres. Behera and Muttagi\textsuperscript{14} adopted three modeling methodologies based on mathematical, empirical and neural network based on radial basis function for comparing their ability to predict woven fabric properties and found that the artificial neural networks produced the least error.

The idea to hybridise the two approaches, namely genetic algorithm and back propagation network, was followed by Whitley and Bogart,\textsuperscript{15} who used genetic algorithms to guide back propagation network in finding the necessary connections instead of all connection in order to enhance the speed of training. Sette \textit{et al}.\textsuperscript{16} used a method to simulate and optimize the fibre to yarn production process using a neural network combined with a genetic algorithm and showed that the simultaneous optimization of yarn qualities was easily achieved as a function of the necessary (optimal) input parameters.

Yarn properties are closely associated with yarn structure, on which fibre properties, spinning technologies and process variables have a determining

\textsuperscript{a}To whom all the correspondence should be addressed.
E-mail : nne@vsnl.com
influence. After the introduction of compact spinning system, the importance of this technique is much felt by the users of ring-spun yarns particularly on the quality aspects such as hairiness, tensile properties and, to an extent, evenness properties of the yarns. Jet ring spinning is essentially a pneumatic tandem spinning technique, which consists of passing a drafted strand of fibres through one or more air-jet nozzles located between the nip of the front roller of the drafting system and the twisting zone of a conventional ring spinning machine. The present study deals with the unexplored jet ring spinning which is considered as an equivalent alternative to the newly invented compact spinning technique. Figure 1 shows the basic process structure in the jet ring spinning along with the chosen input parameters and outputs. The hybrid technique reported in this paper is also suited to other textile production processes.

The literature review reveals that not much work has been reported on the hybrid intelligent system of artificial neural network (ANN)/genetic algorithm (GA) for prediction and optimization of yarn properties or fabric properties or both. Thus, in this work, the importance and effect of some nozzle parameters which play a major role in this technique on the characteristics of jet ring-spun yarns have been studied and the possibilities of developing a numerical network model that could predict the properties of yarns and could be used as a tool by the spinners explored.

2 Materials and Methods

2.1 Materials

A 19.68 tex yarn was produced using 100% cotton mixing with 2.5% span length, 28.5 mm; fineness value, 4.0; bundle strength, 21.5 g/tex; and uniformity ratio, 48. Another mixing of 100% cotton with 2.5% span length, 31 mm; fineness value, 4.2; bundle strength, 22.5 g/tex; and uniformity ratio, 4.5 was used to produce 14.76 tex and 11.81 tex yarns. Single, double and triple air-jet nozzles fabricated using brass, aluminium and teflon were used in the ring spinning machine as retrofits, and yarns produced in three different linear densities were tested using standard tests for determining the characteristics of yarns, namely hairiness, tenacity, elongation and evenness.

2.2 Training and Testing

The types of nozzles, materials of nozzles and various linear densities of yarns produced were included as input variables. The input process parameters on the selected yarn properties were all found to be statistically significant as per ANOVA test conducted using SPSS package. Each parameter was represented by alphabet/number, e.g. single(A), double(B) & triple(C); three types of materials, aluminium (1), brass (2) & teflon (3) and three different linear densities 19.68 tex, 14.76 tex & 11.81 tex. The yarn properties used as outputs (dependent variables) were tenacity, elongation, hairiness and irregularity (Table 1).

The GA applied in this study prior to BPN consists of all the basic operations; reproduction, crossover and mutation supplemented by sharing function and fitness function. The neural network component was fully integrated into the genetic algorithm since it was the means by which the GA’s fitness function was evaluated through the relationship between the predicted property and the target property. Initial population was generated randomly for each linear density of yarn (A 1, B 3, C 2 and A3). In the crossover operation (Fig. 2), the parents and the crossover sites were also chosen randomly.

Figure 3 shows a schematic representation of the back propagation neural network. Number of hidden layer used in the BPN was one and the nature of activation function used was sigmoid function and the data were normalized.

The training data was input to the back propagation neural network algorithm. The neural network was then tested with the test set and the results were compared with the desired value, indicating the error in the predictive performance.

In order to get sufficient training and testing exercise, data of the yarns produced namely 3 × 3 × 3 × 100 = 2700 sample results, were used. Also 3 × 100 samples were used for testing exercise, i.e. three types of nozzles, three different materials used for nozzle construction and three linear densities of yarns, each of the hundred samples produced for the experiments were used for training and for testing.
3 Results and Discussion

The experimental results of the GA/ANN algorithm proposed for optimization and prediction of yarn properties are examined in this study by comparing them with the predicted results. The GA approach is used for optimisation of three nozzle types and three material types for different counts. The back propagation neural network used for fitness evaluation was trained with 2700 training vectors. The network was tested with different nozzle types and materials. Table 2 shows the performance of BPN containing the error percentage of the predicted values for jet ring-spun yarn properties, namely hairiness, evenness, tenacity and elongation for 19.68 tex, 14.76 tex and 11.81 tex yarns. It can be inferred that the error in prediction is minimum for most of the yarn properties.

3.1 Significance of Input Parameters

The main component of the jet ring spinning technology is the air-jet nozzle which condenses the fibre strand coming out of the front roller nip similar to compact spinning prior to twisting the yarn. Almost negligible publications have appeared regarding the effect of various types of nozzles, viz. single, double and triple, used in jet ring spinning as well as the materials used for fabrication of the air-jet nozzle wherein the surface characteristics of the material could play a role in achieving the desired qualities in the final yarn. Hence, the effect of using more number of nozzles could help study the changes in the quality of yarn. In jet spinning, the twist insertion is not possible as in ring spinning but it is applied by means of pneumatic air force. Thus, the surface inside the twisting chamber could be critical, not only because of the friction with the rotating yarn, but also because of the interaction with the rapidly rotating air, and this
particular aspect is taken for study in this work. It is found that this aspect plays a major role in enhancing the properties of the yarns.

In the case of single brass nozzle for 19.68 tex yarn, the actual and predicted values were 16.00 and 16.60 g/tex respectively. The error percentage was well below 3.61. Similarly, almost for all the other properties of yarns, the percentage error was well below 6.5. It is important to note that the neural network is able to assess the complex relationship between inputs and outputs and consistently performs good optimization and prediction of yarn properties.

Thus, in the industry where samples are taken in bulk regularly from the spinning machines and tested with a very large data available, this hybrid technique can be expected to perform in a significantly better manner.

3.2 Yarns from Various Linear Densities

It has been found that there is a direct relationship between yarn linear density and hairiness. The hairiness increases when the yarn linear density decreases. In other words, finer yarns have more hairs than coarser yarns for all the hair lengths.

Cheng and Li\(^7\) have reported that the compact spinning technique is not suitable for <50s count and hence it was found necessary to check the effect of various linear densities on yarn properties, particularly on hairiness, tensile properties and evenness properties wherein the compact spinning plays a major role. To verify the extent of variability of the yarns for the proposed linear densities, three linear densities of yarn samples were spun. The properties of the yarns were evaluated and compared against the predicted yarn properties. Table 2 shows the error analysis results of various yarn properties. It is observed that for individual yarn properties, the mean error percentage ranges from -2.82 to 6.5. Only in certain cases, do the values go beyond this range and to the extent of 11.76 and 12.38. Values of tenacity of yarns, which receive a great attention from the spinners, show a mean error percentage range from –2.82 to 4.28. Similarly, the evenness property shows an error percentage range from –4.04 to 5.55. In the case of hairiness and elongation, only in some cases, the values go beyond the range but in most cases the values are found well below 8%.

Yarn elongation depends mainly on the fibre elongation and the hairiness also on the individual edge fibres; probably, these may be the reason for the higher percentage of mean errors in some cases.

In an earlier exhaustive study\(^18\), it has been reported that the jet ring-spun yarns produced using single brass nozzle and single teflon nozzle have better all-round yarn properties than the others.

4 Conclusions

4.1 The optimization of yarn properties using genetic algorithm and prediction using artificial neural network could be achieved.

4.2 The study shows the feasibility of predicting the yarn properties on the basis of certain air-jet nozzle parameters used in the production of yarns in jet ring spinning with the GA/ANN model.
4.3 The compacting methods are generated randomly and the genetic operations are performed.

4.4 Back propagation neural networks are used for fitness evaluation.

4.5 This network, trained for a set of training vectors, is able to predict the yarn properties for a compacting method with minimum error percentage.

4.6 The accuracy is very good in the case of tenacity and evenness.

4.7 The mean error of individual yarn properties ranges from –3.5% to 6%.

4.8 The proposed GA/BPN model could be extended to suggest a suitable compacting method for the desired yarn properties. Also, it could be used for the other spinning systems as well.

References