

**AUTOMATIC FABRIC INSPECTION USING
DIGITAL IMAGE PROCESSING AND
NEURALNETWORK**

by
M. P. MANI
Department of Textile Technology

Submitted
in fulfillment of the requirements of the degree of Doctor of Philosophy
to the

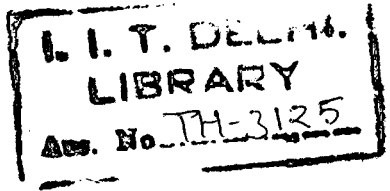
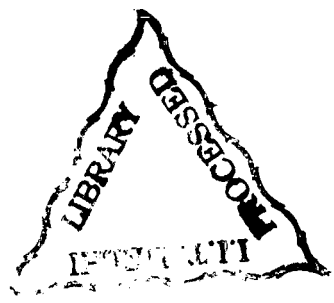


Indian Institute of Technology, Delhi
December 2004

- Textile testing -
Digital image processing

TM
677.01:681.327.57

MAN-A



CERTIFICATE

This is to certify that the thesis entitled “**AUTOMATIC FABRIC INSPECTION USING DIGITAL IMAGE PROCESSING AND NEURALNETWORK**” being submitted by **Mr. M.P.Mani** to the **Department of Textile Technology, Indian Institute of Technology, Delhi** for the award of the **Doctor of Philosophy** is a record of the bonafide research work carried out by him. He has worked under my guidance and supervision, and has fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard.

The results contained herein have not been submitted in part or full to any other university or institution for award of any degree or diploma.



(Dr. B.K. Behera)

Associate Professor

Department of Textile Technology

Indian Institute of Technology

New Delhi-110016

ACKNOWLEDGEMENTS

I express my deep sense of gratitude to Dr. B.K.Behera for his guidance, valuable suggestions, personal involvement, constant encouragement and keen interest throughout the course of this research work.

My deep sense of gratitude goes to Mr. Shyamal Ghosh, Mr K.Rajendran Nair, Mrs. Kiran Dhingra, Mr. B.C. Khatua, Mr. Subodh Kumar, Mr. Deepak Shetti, Dr. M.R.Maji, S. Natarajan and colleagues of Office of the Textile commissioner; Ministry of Textiles, Govt. of India, for deputing me to pursue this research work and constant encouragements throughout the research work.

I wish to express my thanks to Prof. Hari, Prof Chavan, Prof Banerjee, Prof. Devpura, Prof. Kothari, Prof. Chattopadhyay, Dr. Alagirusamy, Dr Rengasamy and all faculty members and staff include Mr. Thukral, Rajkumar of the Department of Textile Technology for their invaluable advice, motivation, and all time assistance.

I am thankful to Directors of M/s. Prolific Engineers, Noida and Expert Vision Ltd, Mumbai, especially Mr. Subash Jain and Mr Nelson Periera, for their constructive help extended in fabricating the mechanical design and interfacing the vision components of the Automatic Fabric Inspection System.

I put my great sense of debt-ness to Dr. Sunit Tuli, Dr. Anuradha Balaram and the continuous help rendered by my friends Francis Sujai, Chockalingam and assistance rendered by K. Gowthaman, S. Arvind, and all my friends.

It will be incomplete if I am not mentioning my family members especially my wife Mrs.M.Tamilselve and my daughter M.Kanchana for their sacrifice and invaluable help. And that I am submitting all my credentials to *my living god, my Mother.*



(M.P.Mani)

ABSTRACT

Conventional method of fabric inspection by visual examination has failed to produce completely flawless fabrics. This Research work proposes economic way of design and development of a system for automatic inspection of fabric defects by using digital image processing techniques along with development of an expert system embedded with artificial neural network for process control in weaving mills. The work comprises fabrication of an inspection machine equipped with all accessories such as scientific illumination system, robotic marking system and specialized image acquisition system.

Fabrication of the system involves modern industrial cameras (Dalsa CCD Camera Line Scan model CL-C3 with 2048 Horizontal resolution and 1 Vertical resolution having sensors of $14 \times 14 \mu$ pitch size) to sense the flaws of fabric to an extent of 300μ with suitable set of specially made rollers to pass the wrinkle free fabric in the midst of lighting using speed adjustable DC motor. Though the machine run speed set at 70 metres / min, speed can be varied from very low upto 128.7 metres / min. This is supported by the use of modern techniques of light set up with special circuit and electronic ballasts to provide adequate constant DC lighting from bottom to the high speed moving fabric. Elliptical reflectors designed in the lighting system focus light on a small required width of area so as to inspect the defect portions efficiently with high accuracy at low response time.

The machine frames containing special adjustable camera stand and special rollers weigh approximately 600 Kgs. Adjustable camera stand offers choice of adjustment of working

distance and selection of number of cameras to suit to the width of the fabric. The machine occupies a limited floor space of about 217 Cm width, 360 cm length and 200 cm height.

Numbers of faults are being introduced in the fabric when yarns were put to use in weaving machine to manufacture fabric due to the inherent defects in the yarn, bad preparation of warp and weft, improper machine condition, bad working practices, ill-maintained ambient condition in the department and so on. Thus wide varieties of sources are responsible for fabric defects. To have an improved product, these factors must be identified, measured, specified through suitable inspection procedures.

To begin with this research work, an extensive industrial survey was conducted selecting certain weaving, composite and garment making units in order to have reliable, adequate, and accurate information pertaining to fabric inspection. Thus a comprehensive database of fabric defects and their possible causes and all necessary information have been gathered from all available sources to form an expert system.

Through the use of image subtractive technique, images of fabric defects were identified and stored. Wavelet was selected as an effective image compression technique in terms of space, time and execution speed, among three fast image compression techniques and two statistical approaches to incorporate in the main program for automatic fabric inspection.

Wavelet combined Probabilistic Neural Network was selected based on accuracy of results, among the five various neural network techniques namely Linear, Back Propagation, Radial Basis Function, Kohonen and Probabilistic Neural Networks.

To provide effective feedback information or a report useful to the weaving and its

preparatory departments for early necessary action on the error making looms / operators, a knowledge-based real time expert system was developed using the knowledge and abilities of experts and all available literature in the field. The expert system was embedded with artificial neural network for faster processing of lot many nonmathematical relationships.

Special software developed for the purpose of “on line inspection” is written using Visual Basic for the front end and Visual C++ for all camera control, image acquisition and image analysis purposes. The highly effective Wavelet image compression technique accompanying with simple but perfect classifier Probabilistic Neural Network produces the defect results for considerably very high no .of 33 fabric defects “on line” accurately at a in-significant time period. Image Microsoft Access carries the real time Expert System provides all required data to prepare a perfect inspection report for fabric grading and as feed back to the back process machinery.

While the run time length measurement device is useful for counting the fabric length from start to end and the Robotic fabric defect marker developed for the purpose to stamp the appropriate colour mark near selvedge by a robotic arm, activated by a relay, once the scanning camera observes a defect on the running fabric.

The system was developed in such a way that after running the full length of the fabric, a report was generated with all requisite details of fabric defects such as nomenclature, description, possible causes, possibilities of mending the defect / remedial measures, person responsible for the defect and number of defects per 100 sq. mts of fabric and number of defect points per 100 sq. mts as per 4 point system.

This information could be used by the grey cloth manufacturing and exporting units for decision making regarding proper quality control operations or decision on export fabric quality. Garment units could use this information whether to accept the lot or not. Though the initial investments lie on the higher side (around Rs. 25 lakhs), the advantages are manifold. With increased production and reduced personnel requirement, it proves to be profitable in long run. Inherent advantage of having an assured fabric quality remains the backbone of the system.

CONTENTS

	Certificate	
	Acknowledgements	
	Abstract	
	Table of contents	i
	List of Figures	xi
	List of Tables	xiv
	List of Appendices	xvi
CHAPTER- I	INTRODUCTION & OBJECTIVES	1
CHAPTER- II	REVIEW OF LITERATURE	13
2.1	INTRODUCTION	13
2.2	CLASSIFICATION OF VARIOUS DEFECTS AND SYSTEMS	14
2.2.1	Four-point system (visual examination)	16
2.2.2	Six Point System	17
2.2.3.	Graniteville System	19
2.2.4	Ten-Point system (visual examination)	19
2.3	FABRIC INSPECTION	21
2.3.1	Conventional inspection method	22
2.3.2	Automatic Inspection method	23

2.3.2.1	Off-loom Fabric Inspection	29
2.3.2.2	On-Loom Fabric Inspection	31
2.4	IMAGE ACQUISITION	35
2.4.1	Illumination	36
2.5	IMAGE FORMATION	39
2.6	IMAGE DETECTION AND SENSING	40
2.6.1	Frame based CCD cameras VS line Scan CCD cameras	43
2.7	DIGITAL IMAGE PROCESSING AND ANALYSIS	47
2.7.1	Advantages of digital image processing:	48
2.7.2	Disadvantages of digital image processing	48
2.7.3	Image Enhancement	49
2.7.4	Image Measurement Extraction	53
2.7.5	Image Compression	54
2.7.6	Transform selection	56
2.7.6.1	Sub-image selection	58
2.7.6.2	Threshold coding	58
2.7.6.3	Fast Fourier Transform (FFT)	59
2.7.6.4	Discrete Cosine Transform (DCT)	60
2.7.6.5	Fast Discrete Cosine Transform	62
2.7.6.6	Wavelet Transform	62
2.7.6.6.1	Haar Wavelet Transformation using Filter Banks	64
2.7.6.6.2	Shannon Wavelets	67

2.7.6.6.3	Daubechies Wavelets (Lagrange Wavelets)	68
2.7.6.6.4	Biorthogonal Wavelets	69
2.7.6.6.5	Butterworth wavelets	69
2.7.6.6.6	Morlet's wavelet	69
2.7.6.6.7	Mexican hat	70
2.7.6.7	Co-occurrence Matrix Values as representation of Image	70
2.7.6.8	Image Statistics features as representation of Image	72
2.8	IMAGE ANALYSIS AND INFERENCE	75
2.8.1	Thresholding	76
2.8.2	Template Matching	76
2.8.3	Texture features extraction	77
2.9	EXPERT (PRODUCTION) SYSTEM	78
2.10	IMAGE CLASSIFICATION USING ANN TRAINING ALGORITHMS	78
2.10.1	Analogy to the Brain	80
2.10.2	Working of Artificial Neurons	80
2.10.3	Fundamentals of Neural Network Structures	84
2.10.4	Network Design	86
2.10.4.1	Learning	90
2.10.4.1.(a)	Unsupervised learning	90
2.10.4.1.(b)	Reinforcement learning	90

2.10.4.1.(c)	Back propagation	91
2.10.4.1. (d)	Off-line or On-line	91
2.10.4.2	Learning laws	91
2.10.4.2.(a)	Hebb's Rule	92
2.10.4.2.(b)	Hopfield Law	92
2.10.4.2.(c)	The Delta Rule	92
2.10.4.2.(d)	Kohonen's Learning Law	93
2.10.4.2.(e)	Prediction	93
2.10.4.2.(f)	Classification	93
2.10.4.2.(g)	Data association	94
2.10.4.2.(h)	Data Conceptualization	94
2.10.4.2.(i)	Data Filtering	94
2.10.4.3	Network Selection	94
2.10.5	Neural Networks and Standard Statistical Methodologies	96
2.10.6	Artificial Neural Network Advantages	97
2.10.7	Artificial Neural Network Disadvantages	98
2.10.8	Methods for Implementing Artificial Neural Network	98
2.10.8.1	Standard MLFF (Multi-Layer Feed Forward) Network	98
2.10.8.2	Radial Basis Function Networks	100
2.10.8.3	The Self-organizing Map (Kohonen) Approach	103
2.10.8.4	Probabilistic Neural Networks	104

2.10.8.5	Linear Networks	106
2.11	LINKING EXPERT SYSTEM	107
2.12	REPORTING	108
2.13	IMAGING TECHNOLOGY APPLICATION IN TEXTILES	110
2.14	SUMMARY AND CONCLUSIONS	117
CHAPTER III	INDUSTRIAL SURVEY ON FABRIC DEFECTS	118
3.1	INTRODUCTION	118
3.2	OBJECTIVES	119
3.3	BASIC CONSIDERATIONS FOR INDUSTRIAL SURVEY	119
3.3.1	Analysis of causes for defects	119
3.3.2	Defect Classification Systems	120
3.3.3	Survey Questionnaire	122
3.4	OBSERVATIONS	123
3.4.1	Fault Classification	123
3.4.2	Methods of Inspection	124
3.5	FABRIC INSPECTION AND GRADING	127
3.5.1	Conventional Grading	128
3.5.2	Point grading system	129
3.5.3	Points calculation	131
3.6	ECONOMICS OF FABRIC MANUAL INSPECTION	132

3.7	CAUSES OF DEFECTS	133
3.8	FABRIC DEFECTS DUE TO MACHINE CONDITIONS.	135
3.9	FABRIC DEFECT AND VALUE LOSS	138
3.9.1	Standard value loss	139
3.9.2	Value loss at different looms	139
3.10	DATABASE FOR EXPERT SYSTEM	139
CHAPTER - IV	DESIGN & DEVELOPMENT OF IMAGE ACQUISITION SYSTEM	141
4.1	INTRODUCTION	141
4.2	DESIGN OF IMAGE ACQUISITION SYSTEM	141
4.2.1	Drive Mechanism	144
4.2.2	Illumination system	147
4.2.2.1	Fermat's Principle	148
4.2.3	Imaging System	150
4.3	LENGTH MEASURING DEVICE	152-B
4.4	ROBOTIC FABRIC DEFECT MARKER	153
4.5	OPTICAL CALCULATIONS FOR SYSTEM DEVELOPMENT	155
4.5.1	Resolution	156
4.5.2	Magnification	156
4.5.3	EXSYNC Frequency	156

4.5.4	Maximum fabric running speed	157
4.5.5	Shaft Encoder Circumference	157
4.5.6	Amount of data to be processed by Hub received from 5 cameras	157
4.5.7	Amount of data to be processed by Computer	157
4.6	ECONOMIC CONSIDERATION	158
4.7	SUMMARY	158
CHAPTER - V	IMAGE GRABBING AND DEFECT DETECTION	159
5.1	INTRODUCTION	159
5.2	METHODOLOGY	159
5.2.1	Image Processing	160
5.2.2	Conversion of Light into Electrical Energy	160
5.2.3	Controlling exposure with PRIN	161
5.2.4	Interfacing of Various System Components	164
5.2.4.1	Electrical interfacing	164
5.2.4.2	Mechanical interfacing	165
5.2.4.3	Optical interfacing	166
5.3	DEFECT DETECTION	166
5.3.1	Image subtraction	167
5.3.2	Defective Images	167
5.4	CONCLUSIONS	170
CHAPTER - VI	IMAGE COMPRESSION	171

6.1	INTRODUCTION	171
6.2	FAST DISCRETE FOURIER TRANSFORM	171
6.3	FAST DISCRETE COSINE TRANSFORM	174
6.3.1	Butterfly operation	175
6.3.2	Re-order the array (Bit reversal).	176
6.4	WAVELET TRANSFORM	177
6.4.1	Co-occurrence Matrix Values as representation of Image	178
6.4.2	Image Statistics features as representation of Image	181
6.5	DISCUSSION	183
6.6	CONCLUSION	184
CHAPTER VII	CLASSIFICATION OF DEFECTS BY ARTIFICIAL NEURAL NETWORK	185
7.1	INTRODUCTION	185
7.2	NEURAL NETWORKS	186
7.2.1	Back-propagation Neural Network with Multilayer Perceptions	187
7.2.1.1	Algorithm	187
7.2.2	Linear Networks	191
7.2.3	Probabilistic Neural Network Classifier	192
7.2.4	Radial Basis Function Networks	195
7.2.5	Kohonen Self Organizing Map (SOM) - Un-Supervised	196

	Neural Network	
7.3	COMPARATIVE PERFORMANCE OF NETWORKS	198
7.3.1	Training time (Secs)	199
7.3.2	Percentage Fabric Defect Identification	199
7.3.3	Defect Identification (No.s out of total 33)	200
7.4	DISCUSSION	201
CHAPTER - VIII	EXPERT SYSTEM FOR FEED BACK	228
	INFORMATION	
8.1	INTRODUCTION	228
8.2	EXPERT SYSTEM	228
8.2.1	Expert Systems Building	229
8.2.2	Components of an Expert System	230
8.3	DEVELOPMENT OF A REAL-TIME EXPERT SYSTEM FOR FABRIC DEFECT ANALYSIS	232
8.4	BUILDING OF THE KNOWLEDGE BASE	235
8.5	IMPLEMENTATION OF MEMORY DATA BASE	236
8.6	PROCESS OF DEFECT IDENTIFICATION	237
8.7	EXPERT SYSTEM EMBEDDED NEURAL NETWORK REAL TIME DEFECT SYSTEM	238
8.8	SUMMARY	239
CHAPTER - IX	CHARACTERIZATION OF FABRIC DEFECTS.	249
9.1	INTRODUCTION	249

9.2	METHODOLOGY	249
9.2.1	Thresholding	250
9.2.2	Canny Edge Detection	251
9.3	DISCUSSION	252
9.4	CONCLUSION	253
CHAPTER - X	CONCLUSIONS	304
CHAPTER - XI	FUTURE SCOPE	307
	REFERENCES	309