UNIVERSITI PUTRA MALAYSIA

NEURAL NETWORK BASED PATTERN RECOGNITION IN VISUAL INSPECTION SYSTEM FOR INTERGRATED CIRCUIT MARK INSPECTION

VENANTIUS KUMAR A/L SEVAMALAI

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BY

VENANTIUS KUMAR A/L SEVAMALAI

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science.

NEURAL NETWORK BASED PATTERN RECOGNITION IN VISUAL INSPECTION SYSTEM FOR INTERGRATED CIRCUIT MARK INSPECTION

By

VENANTIUS KUMAR A/L SEVAMALAI

May 1998

Chairman: Dr. Iskandar Baharin

Faculty : Engineering

Industrial visual machine inspection system uses template or feature matching methods to locate or inspect parts or pattern on parts. These algorithms could not compensate for the change or variation on the inspected parts dynamically. Such problem was faced by a multinational semiconductor manufacturer. Therefore a study was conducted to introduce a new algorithm to inspect integrated circuit package markings. The main intend of the system was to verify if the marking can be read by humans. Algorithms that the current process uses however, was not capable in handling mark variations that was introduced by the marking process. A neural network based pattern recognition system was implemented and tested on images resembling the parts variations.

Feature extraction was made simple by sectioning the region of interest (ROI) on the image into a specified (by the user) number of sections. The ratio of object pixels to the entire area of each section is calculated and used as an input into a feedforward neural network. Error-back propagation algorithm was used to train the network. The objective was to test the robustness of the network in handling pattern variations as well as the feasibility of implementing it on the production floor in terms of execution speed.

Two separate programme modules were written in C++; one for feature extraction and another for neural networks classifier. The feature extraction module was tested for its speed using various ROI sizes. The time taken for processing was found to be almost linearly related to the ROI size and not at all effected by the number of sections. The minimum ROI setting (200 X 200 pixels) was considerably slower at 55ms compared to what was required - 20ms. The neural networks classifier was very successful in classifying 13 different image patterns by learning from 4 training patterns. The classifier also clocked an average speed of 9.6ms which makes it feasible to implement it on the production floor. As a final say, it can be concluded that by carefully surveying the choices of hardware and software and its appropriate combination, this system can be seriously considered for implementation on the semiconductor production floor.

Abstrak tesis yang dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains.

PENGECAMAN CORAK BERASASKAN RANGKAIAN NEURAL UNTUK SISTEM PENYEMAKAN VISUAL TULISAN DAN TANDA PADA LITAR BERSEPADU.

Oleh

VENANTIUS KUMAR A/L SEVAMALAI

Mei 1998

Pengerusi: Dr. Iskandar Baharin

Fakulti: Kejuruteraan

Sistem pemeriksaan mesin visual industri menggunakan cara pengecaman corak atau pengecaman ciri untuk mencari kedudukan atau memeriksa bahan dalam proses pembuatan. Algoritma yang digunakan tidak dapat mengendali variasi yang wujud pada bahan yang diperiksa secara dinamik. Masalah seperti ini sedang dihadapi oleh sebuah kilang semikonduktor bertaraf antarabangsa. Satu kajian telah di jalankan untuk menggunakan algoritma baru untuk menyemak corak tulisan pada pakej litar bersepadu. Tugas utama sistem tersebut adalah untuk menyemak kejelasan tulisan supaya ia dapat dibaca oleh manusia. Algoritma yang digunakan sekarang tidak dapat berfungsi dengan baik disebabkan oleh ketidakseimbangan dalam proses pembuatan. Untuk mengatasi masalah ini, suatu algoritma pengecaman corak berasaskan rangkaian neural telah diuji untuk mengenali corak-corak yang serupa dengan yang dikeluarkan oleh kilang tersebut.

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Suatu cara yang agak ringkas telah digunakan untuk mengekstrak ciri-ciri dari imej yang diberi. Kawasan tumpuan (*region of interest*-ROI) dalam imej dibahagikan kepada beberapa bahagian yang lebih kecil seperti yang ditentukan oleh pengguna. Bagi setiap bahagian ini, nisbah pixel yang menentukan objek kepada luas seluruh bahagian itu dikira. Nisbah-nisbah ini kemudian digunakan sebagai input dalam rangkaian neural. Algoritma "error-back propagation" telah di gunakan untuk melatih rangkaian neural tersebut. Objektif projek ini adalah untuk menguji keteguhan rangkaian neural untuk mengendali perubahan pada imej dan juga kebolehannya untuk beroperasi dalam keadaan sebenar pembuatan di kilang.

Pengaturcaraan telah dibuat dalam dua modul; satu untuk pengekstrakan ciri dan satu lagi untuk rangkaian neural. Pengekstrakan ciri telah diuji untuk kepantasan pemprosesan dengan menggunakan saiz-saiz ROI yang berlainan. Masa pemprosesan didapati hampir berkadar terus dengan saiz ROI. Walau bagaimanapun, untuk ROI paling minimum yang diuji, masa yang didapati adalah 55ms manakala masa yang diperlukan untuk seluruh proses adalah hanya 20ms. Rangkaian neural pula berjaya mengklasifikasikan 13 corak imej yang berbeza dengan mempelajari 4 imej sebagai latihan. Rangkaian ini juga dapat menghabiskan tugasnya dengan purata masa 9.6ms. Ini membolehkan rangkaian neural digunakan untuk proses pengecaman dalam industri. Sebagai akhir kata, boleh disimpulkan bahawa dengan membuat pilihan kombinasi perkakasan dan perisian komputer yang tepat, sistem ini boleh diimplimentasikan dalam keadaan kilang yang sebenar.

CHAPTER I

INTRODUCTION

General Overview

Among all the senses that humans have, the visual sense has always been regarded as the most important. Vision has given man the ability to assess a situation or an object without getting into physical contact with the environment. This has inspired the development of artificial vision for machines particularly computers. These vision machines have the capability to capture a scene and process it to extract useful information which may be used to take further action. The progress in machine vision has given a wide range of application from medical imaging to military defence systems. The complexity of these systems also varies from three dimensional scene analysis to a simple binary image feature extraction or measurement. The industrial usage of such systems are usually of lower complexity levels. They are used to locate, inspect or measure components in a manufacturing line. These systems effectively replace human operators in doing repetitive tasks which causes fatigue and loss of concentration after a prolonged duration. The reliability and repeatability of such systems are naturally better than the human counterpart.

Of the three operations mentioned before, the inspection aspect is the focal point of this thesis. The inspection system checks for physical or cosmetics flaws of a product. This includes labels or markings on the product. These markings are usually characters that gives the description of the product. The goal of the vision system here is to recognise the marked characters which are considered as pattern.

Pattern Recognition

Pattern Recognition (PR) is the process of identifying objects of interests in an image or scene. Within the context of image processing (IP), PR stands at the level of classifying an object within the image. There are two generally accepted techniques to approach PR - *decision theoretic* methods and *structural* methods. In either case the most important issue to be considered is the feature selection.

In decision theoretic methods the number of features used are fixed. These features (or commonly known as feature vectors) are usually passed through several decision functions. The number of decision functions depends upon the number of classes that these vectors can be classified into. Each function will represent a class. The function that yields the highest value upon substituting a set of feature vectors will represent the class that the pattern belongs to. One of the simplest form of decision theoretic method is the correlation technique. Traditionally this is known as *template matching.* This method is very common in the industrial inspection systems. In its most primitive form, an image is tested using a sub-image (or template) of the actual object. The template is moved across the entire image testing for correlation between the pixels. Here the feature vectors are pixels themselves. The correlation between the template pixels and the image pixels are calculated. The position with the highest correlation indicates that an object represented by the template is found. This method is very sensitive to scaling and rotation. If scaling and rotational variations are to be included as a template in the matching process then the computational time will increase to an unacceptable level.

A more popular approach to decision theoretic PR is the statistical method. Here features of object(s) are taken from many samples. These collection of features are used to create a probability density function (PDF). Each set of features under inspection is classified by finding the probability of that feature to belong to a certain class. The decision function here is usually given by a famous Bayes Theorem. The construction of PDFs needs a very large amount of sample data. The performance of such system is based on the assumption that the features of the test object(s) will lie within the domain of the PDF.

Advances in neural computing has given yet another choice of classifier implementation. Works by Rumelhart, *et al.* (1986) brought the *back-propagation* training algorithm which has been successfully implemented in several applications, especially in Optical Character Recognition (OCR). Neural Networks are modelled after the massively interconnected neurones in the brain. This network or system consists of many processing elements called nodes or neurones. These nodes are interconnected and the strength of each connection (called *weights*) stores and recalls a pattern. 'Training' or 'Learning' is referred to the process of modifying these weights to response to a particular set of patterns. The back-propagation algorithm by Rumelhart *et al.* (1986), is a very widely accepted training method. Another alternative algorithm would be Kohonen's *self-organising map* (Kohonen, 1981). Both these architectures will be covered in-depth in chapter 3, with much emphasis on back-propagation algorithm.

The structural method mentioned earlier, takes the shape of the object as its primary source of pattern vectors. The outline of the object is seen as a composition of primitive set of shapes. Each shape in the primitive set is given a number. The total outline of the object is then recorded as a string of these shape numbers. Later these are identified by matching them with the ones that are already known. The most prevailing technique using the structural approach in PR is the *syntactic* method. This technique requires a set of rules that specifies how a pattern string should be formed (known as *grammar*) and a recogniser (known as *automaton*) that determines if the string satisfy the rules of the grammar.

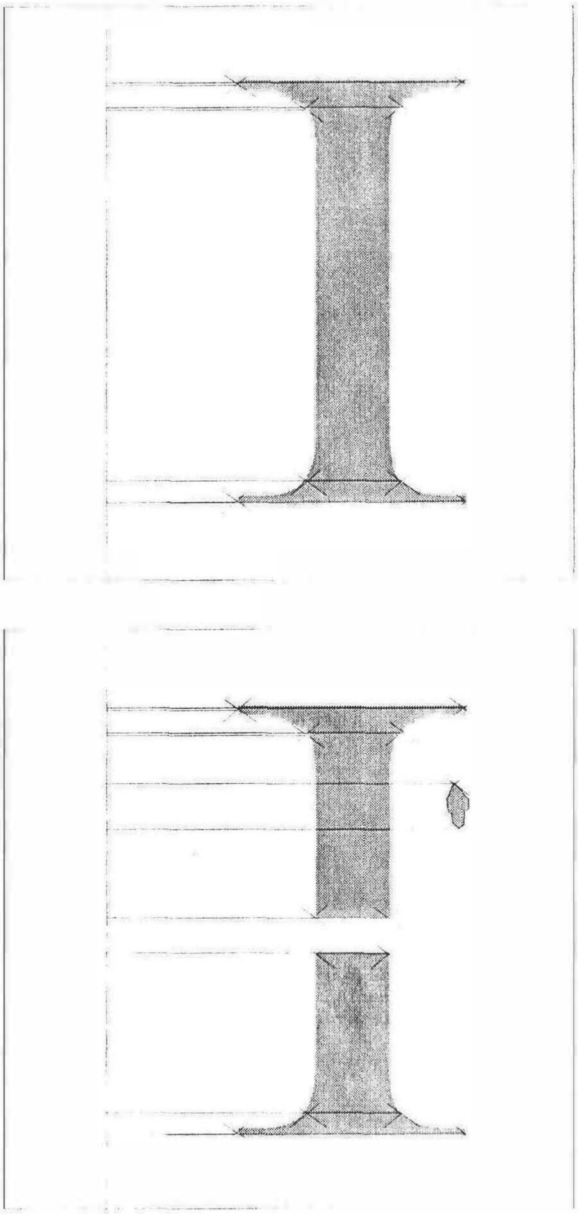
Visual Inspection

Most visual inspection systems use fast template matching algorithms. These algorithms work very well in a very controlled environment. Most of the machinery in the manufacturing industry, however, are not perfect. There are situations when the object under inspection is tilted at a small angle, or in the case of integrated circuit (IC) package mark inspection, a tiny spec or a slight fattening of characters (due to illumination) occurs. The system will reject the object in such a situation. A better technique is to extract some salient features of the characters or markings such as corners, curves and mid concavities. These too will fail when there are specs or spots on the IC. Additional processing is also needed to extract features.

In this study, an example project of IC mark inspection system from Motorola Semiconductor Seremban is investigated and a solution is proposed. The **objective** here is to develop a solution for the above mentioned problems by using pattern recognition with neural network classifier. The main advantage of using Neural Network (NN) is that it can mimic the human recognition system in adapting to variation that may arise. Generally NN classifier is said to be faster and more tolerable then statistical classifiers.

Problem Statement

The system currently used is a dedicated Image Processing computer based on the MC68000 microprocessor. It uses feature matching techniques i.e. using curves on the character blob as the template to check the mark. ICs with some small dots or specs are rejected, when all that is required is that the markings can be read.



(A)

(B)

Figure 1.1: Current system that uses edge point features.

This system uses edge points as features to represent each character (refer Figure 1.1(A)). During the teaching phase, a good IC mark is scanned and blob analysis is done. Edge detection is done for each blob and specific edge points such as the tips, corners and curves are marked. The location of each of these points relative to a reference point is calculated. During the production run, these points are found for the inspected IC marking and compared with the previously stored values. Common irregularities found are extra spots or break in the image that produces extra points (refer to Figure 1.1(B)). This will be found to be mismatched with the stored points.

The main problem with this system (and template match system) is that its error is accumulated globally, that is the total error throughout the entire image is compared to a given threshold. The solution for this would be to break the image into smaller regions and then compare the similarities for each region. This localises the error to a subsection.

The **objectives** of this study is to ensure that **slight variations in the markings of an IC can be recognised** by a proposed visual inspection system and its **processing time is acceptable** to a manufacturing environment. This system will consists of feature extraction such as described above and a neural classifier to recognise the extracted features.

Thesis Summary

The following are a brief description of the contents of each chapter. The next chapter reviews literature on neural networks and optical character recognition. It traces through the history of neural networks and its contribution towards image processing. Literature from Zheru Chi *et al.* (1995) and Jun Cao *et al.* (1995) will be reviewed. These two works have greatly contributed towards this thesis.

Chapter three will focus on the theory of image processing and neural networks. Topics covered will include binarisation, morphological operations and feature extraction for image processing. As for neural network, the architecture for multilayered feed forward network with error back propagation learning algorithms and the Kohonen Self Organising Map are covered. This also includes their respective mathematical formulas. Derivation of these formulas are not covered, however, because they are deemed unnecessary to this project.

The following chapter on methodology, first describes the hardware and software used in developing the programmes. A model diagram for the whole system is presented. The internal functions of the software design is discussed for both image processing and neural network components.

Chapter five is dedicated to presenting the results of the development and running the programme. All timings obtained are presented in a tabular form to show a better view of the processing speed. These results are also discussed along with the problems faced and their respective solutions as it was implemented.

The thesis is concluded with a brief recap of the entire project in chapter six. The main objectives are presented and its respective achievements are discussed. This chapter is concluded with various suggestions for improvements and further study for the future.

CHAPTER II

LITERATURE REVIEW

Introduction

Industrial visual inspection systems are an extension of pattern recognition in image processing. However they require fast computation in order to produce higher yield. Visual inspection systems are usually much faster compared to the mechanical production machinery in a manufacturing plant. But when these systems are used for more complex visual tasks, they take their toll of the processing time. This still doesn't produce a bottleneck as faster processors are marketed at cheaper prices. This has encouraged developers to look into more powerful number crunching algorithms to be implemented. Following this, neural network based pattern recognition systems are being adopted (Gosh, 1994). This review will trace out the history of neural networks and its achievements. It will be biased towards image processing applications. The review will continue with an introduction of Optical Character Recognition researches and development and then with the works of Zheru Chi *et al.* (1995) and Jun Cao *et al.* (1995) which forms the basis of this project. All papers reviewed here are on Optical Character Recognition (OCR) since their applications are leading the way in implementing neural networks as classifiers.

Artificial Neural Network

The biological neurones were first modelled by McCulloch and Pitts (1943). Their computational model simulated the nervous system by performing single threshold logic. McCulloch-Pitts work motivated several others to investigate further. Among them, most significant result came from Hebb (1949). Hebb suggested that the synaptic strength changes during the learning period. His hypothesis survived until today in one of the simplest mathematical formulation:

$$\Delta w_i = \varepsilon y(x) x_i \qquad (2.1)$$

where w_i is the synaptic strength, x_i is the *i*th synapse, y(x) the excitation function and ε the learning rate.

Further works by Rosenblatt (1958) combined the McCulloch-Pitts model and Hebbs hypothesis producing a functioning neural network hardware. This was the first functioning visual pattern recognition system known popularly as *perceptron*. His work has served as a stepping stone for the networks of the 1980s and 90s. However Minsky and Papert (1968) gave a rigorous analysis to the perceptron model and came to the conclusion that not all problems can be solved. They went on modifying the perceptron model by introducing hidden layers which eventually succeeded in solving those problems.

Following this Hopfield (1982) advanced this structure by proposing a feedback network. Rumelhart *et al.* (1986) then formulated a feedback learning algorithm based on propagating the error of the output node into the network for correcting the weights in 1986. This algorithm has advanced and is very popular and is being used as the network learning algorithm for this project.

In the same year Sejnowski and Rosenberg (1986) demonstrated a working system based on a network that could learn and speak like a six year old child. By then the first commercial neural computer was already marketed by TRW AI Research in 1985 (Mori, *et al.* (1993)).

Meanwhile another development was taking place in Europe. The learning process of the brain has been observed to organise its the synaptic strength as such that different cells correspond to differing signals. This ordered feature of the mapped brain has led to the development of Self–Organising Map — a brain child of Kohonen (1981) from the University of Helsinki . This is yet another popular architecture that has been developed further. He has successfully applied this architecture to speech recognition systems. One practical system that was very successful was the Finnish Phonetic Typewriter (Kohonen, 1981). Spoken Finnish words are broken down to their phoneme (or basic sound syllables) and the system will be able to recognise these phonemes and change them to text characters.

Fukushima (1988) of the Science and Technical Laboratories of Japan designed a neural network based image recogniser using techniques similar to Kohonen's Self Organising Map. It was called Neocognitron. It uses multiple layers of neurones to effectively classify hand-written numerals.

Optical Character Recognition (OCR)

Research and interests in Optical Character Recognition (OCR) can be traced back to Tauschek (1929) who patented a template matching principle. His patent was based on optical and mechanical technology that existed at that period. There was not much development after that until the dawn of computers. With the introduction of computers, OCR, which was a dream until then, became a reality.

Research continued by Glauberman (1956) produced a technique where the two dimensional image data of characters was projected onto one dimension. This was done by simply scanning the character vertically through a slit. Light that is reflected is detected by a photodetector. The black portion (which is part of the character) is calculated by simple analogue addition. The sampled values are converted to digital values and matched against pre-recorded template.

In 1957, Solatron Electronics Group Ltd., made an OCR machine based on a technique called 'peephole' method. This method analyses the image in two dimensions. Pixels values from various strategic locations of the character, so as to differentiate characters, are taken and matched. Soon afterwards, Iijima *et. al.* (1958) designed a machine based on the same principle but using 3 logic levels.

Another type of OCR is the recognition of hand written characters which developed simultaneously. Due to the large variation in hand writings, methods to analyse the structure of the characters were developed. The simplest form was proposed by Rohland (1954), where he scanned the image vertically and counted the black pixels on each line. Following this, Weeks (1961), scanned the image in four directions - vertical, horizontal and both the orthogonal diagonals. An advance approach of run-length encoding was taken by Doyle (1960). Doyle used the distance from a vertical base line to the first black pixel of the image when scanned from top to bottom as a geometrical feature.

A hybrid of template matching and structure analysis was proposed by Munson (1968). It was found that template matching has the advantage on the lager scale, whereas structure method was more robust and accurate in detecting features. The combination of these two can be termed as feature matching. The character under probe was divided into various subregions. In each region, the local structure is analysed. This reduces the sensitivity of the template matching by comparing the feature of each subregion instead of the whole character image.

Many hand written character recognition systems are adopting neural network as their classifiers due to the flexibility it gives. Works by Cao *et al.* (1995), for instance, uses incremental clustering neural network and subclass neural network with back propagation for classification. In their experiments, grey scale feature histogram was used. The entire image was applied with 3 X 3 mean filter for about 6 times. Cao followed the hybrid method of Munson. The image was then divided into 16 X 16 regions. The grey value for each region was fed into the clustering neural network for classification. If the clustering network doesn't succeed in classifying the character then the pattern is fed into a second stage subclassifier. The second stage classifier is an error backpropagation feedfoward algorithm (Cao *et al.*, 1995). This method is considered to be slow for real time applications. However, part of the feature extraction technique is very useful to this project, that is sectioning the image into 16 X 16 regions.

Another hand written numeral recognition system proposed by Chi *et al.* (1995), gives a more promising outlook for the problem at hand. They divided the binary image into 8 X 8 subsections. In each section the number of image pixels belonging to the character were counted and normalised to be within the range of 0.0 and 1.0. These normalised values were fed into a self organising map classifier that has been trained to obtained the result. The sectioning of the image has the advantage that the image is only scanned once and the output may be classified in a single stage.

The one common feature found in both the technique is that the image is divided (or sectioned) into smaller subsections. Usually algorithms based on template matching and feature matching treats the whole image (or the region of interest within the image) as one entity, thus spurious errors throughout the image is collectively measured against a threshold limit and a negative result is obtained if it exceeds this limit. By subsectioning the image, the processing is localised. Thus the errors are contained within the section. As such the total error when considering the entire image will be below the threshold level.