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Review of Application of Artificial Neural Networks in Textiles and Clothing Industries over Last Decades

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1. Introduction

An Artificial Neural Network (ANN) is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurones) working in unison to solve specific problems. ANNs, like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning in biological systems involves adjustments to the synaptic connections that exist between the neurones. The ANN has recently been applied in process control, identification, diagnostics, character recognition, sensory prediction, robot vision, and forecasting.

In Textiles and Clothing industries, it involves the interaction of a large number of variables. Because of the high degree of variability in raw materials, multistage processing and a lack of precise control on process parameters, the relation between such variables and the product properties is relied on the human knowledge but it is not possible for human being to remember all the details of the process-related data over the years. As the computing power has substantially improved over last decade, the ANN is able to learn such datasets to reveal the unknown relation between various variables effectively. Therefore, the application of ANN is more widespread in textiles and clothing industries over last decade.

In this chapter, it aims to review current application of ANN in textiles and clothing industries over last decade. Based on literature reviews, the challenges encountered by ANN used in the industries will be discussed and the potential future application of ANN in the industries will also be addressed. The structure of this chapter comprises of seven sections. The first section includes background of ANN, importance of ANN in textiles and clothing and the arrangement of this chapter. In forthcoming three sections, they include review of applications of ANN in fibres and yarns, in chemical processing, and in clothing over last decade. Afterwards, challenges encountered by ANN used in textiles and clothing industries will be discussed and potential future application of ANN in textiles and clothing industries will be addressed in last section.

2. Applications to fibres and yarns

2.1 Fibre classification

Kang and Kim (2002) developed an image system for the current cotton grading system of raw cotton involving a trained artificial neural network with a good classifying ability. Trash from a raw cotton image can be characterized by a captured color by a color CCD camera and acquire color parameters. The number of trash particles and their content, size, size distribution, and spatial density can be evaluated after raw cotton images of the physical standards are thresholded and connectivity was checked. The color grading of raw cotton can be influenced by trash. Therefore, the effect of trash on color grading was investigated using a color difference equation that measured the color difference between a trash-containing image and a trash-removed image. The artificial neural network, which has eight color parameters as input data, was a highly reliable and useful tool for classifying color grades automatically and objectively.

She *et al.*, (2002) developed an intelligent system using artificial neural networks (ANN) and image processing to classify two kinds of animal fibres objectively between merino and mohair; which are determined in accordance with the complexity of the scale structure and the accuracy of the model. An unsupervised artificial neural network was used to extract eighty, fifty, and twenty implicit features automatically while image processing technique was used to extract nine explicit features. Then the supervised ANN was employed to classify these fibers, based on the features extracted with image processing and unsupervised artificial neural networks. The classification with features extracted explicitly by image processing is more accurate than with features from unsupervised artificial neural networks but it required more effort for image processing and more prior knowledge. On the contrary, the classification with combined unsupervised and supervised ANN was more robust because it needed only raw images, limited image processing and prior knowledge. Since only ordinary optical images taken with a microscope were employed, this approach for many textile applications without expensive equipment such as scanning electron microscopy can be developed.

Durand *et al.*, (2007) studied different approaches for variable selection in the context of near-infrared (NIR) multivariate calibration of the cotton-viscose textiles composition. First, a model-based regression method was proposed. It consisted of genetic algorithm optimization combined with partial least squares regression (GA-PLS). The second approach was a relevance measure of spectral variables based on mutual information (MI), which can be performed independently of any given regression model. As MI made no assumption on the relationship between X and Y, non-linear methods such as feed-forward artificial neural network (ANN) were thus encouraged for modeling in a prediction context (MI-ANN). GA-PLS and MI-ANN models were developed for NIR quantitative prediction of cotton content in cotton-viscose textile samples. The results were compared to full spectrum (480 variables) PLS model (FS-PLS). The model required 11 latent variables and yielded a 3.74% RMS prediction error in the range 0-100%. GA-PLS provided more robust model based on 120 variables and slightly enhanced prediction performance (3.44% RMS error). Considering MI variable selection procedure, great improvement can be obtained as 12 variables only were retained. On the basis of these variables, a 12 inputs of ANN model was trained and the corresponding prediction error was 3.43% RMS error.

2.2 Yarn manufacture

Beltran *et al.*, (2004) developed an artificial neural network (ANN) trained with back-propagation encompassed all known processing variables that existed in different

spinning mills, and then generalized this information to accurately predict yarn quality of worsted spinning performance for an individual mill. The ANN was then subsequently trained with commercial mill data to assess the feasibility of the method as a mill-specific performance prediction tool. The ANN was a suitable tool for predicting worsted yarn quality for a specific mill.

Farooq and Cherif (2008) have reported a method of predicting the leveling action point, which was one of the important auto-leveling parameters of the drawing frame and strongly influences the quality of the manufactured yarn, by using artificial neural networks (ANN). Various leveling action point affecting variables were selected as inputs for training the artificial neural networks, which was aimed to optimize the auto-leveling by limiting the leveling action point search range. The Levenberg-Marquardt algorithm was incorporated into the back-propagation to accelerate the training and Bayesian regularization was applied to improve the generalization of the networks. The results obtained were quite promising that the accuracy in computation can lead to better sliver CV% and better yarn quality.

2.3 Yarn-property prediction

Kuo *et al.*, (2004) applied neural network theory to consider the extruder screw speed, gear pump gear speed, and winder winding speed of a melt spinning system as the inputs and the tensile strength and yarn count of spun fibers as the outputs. The data from the experiments were used as learning information for the neural network to establish a reliable prediction model that can be applied to new projects. The neural network model can predict the tensile strength and yarn count of spun fibers so that it can provide a very good and reliable reference for spun fiber processing.

Zeng *et al.*, (2004) tried to predict the tensile properties (yarn tenacity) of air-jet spun yarns produced from 75/25 polyester on an air-jet spintester by two models, namely neural network model and numerical simulation. Fifty tests were undergone to obtain average yarn tenacity values for each sample. A neural network model provided quantitative predictions of yarn tenacity by using the following parameters as inputs: first and second nozzle pressures, spinning speed, distance between front roller nip and first nozzle inlet, and the position of the jet orifice in the first nozzle so that the effects of parameters on yarn tenacity can be determined. Meanwhile, a numerical simulation provided a useful insight into the flow characteristics and wrapping formation process of edge fibers in the nozzle of an air-jet spinning machine; hence, the effects of nozzle parameters on yarn tensile properties can be predicted. The result showed that excellent agreement was obtained between these two methods. Moreover, the predicted and experimental values agreed well to indicate that the neural network was an excellent method for predictors.

Lin (2007) studied the shrinkages of warp and weft yarns of 26 woven fabrics manufactured by air jet loom by using neural net model which were used to determine the relationships between the shrinkage of yarns and the cover factors of yarns and fabrics. The shrinkages were affected by various factors such as loom setting, fabric type, and the properties of warp and weft yarns. The neural net was trained with 13 experimental data points. A test on 13 data points showed that the mean errors between the known output values and the output values calculated using the neural net were only 0.0090 and 0.0059 for the shrinkage ratio of warp (S1) and weft (S2) yarn, respectively. There was a close match between the actual and predicted shrinkage of the warp (weft) yarn. The test results gave R^2 values of 0.85 and 0.87 for the shrinkage of the warp (i.e., S1) and weft (i.e., S2), respectively. This showed that the

neural net produced good results for predicting the shrinkage of yarns in woven fabrics. Different woven fabrics manufactured on different looms like rapier, gripper, etc., raw material yarn ingredients (e.g., T/C × T/R, T/R × T/R, T/C × C, etc.), and fabric structural class (e.g., twill, satin, etc.) were examined to measure the shrinkage ratio of warp and weft yarns. The developed neural net model was then used to train the obtained data and the result showed that the prediction of yarn shrinkage in the off-loomed fabrics can be fulfilled through a prediction model constructed with neural net.

Xu *et al.*, (2007) studied a neural network method of analyzing cross-sectional images of a wool/silk blended yarn. The process of original yarn cross-sectional images including image enhancement and shape filtering; and the determination of characteristic parameters for distinguishing wool and silk fibers in the enhanced yarn cross-sectional images were in the study. A neural network computing approach, single-layer perceptrons, was used for learning the target parameters. The neural network model had a good capability of tolerance and learning. The study indicated that preparation of the yarn sample slices was critically important to obtain undistorted fiber images and to ensure the accuracy of fiber recognition. The overall error estimated for recognizing wool or silk fiber was 5%.

Khan *et al.*, (2009) studied the performance of multilayer perceptron (MLP) and multivariate linear regression (MLR) models for predicting the hairiness of worsted-spun wool yarns objectively by examining 75 sets of yarns consisting of various top specifications and processing parameters of shrink-resist treated, single-ply, pure wool worsted yarns. The results indicated that the MLP model predicted yarn hairiness was more accurately than the MLR model and showed that a degree of nonlinearity existed in the relationship between yarn hairiness and the input factors considered. Therefore, the artificial neural network (ANN) model had the potential for wide mill specific applications for high precision prediction of hairiness of a yarn from limited top, yarn and processing parameters. The use of the ANN model as an analytical tool may facilitate the improvement of current products by offering alternative material specification and/or selection and improved processing parameters governed by the predicted outcomes of the model. On sensitivity analysis on the MLP model, yarn twist, ring size, average fiber length (hauteur) had the greatest effect on yarn hairiness with twist having the greatest impact on yarn hairiness.

Ünal *et al.*, (2010) investigated the retained spliced diameter with regard to splicing parameters and fiber and yarn properties. The yarns were produced from eight different cotton types in three yarn counts (29.5, 19.7 and 14.8 tex) and three different twist coefficients ($\alpha_{\text{Tex}} 3653$, $\alpha_{\text{Tex}} 4038$, $\alpha_{\text{Tex}} 4423$). To investigate the effects of splicing parameters on the retained spliced diameter, opening air pressure, splicing air pressure and splicing air time were set according to an orthogonal experimental design. The retained spliced diameter was calculated and predicted by using an artificial neural network (ANN) and response surface methods. Analyses showed that ANN models were more powerful compared with response surface models in predicting the retained spliced diameter of ring spun cotton yarns.

2.4 Fibre and Yarn relationship

Admuthe and Apte (2010) used multiple regression model such as artificial neural network (ANN) in an attempt to develop the relationship between fiber and yarn in the spinning process. 30 different cotton fibres were selected covering all of the staple length groups of cotton grown in India. The yarn (output) produced from the spinning process had a unique

relationship with the fibers (input). However, ANN failed to develop exact relationships between the fiber and the yarn, then a hybrid approach was used to achieving the solution. Hence, a new hybrid technique, Adaptive Neuro-Fuzzy Inference System (ANFIS) which was combined with subtractive clustering was used to predict yarn properties. The result shown that the ANFIS gave better co-relation values. The test results show better accuracy for all datasets when compared it to the ANN model.

3. Applications to fabrics

3.1 Fabric manufacture

Yao *et al.*, (2005) investigated the predictability of the warp breakage rate from a sizing yarn quality index using a feed-forward back-propagation network in an artificial neural network system. An eight-quality index (size add-on, abrasion resistance, abrasion resistance irregularity, hairiness beyond 3 mm, breaking strength, breaking strength irregularity, breaking elongation, and breaking elongation irregularity) and warp breakage rates were rated in controlled conditions. A good correlation between predicted and actual warp breakage rates indicated that warp breakage rates can be predicted by neural networks. A model with a single sigmoid hidden layer with four neurons was able to produce better predictions than the other models of this particular data set in the study.

Behera and Karthikeyan (2006) described the method of applying artificial NNs for the prediction of both construction and performance parameters of canopy fabrics. Based on the influence on the performance of the canopy fabric, constructional parameters were chosen. Constructional parameters were used as input for predicting the performance parameter in forward engineering, and the parameters were reversed for the reverse engineering prediction. Comparison between actual results and predicted results was made. The results of the design prediction had excellent correlation with all the samples.

Behera and Goyal (2009) described the method of applying the artificial neural network for the prediction performance parameters for airbag fabrics. The results of the ANN performance prediction had low prediction error of 12% with all the samples and the artificial neural network based on Error Back-propagation were found promising for a new domain of design prediction technique. The prediction performance of the neural network was based on the amount of training. The diversity of the data and the amount of data resulted in better the mapping of the network, and better predictions. Therefore, airbag fabrics could be successfully engineered using artificial neural network.

3.2 Fabric-property prediction

Ertugrul and Ucar (2000) have shown how the bursting strength of cotton plain knitted fabrics can be predicted before manufacturing by using intelligent techniques of neural network and neuro-fuzzy approaches. Fabric bursting strength affected by fabric weight, yarn breaking strength, and yarn breaking elongation were input elements for the predictions. Both the multi-layer feed-forward neural network and adaptive network based fuzzy inference system, a combination of a radial basis neural network and the Sugeno-Takagi fuzzy system, were studied. Both systems had the ability to learn training data successfully, and testing errors can give an approximate knowledge of the bursting strength which fabric can be knitted.

Chen *et al.*, (2001) proposed a neural network computing technique to predict fabric end-use. One hundred samples of apparel fabrics for suiting, shirting, and blouse uses were selected and fabric properties of extension, shear, bending, compression, and friction and

roughness were measured by using the Kawabata KES instruments. Instrumental data of the fabric properties and information on fabric end-uses were input into neural network software to train a multilayer perceptron model. The prediction error rate from the established neural network model was estimated by using a cross-validation method. The estimated error rate for prediction was 0.07. The established neural network model could be upgraded by inputting new fabric samples and be implemented for applications in garment design and manufacture.

Shyr *et al.*, (2004) have taken new approaches in using a one-step transformation process to establish translation equations for total hand evaluations of fabrics by employing a stepwise regression method and an artificial neural network. The key mechanical properties selected from sixteen fabric mechanical properties based on a KES system, using the stepwise regression selection method, were the parameters. The translation equations were developed directly with parameters without a primary hand value transformation process. 114 polyester/cotton blended woven fabrics were selected for investigation. Four mechanical properties LC, 2HG, B, and WT were the parameters for developing the translation equations. The correlation coefficients of the translation equations developed from the stepwise regression and artificial neural network methods were 0.925 and 0.955, respectively. Both translation equations had high correlation coefficients between the calculated and practical values. The approaches were identified effectively to develop translation equations for new fabrics in the textile industry.

Behera and Mishra (2007) investigated the prediction of non-linear relations of functional and aesthetic properties of worsted suiting fabrics for fabric development by an engineered approach of a radial basis function network which was trained with worsted fabric constructional parameters. Therefore, an objective method of fabric appearance evaluation with the help of digital image processing was introduced. The radial basis function network can successfully predict the fabric functional and aesthetic properties from basic fibre characteristics and fabric constructional parameters with considerable accuracy. The network prediction was in good correlation with the actual experimental data. There was some error in predicting the fabric properties from the constructional parameters. The variation in the actual values and predicted values was due to the small sample size. Moreover, the properties of worsted fabrics were greatly influenced by the finishing parameters which are not taken into consideration in the training of the network.

Murrells *et al.*, (2009) employed an artificial neural network (ANN) model and a standard multiple linear regression model for the prediction of the degree of spirality of single jersey fabrics made from a total of 66 fabric samples produced from three types of 100% cotton yarn samples including conventional ring yarns, low torque ring yarns and plied yarns. The data were randomly divided into 53 and 13 sets of data that were used for training and evaluating the performance of the predictive models. A statistical analysis was undertaken to check the validity by comparing the results obtained from the two types of model with relatively good agreement between predictions and actual measured values of fabric spirality with a correlation coefficient, R , of 0.976 in out-of-sample testing. Therefore, the results demonstrated that the neural network model produced superior results to predict the degree of fabric spirality after three washing and drying cycles. Both the ANN and the regression approach showed that twist liveliness, tightness factor and yarn linear density were the most important factors in predicting fabric spirality. Twist liveliness was the major contributor to spirality with the other factors such as yarn type, the number of feeders,

rotational direction and gauge (needles/inch) of the knitting machine and dyeing method having a minor influence.

Hadizadeh *et al.*, (2009) used an ANN model for predicting initial load-extension behavior (Young's modulus) in the warp and weft directions of plain weave and plain weave derivative fabrics by modeling the relationship between a combination of the yarn modular length, yarn spacing, the ratio of occupied spacing to total length of yarn in one weave repeat, and the yarn flexural rigidity with satisfactory accuracy. A single hidden layer feed-forward ANN based on a back-propagation algorithm with four input neurons and one output neuron was developed to predict initial modulus in the warp and weft directions. Input values were defined as combination expressions of geometrical parameters of fabric and yarn flexural rigidity, which were obtained from Leaf's mathematical model. Data were divided into two groups as training and test sets. A very good agreement between the examined and predicted values was achieved and the model's suitability was confirmed by the low performance factor (PF/3) and the high coefficient of correlation.

Hadizadeh *et al.*, (2010) introduced a new model based on an adaptive neuro-fuzzy inference system (ANFIS) for predicting initial load-extension behavior of plain-woven fabrics. Input values defined as combination expressions of geometrical parameters of fabric and yarn flexural rigidity, yarn-spacing, weave angle and yarn modular length, which were extracted from Leaf's mathematical model. The results showed that the neuro-fuzzy system can be used for modeling initial modulus in the warp and weft directions of plain-woven fabrics. Outputs of the neuro-fuzzy model were also compared with results obtained by Leaf's models. The calculated results were in good agreement with the real data upon finding the importance of inputs.

3.3 Fabric defect

Hu and Tsai (2000) used best wavelet packet bases and an artificial neural network (ANN) to inspect four kinds of fabric defects. Multi-resolution representation of an image using wavelet transform was a new and effective approach for analyzing image information content. The values and positions for the smallest-six entropy were found in a wavelet packet best tree that acted as the feature parameters of the ANN for identifying fabric defects. They explored three basic considerations of the classification rate of fabric defect inspection comprising wavelets with various maximum vanishing moments, different numbers of resolution levels, and differently scaled fabric images. The results showed that the total classification rate for a wavelet function with a maximum vanishing moment of four and three resolution levels can reach 100%, and differently scaled fabric images had no obvious effect on the classification rate.

Shiau *et al.*, (2000) constructed a back-propagation neural network topology to automatically recognize neps and trash in a web by color image processing. The ideal background color under moderate conditions of brightness and contrast to overcome the translucent problem of fibers in a web, specimens were reproduced in a color BMP image file format. With a back-propagation neural network, the RGB (red, green, and blue) values corresponding with the image pixels were used to perform the recognition, and three categories (i.e., normal web, nep, and trash) can be recognized to determine the numbers and areas of both neps and trash. According to experimental analysis, the recognition rate can reach 99.63% under circumstances in which the neural network topology is 3-3-3. Both contrast and brightness were set at 60% with an azure background color. The results showed that both neps and

trash can be recognized well, and the method was suitable not only for cotton and man-made fibers of different lengths, but also for different web thicknesses as to a limit of 32.9 g/m².

Choi *et al.*, (2001) developed a new method for a fabric defect identifying system by using fuzzy inference in multi-conditions. The system has applied fuzzy inference rules, and the membership function for these rules to adopt a neural network approach. Only a small number of fuzzy inference rules were required to make the identifications of non-defect, slub (warp direction), slub (weft direction), nep, and composite defect. One fuzzy inference rule can replace many crisp rules. This system can be used to design a reliable system for identifying fabric defects. Experimental results with this approach have demonstrated the identification ability which was comparable to that of a human inspector.

Huang and Chen (2001) investigated an image classification by a neural-fuzzy system for normal fabrics and eight kinds of fabric defects. This system combined the fuzzification technique with fuzzy logic and a back-propagation learning algorithm with neural networks. Four inputs featured the ratio of projection lengths in the horizontal and vertical directions, the gray-level mean and standard deviation of the image, and the large number emphasis (LNE) based on the neighboring gray level dependence matrix for the defect area. The neural network was also implemented and compared with the neural-fuzzy system. The results demonstrated that the neural-fuzzy system was superior to the neural network in classification ability.

Saeidi *et al.*, (2005) described a computer vision-based fabric inspection system implemented on a circular knitting machine to inspect the fabric under construction. The detection of defects in knitted fabric was performed and the performance of three different spectral methods, namely, the discrete Fourier transform, the wavelet and the Gabor transforms were evaluated off-line. Knitted fabric defect-detection and classification was implemented on-line. The captured images were subjected to a defect-detection algorithm, which was based on the concepts of the Gabor wavelet transform, and a neural network as a classifier. An operator encountering defects also evaluated the performance of the system. The fabric images were broadly classified into seven main categories as well as seven combined defects. The results of the designed system were compared with those of human vision.

Shady *et al.*, (2006) developed a new method for knitted fabric defect detection and classification using image analysis and neural networks. Images of six different induced defects (broken needle, fly, hole, barré, thick and thin yarn) were used in the analysis. Statistical procedures and Fourier Transforms were utilized in the feature extraction effort and neural networks were used to detect and classify the defects. The results showed success in classifying most of the defects but the classification results for the barré defect were not identified using either approach due to the nature of the defect shape which caused it to interfere with other defects such as thick/thin yarn defects. The results of using the Fourier Transform features extraction approach were slightly more successful than the statistical approach in detecting the free defect and classifying most of the other defects.

Yuen *et al.*, (2009) explored a novel method to detect the fabric defect automatically with a segmented window technique which was presented to segment an image for a three layer BP neural network to classify fabric stitching defects. This method was specifically designed for evaluating fabric stitches or seams of semi-finished and finished garments.

A fabric stitching inspection method was proposed for knitted fabric in which a segmented window technique was developed to segment images into three classes using a

monochrome single-loop ribwork of knitted fabric: (1) seams without sewing defects; (2) seams with pleated defects; and (3) seams with puckering defects caused by stitching faults. Nine characteristic variables were obtained from the segmented images and input into a Back Propagation (BP) neural network for classification and object recognition. The classification results demonstrated that the inspection method developed was effective in identifying the three classes of knitted-fabric stitching. It was proved that the classifier with nine characteristic variables outperformed those with five and seven variables and the neural network technique using either BP or radial basis (RB) was effective for classifying the fabric stitching defects. By using the BP neural network, the recognition rate was 100%. The experiment results showed that the method developed in this study is feasible and applicable.

3.4 Sewing

Jeong *et al.*, (2000) constructed a neural network and subjoined local approximation technique for application to the sewing process by selecting optimal interlinings for woolen fabrics. Men's woolen suitings and ten optimal interlinings were selected and matched. A single hidden layer neural network was constructed with five input nodes, ten hidden nodes, and two output nodes. Both input and output of the mechanical parameters measured on the KES-FB system were used to train the network with a back-propagation learning algorithm. The inputs for the fabrics were tensile energy, bending rigidity, bending hysteresis, shear stiffness, and shear hysteresis, while outputs for the interlinings were bending rigidity and shear stiffness. This research presented a few methods for improving the efficiency of the learning process. The raw data from the KES-FB system were nonlinearly normalized, and input orders were randomized. The procedure produced a good result because the selection agreed well with the experts' selections. Consequently, the results showed that the neural network and subjoined techniques had a strong potential for selecting optimum interlinings for woolen fabrics.

Hui *et al.*, (2007) investigated the use of artificial neural networks (ANN) to predict the sewing performance of woven fabrics for efficient planning and control for the sewing operation. This was based on the physical and mechanical properties of fabrics such as the critical parameters of a fabric constructional and behavioural pattern as all input units and to verify the ANN techniques as human decision in the prediction of sewing performance of fabrics by testing 109 data sets of fabrics through simple testing system and the sewing performance of each fabric's specimen by the domain experts. Among 109 input-output data pairs, 94 were used to train the proposed back-propagation (BP) neural network for the prediction of the unknown sewing performance of a given fabric, and 15 were used to test the proposed BP neural network. A three-layered BP neural network that consists of 21 input units, 21 hidden units, and 16 output units was developed. The output units of the model were the control levels of sewing performance in the areas of puckering, needle damages, distortion, and overfeeding. After 10,000 iterations of training of BP neural network, the neural network converged to the minimum error level. The evaluation of the model showed that the overall prediction accuracy of the developed BP model was at 93 per cent which was the same as the accuracy of prediction made by human assessment. The predicted values of most fabrics were found to be in good agreement with the results of sewing tests carried out by domain experts.

3.5 Seam performance

Hui and Ng (2009) investigated the capability of artificial neural networks based on a back propagation algorithm with weight decay technique and multiple logarithm regression (MLR) methods for modeling seam performance of fifty commercial woven fabrics used for the manufacture of men's and women's outerwear based on seam puckering, seam flotation and seam efficiency. The developed models were assessed by verifying Mean Square Error (MSE) and Correlation Coefficient (R -value) of test data prediction. The results indicated that the artificial neural network (ANN) model has better performance in comparison with the multiple logarithm regression model. The difference between the MSE of predicting in these two models for predicting seam puckering, seam flotation, and seam efficiency was 0.0394, 0.0096, and 0.0049, respectively. Thus, the ANN model was found to be more accurate than MLR, and the prediction errors of ANNs were low despite the availability of only a small training data set. However, the difference in prediction errors made by both models was not significantly high. It was found that MLR models were quicker to construct, more transparent, and less likely to overfit the minimal amount of data available. Therefore, both models were effectively predicting the seam performance of woven fabrics.

Onal *et al.*, (2009) studied the effect of factors on seam strength of webbings made from polyamide 6.6 which were used in parachute assemblies as reinforcing units for providing strength by using both Taguchi's design of experiment (TDOE) as well as an artificial neural network (ANN), then compared them with the strength physically obtained from mechanical tests on notched webbing specimens. It was established from these comparisons, in which the root mean square error was used as an accuracy measure, that the predictions by ANN were better predictions of the experimental seam strength of jointed notched webbing in accuracy than those predicted by TDOE. An L8 design was adopted and an orthogonal array was generated. The contribution of each factor to seam strength was analyzed using analysis of variance (ANOVA) and signal to noise ratio methods. From the analysis, the TDOE revealed (based on SNR performance criteria) that the fabric width, folding length of joint and interaction between the folding length of joint and the seam design affected seam strength significantly. An optimal configuration of levels of factors was found by using TDOE.

4. Applications to chemical processing

Huang and Yu (2001) used image processing and fuzzy neural network approaches to classify seven kinds of dyeing defects including filling band in shade, dye and carrier spots, mist, oil stain, tailing, listing, and uneven dyeing on selvage. The fuzzy neural classification system was constructed by a fuzzy expert system with the neural network as a fuzzy inference engine so it was more intelligent in handling pattern recognition and classification problems. The neural network was trained to become the inference engine using sample data. Region growing was adopted to directly detect different defect regions in an image. Seventy samples, ten samples for each defect, were obtained for training and testing. The results demonstrated that the fuzzy neural network approach could precisely classify the defective samples by the features selected.

5. Applications to clothing

5.1 Pattern fitting prediction

Hu *et al.*, (2009) developed a system to utilize the successful experiences and help the beginners of garment pattern design (GPD) through optimization methods by proposing a

hybrid system (NN-ICEA) based on neural network (NN) and immune co-evolutionary algorithm (ICEA) to predict the fit of the garments and search optimal sizes. ICEA takes NN as fitness function and procedures including clonal proliferation, hypermutation and co-evolution search the optimal size values. A series of experiments with a dataset of 450 pieces of pants was conducted to demonstrate the prediction and optimization capabilities of NN-ICEA. In the comparative studies, NN-ICEA was compared with NN-genetic algorithm to show the value of immune-inspired operators. Four types of GPD method have been summarized and compared. The research was a feasible and effective attempt aiming at a valuable problem and provides key algorithms for fit prediction and size optimization. The algorithms can be incorporated into garment computer-aided design system (CAD).

5.2 Clothing sensory comfort

Wong *et al.*, (2003) investigated the predictability of clothing sensory comfort from psychological perceptions by using a feed-forward back-propagation network in an artificial neural network (ANN) system. Wear trials were conducted ten sensory perceptions (clammy, clingy, damp, sticky, heavy, prickly, scratchy, fit, breathable, and thermal) and overall clothing comfort (comfort) which were rated by twenty-two professional athletes in a controlled laboratory. Four different garments in each trial and rate the sensations above during a 90-minute exercising period were scored as input into five different feed-forward back-propagation neural network models, consisting of six different numbers of hidden and output transfer neurons. The results showed a good correlation between predicted and actual comfort ratings with a significance of $p < 0.001$. Good agreement between predicted and actual clothing comfort perceptions proved that the neural network was an effective technique for modeling the psychological perceptions of clothing sensory comfort. The predicted comfort score generated from the model with the log-sigmoid hidden neurons and the linear output neuron had a better fit with the actual comfort score than other models with different combinations of hidden and output neurons. Compared with statistical modeling techniques, the neural network was a fast, flexible, predictive tool with a self-learning ability for clothing comfort perceptions.

Wong *et al.*, (2004) investigated the process of human psychological perceptions of clothing related sensations and comfort to develop an intellectual understanding of and methodology for predicting clothing comfort performance from fabric physical properties. Various hybrid models were developed using different modeling techniques by studying human sensory perception and judgement processes. By combining the strengths of statistics (data reduction and information summation), a neural network (self-learning ability), and fuzzy logic (fuzzy reasoning ability), hybrid models were developed to simulate different stages of the perception process. Results showed that the TS-TS-NN-FL model had the highest ability to predict overall comfort performance from fabric physical properties. The three key elements in predicting psychological perceptions of clothing comfort from fabric physical properties were data reduction and summation, self-learning, and fuzzy reasoning. The model was shown that these three elements can generate the best predictions compared with other hybrid models.

All research outputs in application of ANN in textiles and clothing areas over last decade are summarized as shown in Appendix.

6. Challenges encountered by ANN used in textiles and clothing industries

In the application of ANN in different disciplines of textiles and clothing industries, there are the following limitations which has encountered.

Fibre classification: More powerful learning strategies are required to improve the classification accuracy made by the ANN.

Yarn manufacture: Additional work is needed to accurately model the occurrence of spinning ends-down and neps by using the ANN. To improve the predictions on such parameters, additional mill-specific data and further developments of the ANN simulations are necessary.

Yarn-property prediction: Some researchers reported that yarn tenacity decreases when spinning speed exceeds a certain value, say, 210 m/min. Since we used an air-jet spinstester in this research, spinning speed could not exceed 200 m/min because of the restriction of the machine, so the decreasing trend of yarn tenacity could not be predicted. In addition, the difficulty in developing a universal empirical model that can accurately predict yarn hairiness for different mills stems from the variability in processing methodologies and equipment.

As many independent variables exist, further difficulty arises in covering the entire range of parameters with the capability of interpolating and extrapolating experimental observations or mill measurements and to take into account the interactive contribution between each input factor. It is, therefore, desirable to possess the capacity to discover regularities directly from the data being modeled, that can dynamically evolve with time taking into account changes in materials' specifications and processing techniques within a given mill. The MLP model, one of ANN model does possess this characteristic and has the potential for wider applicability in industry.

Fabric manufacture: To improve the correlation between actual and predicted values, in the case of reverse engineering, constraints are posed to limit the ranges of constructional parameters in ANN.

Fabric-property prediction: Besides the possibility of trying different ANN configurations, the quantity and the quality of training data are also very important to the results. Even though we do not include coefficient of variation (CV) values in the training pairs as inputs, we have concluded that the ANN has a higher chance of giving big errors if the data include many training pairs with high CV values because they feed inconsistent information to the ANN. For future work, we suggest that there should be enough training pairs and the CV values of these data should also be known for higher reliability.

In addition, prediction performance can be further improved by including these parameters as input during the training phase. In few cases, the network has predicted contradictory trends which are found difficult to be explained. Also, the neural network model outperformed the multiple regression models in predicting the angle of spirality using data that were not used to train the network. This indicates that it is worthwhile using the more complex ANN technique if a large amount of different types of data are available.

Fabric defect: Since neps and trash in a web can be recognized, yarn quality is able to improve using a reference for adjusting manufacturing parameters. In addition, the CCD (charge coupled device) must be mounted, despite the scanner, because of on-line considerations. Patterned and complex fabrics can be inspected as well as plain fabrics. Further research such as a neuro-fuzzy expert system can identify actual defect types like reed marks, mispicks, pilling, finger marks, and others.

Since this research is limited by the speed of the knitting machine, further studies are required to inspect the fabric defects in higher speed, circular knitting machines. Application of ANN in fabric defect is still needed to be done in two major aspects: (1) the applicability of the developed method in studying other manufacturing defects needs to be validated; and (2) the current 2-D-based investigation needs to be extended to three-dimensional (3-D) space for actual manual inspection.

Seam performance: In these comparisons, RMSE values were used as comparative metrics. As a result, it can be said that ANN appears to be a reliable and useful tool in characterizing the effect of some critical manufacturing parameters on the seam strength of webbing if a sufficient number of replicated experimental data are available to train the ANN.

Applications to Chemical Processing: Fuzzification maps the input feature value to fuzzy sets and the dimensions of the feature space are increased. When fuzzy sets are appropriately chosen, they can increase the separated ability of classes in the feature space. This allows the fuzzy neural network model to fit input-output data more accurately with enhanced classification ability.

Pattern fitting prediction: The current scale is definitely not enough to study all sizes of the garment. In order to present the fuzzy and stochastic nature of the garment and body sizes, it should be modeled as fuzzy vector or stochastic vector. In addition, it is valuable to incorporate NN-ICEA into garment CAD system and thus the 2D and 3D effects of garments can provide intuitive impressions.

Clothing sensory comfort: The functions and interrelationships of individual sensory perceptions and comfort are unknown. It is difficult to learn their relationships using ANN. In conclusion, the major challenges of using ANN in textiles and clothing industries are lack of sufficient data for learning and long computational time required for handling a large size of dataset. To improve the performance of ANN models, some major factors shall be considered to include the determination of adequate model inputs, data division and preprocessing, choice of suitable network architecture, careful selection of some internal parameters that control the optimization method, stopping criteria, and model validation.

7. Potential future application of ANN in textiles and clothing industries

A large number of applications of ANN in textiles and clothing industries are used feedforward and Kohonen networks. The other types of artificial neural networks such as recurrent neural network, associative neural network and dynamic neural networks (refer to http://en.wikipedia.org/wiki/Types_of_artificial_neural_networks website) are rarely used. Meanwhile, quite a few areas remains insufficiently explored such as knitting, nonwoven fabrics and finishing control. Exploring such areas using new ANN models is a new trend in future research.

In the future research, the following issues shall be taken into consideration to the application of ANN in textiles and clothing industries.

- a. improve the data collection method for training ANNs such as online data captured from the process
- b. improve the feature-extraction procedures before the data can be fed to an ANN
- c. improve extrapolation ability of the system to strengthen the prediction capability
- d. improve the user-friendly interface between user and machine

These issues are important for further development of using ANN in textiles and clothing industries. Further research works shall deal with such issues in order to set up intelligent systems in textiles and clothing fields instead of human judgment.

Study Area		No	Title	Author	Journal	Year	Vol(No),pp.	Findings
2. Fibres and Yarn	2.1 Fibre classification	1	Objective Evaluation of the Trash and Color of Raw Cotton by Image Processing and Neural Network	Kang and Kim	Textile Research Journal	2002	72(9), 776-782.	an image for the cu cotton gra system of cotton
		2	Intelligent Animal Fiber Classification with Artificial Neural Networks	She et al.	Textile Research Journal	2002	72(7), 594-600.	classify tw of animal objectivel between r and moha
		3	Genetic algorithm optimisation combined with partial least squares regression and mutual information variable selection procedures in near-infrared quantitative analysis of cotton-viscose textiles	Durand et al.	Analytica Chimica Acta	2007	595(1-2), 72-79.	variable s in the con near-infra (NIR) mu calibration cotton-vis textiles compositi
	2.2 Yarn manufacture	4	Predicting Worstest Spinning Performance with an Artificial Neural Network Model	Beltran et al.	Textile Research Journal	2004	74(9), 757-763.	predict ya quality of spinning performan an individ

Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findings
	5	Use of Artificial Neural Networks for Determining the Leveling Action Point at the Auto-leveling Draw Frame	Farooq and Cherif	Textile Research Journal	2008	78(6), 502-509.	prediction leveling point, one of the important leveling parameters drawing and strong influence quality manufacturing yarn
2.3 Yarn-property prediction	6	Using Neural Network Theory to Predict the Properties of Melt Spun Fibers	Kuo et al.	Textile Research Journal	2004	74(9), 840-843.	established prediction for tenacity and yarn as-spun that it is a very reliable for as-spun process
	7	Predicting the Tensile Properties of Air-Jet Spun Yarns	Zeng et al.	Textile Research Journal	2004	74(8), 689-694.	prediction properties tenacity spun yarn

Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findings
							produced by an air-spinner by two names network and simulation
	8	Prediction of Yarn Shrinkage using Neural Nets	Lin	Textile Research Journal	2007	77(5), 336-342.	the shrinkage of warp and weft yarns in fabrics manufactured by air jet spinning using a neural network model which can be used to determine the relationship between shrinkage and the factors and factors
	9	Neural Network Technique for Fiber Image Recognition	Xu et al.	Journal of Industrial Textiles	2007	36(4), 329-336.	analyzed the cross-section of a woven fabric blend

Study Area		No	Title	Author	Journal	Year	Vol(No),pp.	Findings
		10	An Artificial Neural Network-based Hairiness Prediction Model for Worsted Wool Yarns	Khan et al.	Textile Research Journal	2009	79(8), 714-720	the performance of multivariate perceptron and multivariate linear regression (MLR) in predicting hairiness of worsted wool yarns objectively

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Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findin
	11	The Effect of Fiber Properties on the Characteristics of Spliced Yarns: Part II: Prediction of Retained Spliced Diameter	Ünal et al.	Textile Research Journal	2010	0(0), 1-8.	the ret spliced with r splicin param fiber a proper

Study Area		No	Title	Author	Journal	Year	Vol(No),pp.	Findings
	2.4 Fibre and Yarn relationship	12	Adaptive Neuro-fuzzy Inference System with Subtractive Clustering: A Model to Predict Fiber and Yarn Relationship	Admutha and Apte	Textile Research Journal	2010	80(9), 841-846.	to develop relationship between yarn in spinning
3. Applications to Fabrics	3.1 Fabric manufacture	13	Predicting the Warp Breakage Rate in Weaving by Neural Network Techniques	Yao et al.	Textile Research Journal	2005	75(3), 274-278	the prediction of the breakage from a quality using forward propagation network artificial network
		14	Artificial Neural Network-embedded Expert System for the Design of Canopy Fabrics	Behera and Karthikeyan	Journal of Industrial Textiles	2006	36(2), 111-123.	prediction construction performance param canopy
		15	Artificial Neural Network System for the Design of Airbag Fabrics	Behera and Goyal	Journal of Industrial Textiles	2009	39(1), 45-55.	the prediction performance param airbag

Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findings
3.2 Fabric-property prediction	16	Predicting Bursting Strength of Cotton Plain Knitted Fabrics Using Intelligent Techniques	Ertugrul and Ucar	Textile Research Journal	2000	70(10), 845-851.	how the strength of plain knitted fabrics can be predicted using intelligent techniques such as neural networks and neuro-fuzzy approaches

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Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findings
	17	Prediction of Fabric End-use Using a Neural Network Technique	Chen et al.	Journal of the Textile Institute	2001	92(2), 157-163.	to predict end-use
	18	New Approaches to Establishing Translation Equations for the Total Hand Value of Fabric	Shyr et al.	Textile Research Journal	2004	74(6), 528-534.	a one-step process to establish translation equations for hand value of fabric employed a stepwise regression and an artificial neural network
	19	Artificial neural network-based prediction of aesthetic and functional properties of worsted suiting fabrics	Behera and Mishra	International Journal of Clothing Science and Technology	2007	19(5), 259-276.	investigation of linear and nonlinear functions for aesthetic and functional properties of worsted suiting fabrics

Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findings
							fabric developed an engineering approach radial function which with w fabric constr param
	20	An Artificial Neural Network Model for the Prediction of Spirality of Fully Relaxed Single Jersey Fabrics	Murrells et al.	Textile Research Journal	2009	79(3), 227-234.	the pr the de spirali jersey made of 66 f sampl from t of 100 yarn s

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Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findings
	21	The Prediction of Initial Load-extension Behavior of Woven Fabrics Using Artificial Neural Network	Hadizadeh et al.	Textile Research Journal	2009	79(17), 1599-1609.	prediction of load-extension behavior of woven fabrics using artificial neural network
	22	Application of an Adaptive Neuro-fuzzy System for Prediction of Initial Load--Extension Behavior of Plain-woven Fabrics	Hadizadeh et al.	Textile Research Journal	2010	80(10), 981-990.	prediction of load-extension behavior of woven fabrics based on adaptive neuro-fuzzy system
3.3 Fabric defect	23	Fabric Inspection Based on Best Wavelet Packet Bases	Hu and Tsai	Textile Research Journal	2000	70(8), 662-670.	best wavelet packet bases for an artificial neural network inspection of fabric defects
	24	Classifying Web Defects with a Back-Propagation Neural Network by Color Image Processing	Shiau et al.	Textile Research Journal	2000	70(7), 633-640.	a back-propagation neural network topology for automatic recognition and tracking of fabric defects by color image processing

Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findings
	25	Detecting Fabric Defects with Computer Vision and Fuzzy Rule Generation. Part II: Defect Identification by a Fuzzy Expert System	Choi et al.	Textile Research Journal	2001	71(7), 563-573.	a fabric defect identification system by using fuzzy inference method for multiple
	26	Neural-Fuzzy Classification for Fabric Defects	Huang and Chen	Textile Research Journal	2001	71(3), 220-224.	an image classification system for fabric defects using neural network and fuzzy inference

Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findings
	27	Computer Vision-Aided Fabric Inspection System for On-Circular Knitting Machine	Saeidi et al.	Textile Research Journal	2005	75(6), 492-497.	a computer based inspection system for circular knitting machine the fabric under construction
	28	Detection and Classification of Defects in Knitted Fabric Structures	Shady et al.	Textile Research Journal	2006	76(4), 295-300.	for knitted fabric defect detection and classification using neural network analysis
	29	Fabric Stitching Inspection Using Segmented Window Technique and BP Neural Network	Yuen et al.	Textile Research Journal	2009	79(1), 24-35.	a novel method for defect detection in fabric stitching using a segmented window technique which presents a segmented window for a BP neural network to classify stitching

Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findings
3.4 Sewing	30	Selecting Optimal Interlinings with a Neural Network	Jeong et al.	Textile Research Journal	2000	70(11), 1005-1010.	a neural network and a local approximation technique are applied to select the optimal interlining wools.
	31	Application of artificial neural networks to the prediction of sewing performance of fabrics	Hui et al.	International Journal of Clothing Science and Technology	2007	19(5), 291-318.	to predict sewing performance of woven fabrics and compare with conventional sewing based on physical mechanical properties of fabrics.

Study Area		No	Title	Author	Journal	Year	Vol(No),pp.	Findin
3.5 Seam performance		32	Predicting Seam Performance of Commercial Woven Fabrics Using Multiple Logarithm Regression and Artificial Neural Networks	Hui and Ng	Textile Research Journal	2009	79(18), 1649-1657.	the cap artifici netwo a back propag algorit weigh techni multip logarit regres metho model perfor fifty co wover used f manuf men's wome outerv
		33	Predicting the Seam Strength of Notched Webbing for Parachute Assemblies Using the Taguchi's Design of Experiment and Artificial Neural Networks	Onal et al.	Textile Research Journal	2009	79(5), 468-478.	the eff factors streng webbi from p 6.6

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Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findin
4. Applications to Chemical Processing	34	Fuzzy Neural Network Approach to Classifying Dyeing Defects	Huang and Yu	Textile Research Journal	2001	71(2), 100-104.	image and fu netwo approo classif kinds defect:

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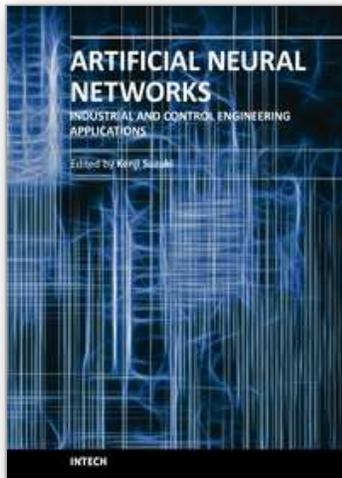
Study Area		No	Title	Author	Journal	Year	Vol(No),pp.	Findin
5. Applications to Clothing	5.1 Pattern fitting prediction	35	A Hybrid Neural Network and Immune Algorithm Approach for Fit Garment Design	Hu et al.	Textile Research Journal	2009	79(14), 1319-1330.	to pre the ga search sizes

Study Area	No	Title	Author	Journal	Year	Vol(No),pp.	Findings
5.2 Clothing sensory comfort	36	Neural Network Predictions of Human Psychological Perceptions of Clothing Sensory Comfort	Wong et al.	Textile Research Journal	2003	73(1), 31-37.	the pro of clothe sensor from psycho percep using forward propa netwo artifici netwo system
	37	Predicting Clothing Sensory Comfort with Artificial Intelligence Hybrid Models	Wong et al.	Textile Research Journal	2004	74(1), 13-19.	to dev intelle unders and m for pre clothin perfor fabric physic proper

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Artificial neural networks may probably be the single most successful technology in the last two decades which has been widely used in a large variety of applications. The purpose of this book is to provide recent advances of artificial neural networks in industrial and control engineering applications. The book begins with a review of applications of artificial neural networks in textile industries. Particular applications in textile industries follow. Parts continue with applications in materials science and industry such as material identification, and estimation of material property and state, food industry such as meat, electric and power industry such as batteries and power systems, mechanical engineering such as engines and machines, and control and robotic engineering such as system control and identification, fault diagnosis systems, and robot manipulation. Thus, this book will be a fundamental source of recent advances and applications of artificial neural networks in industrial and control engineering areas. The target audience includes professors and students in engineering schools, and researchers and engineers in industries.

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