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Artificial Intelligence Techniques In IC Chip Marking Inspection

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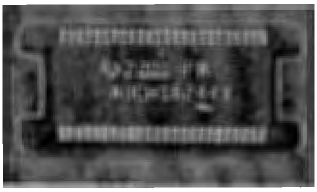
ABSTRACT

In this paper, an industrial machine vision system incorporating Optical Character Recognition (OCR) is employed to inspect the marking on the Integrated Circuit (IC) Chips. This inspection is carried out while the ICs are coming out from the manufacturing line. A TSSOP-DGG type of IC package from Texas Instrument is used in this investigation. The IC chips markings are laser printed. This inspection system tests are laser printed marking on IC chips and are according to the specifications. Artificial intelligence (AI) techniques are used in this inspection. AI techniques utilized are neural network and fuzzy logic. The inspection is carried out to find the print errors; such as illegible character, upside down print and missing characters. The vision inspection of the printed markings on the IC chip is carried out in three phases, namely, image preprocessing, feature extraction and classification. MATLAB platform and its toolboxes are used for designing the inspection processing technique. The percentage of accuracy of the classification is found to be between 97% - 100%.

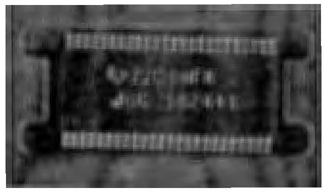
INTRODUCTION

In 1954, Rainbow developed a prototype machine that was able to read upper case written output at the speed of one character per minutes [1]. From the late 1960's, the OCR technology has undergone many dramatic developments. Multiple recognition system used in the postal department has the capability to read and recognize the characters one by one [2]. Now, reading several hundred characters per minutes is a reality [3]. The document analysis has reached an important position in certain market. The application of OCR in the postal automation followed into the banks and industrial inspection [4, 5]. Further more, a successful recognition rate of 99.9% of multifont of any size has been reported [6].

IC chips play a vital role in the electronic industry. Mass production of IC chips have brought down the price of the electronic products. Texas Instrument is one of the well-established IC chips manufacturing companies in the world market. Texas Instrument, Malaysia is one of the leading producers of IC chips in this region of the world. The IC chips undergo many inspections and verifications steps to ensure a guaranteed quality. Quality control of IC is performed by inspecting the placement of die, inspecting lead dimension, inspecting packaging and inspecting marking of symbols (IC number, year of manufacture and batch code etc). In this research work the OCR is employed to check especially the markings of the IC chips on the *Thin Shrink Small Outline Packages (TSSOP-DGG)*. Figure 1 illustrates various marking errors that can occur during production whereas Figure 2 shows the error free marking.



(a) Illegible



(b) Missing Character

Figure 1: IC marking in illegible character group.

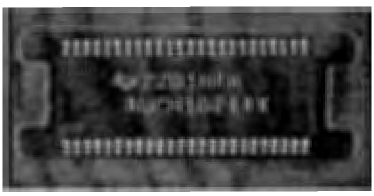


Figure 2: An error free marking.

INDUSTRIAL SETUP

A digital video camera is used to capture the IC chips coming out of manufacturing line one by one and to send them for inspection. These images are zoomed about 20 to 30 times in size. The zooming index depends on the size of the IC chip. Inspection module of the earlier commercially available industrial version checks about 7300 to 7500 IC chips per hour. IC chips undergo on-fly inspection, where OCR checks any defects in the markings on the ICs. If there is any defect in the IC chip marking, a fuzzy logic module will inform the production inspector the classification of defect; the production inspector will then inspects the IC chip manually before taking any further decision. A monitor displays the current image of the IC. A moving image can also be seen in the monitor.

MARKING INSPECTION PROCESS

After the final packaging, the IC chips are lined up in a conveyor for marking inspection. The marking on the IC chips are captured as a movie clip by a Charge Couple Device (CCD) non-standard camera. Images of the IC chips are extracted from the MPEG format. The extracted images undergo certain image processing techniques [12] namely preprocessing [1, 2], feature extraction [1] and detection using AI technique [5-9]. These processing stages are shown in Figure 3.

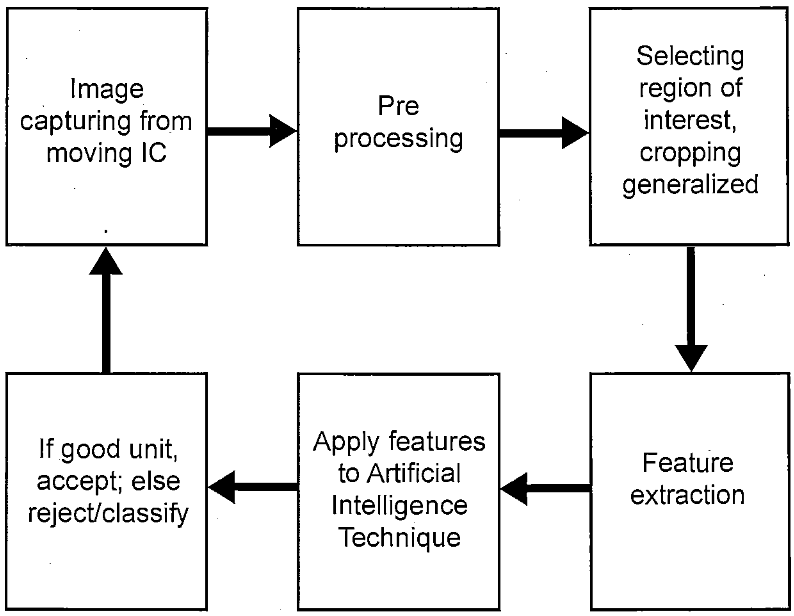


Figure 3: AI based processing sequence.

Preprocessing

The inspection begins with the extraction of a single image from the moving picture. The extracted color image is converted into a 256 gray scale image. The gray scale image is as shown in Figure 4. Then, the gray scale image is binarized with a threshold value. The binarization converts the image pixels into '0' (black) and '1' (white). The binarized image is as shown in Figure 5. The threshold value differentiates the marking and background of the given image. Region of Interest (ROI), as specified by the production inspector is extracted for feature extraction. The ROI area of binarized image is given in Figure 6. If the ROI is not specified, a search for the ROI from the extracted full image need to be done, but it is time consuming.

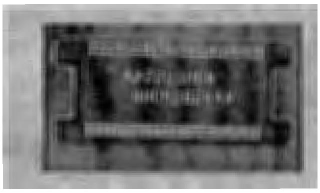


Figure 4: Gray scale image.

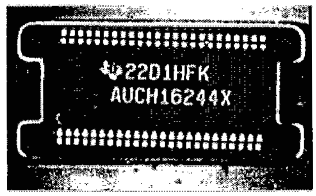


Figure 5: Binarized image.

Figure 6: ROI area of binarized image.

Feature Extraction

There are two different feature extractions carried out for this inspection, they are namely zoning and profile projection.

Zoning

The term 'zone' implies a segmentation of more complex spatial realities. It has a high degree of similarity with the term 'region'. Zoned region of the image will be the same throughout the image processing stage. Zoning is widely used in commercial OCR system. The recognizer uses information about the word shape. As this information is strongly related to word zoning [13]. It was designed to recognize the machine printed characters. A two level zoning is shown in Figure 7. Here, the image is separated into two portions as top and bottom zones. The presence of white pixels in each zone is summed up. Zoning is applied to marking but this has a limitation. The sum of each zone, sometimes, will be the same value even though the character is illegible. But by taking both zone sum values, the marking can be classified. These sums of each zone can be taken as features of top and bottom zones.

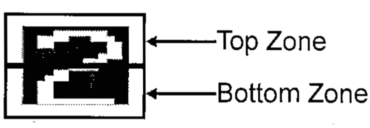


Figure 7: Zoning for character'2'.

Projection Profile

The determined row-sum (P_h) and column-sum (P_v) features are displayed as projection profiles. Horizontal projection (row sum) and vertical projection (column sum) as shown in Fig.8 are extracted for the each character image.

Let S (n, m) be a binary image of n rows and m columns.

Vertical Profile: Sum of white pixels of each column perpendicular to the x-axis; this is represented by the vector P_v of size n as defined by [11]:

$$P_v[i] = \sum_{j=1}^{n} S[i, j]. \qquad i = 1,2,3,\ldots,m \tag{1}$$

Horizontal Profile: Sum of white pixels of each row perpendicular to the y-axis; this is represented by the vector P_h of size m

$$P_h[j] = \sum_{i=1}^{m} S[i, j]. \qquad j = 1,2,3,\ldots,n \tag{2}$$

Profile projection of an acceptable image character 'A' and an illegible character 'A' are shown in Figure 8 and Figure 9 respectively along with their vertical and horizontal profiles.

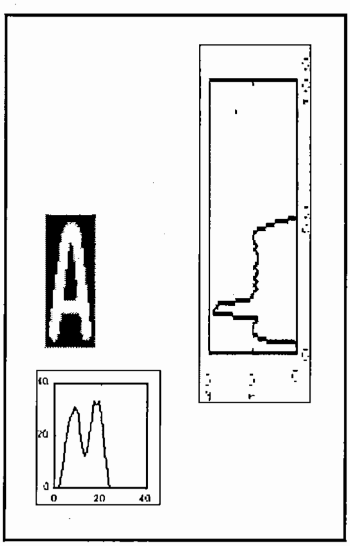


Figure 8: Projection profile for acceptable IC image 'A'.

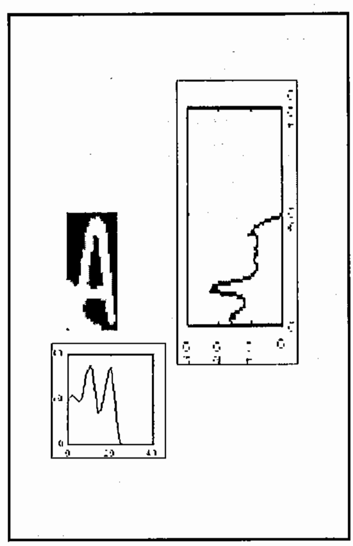


Figure 9: Projection profile for illegible image 'A'.

CLASSIFICATION USING ARTIFICIAL INTELLIGENCE TECHNIQUE

Fuzzy Logic

Fuzzy logic was first developed by Zadeh [10]. It was developed for solving decision making problems with 'IF-THEN' rules. Later, it was used to deal with uncertainty and imprecise data management. For several years fuzzy logic has been applied in controlling aircraft flight, chemical reactor and processes, nonlinear systems, character recognition etc [14]. The implementation of fuzzy logic system in semiconductor industry is being developed for wafer inspection [15,16]. In this paper, fuzzy logic is used to implement a marking inspection scheme for the IC chips coming out from the manufacturing line. The preprocessing procedure, including the feature extraction is performed on the acquired image. Here the image is separated into two portions as top and bottom zone. The presences of white pixels in each zone are summed up. These two zone sums are taken as two input features. These two features are applied with Fuzzy rule-base.

Application of Fuzzy Rule-Base to Features

A fuzzy rule base has been set, so that it can classify the input features as missing, good and illegible. Two membership functions for feature input are developed with one output membership function as shown in Figure 10 to Figure 12. Nine fuzzy rules are framed and listed in Table 1. These rules are applied for marking inspection and classification of marking as good, illegible and missing. It is found that the fuzzy rule based method of marking inspection provides 97% successful rate. The processing time is shown in Table 2.

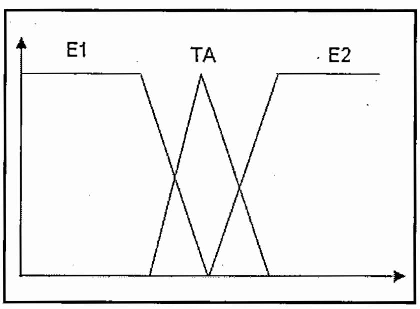


Figure 10: Feature input 1 membership function.

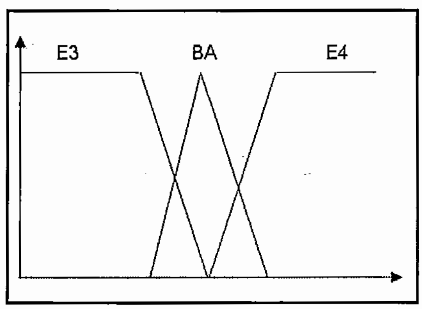


Figure 11: Feature input 2 membership function.

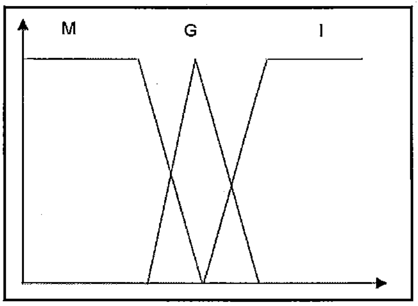


Figure 12: Output membership function.

Table 1: Fuzzy Rule Base for Inspection.

S.No	IF Feature 1 input	AND Feature 2 input	THEN Output
1	TA	BA	G
2	TA	E3	M
3	E2	BA	I
4	E2	E3	I
5	E1	E3	M
6	E1	BA	M
7	E1	E4	M
8	TA	E4	I
9	E2	E4	I

where
E1 = Error 1 range; TA = Top zone acceptable range; E2 = Error 2 range; E3 = Error 3 range; BA= Bottom zone acceptable range; E4 = Error 4 range; M = Missing; G = Good; I = Illegible.

Table 2: Processing Time for Inspection.

S.NO	Description	Processing Time
1	Fuzzy output for 1 marking (full operation)	220ms
2	Image reading and processing and writing to files(for 17 char)	450ms
3	Only fuzzy logic operation for 1 marking	40-50ms
4	Only fuzzy logic operation for 17 marking	680-850ms
5	Total processing time for 17 marking of one IC sample	1130-1300ms

Neural Network Configuration And Results

Neural network is closer to theories of human perception that employs mathematical minimization techniques. The publication of the back propagation technique by Rumerlhart et.al. has unquestionably been the most influential development in the field of neural network during the past decade. [10]. Neural network (Backpropagation) is employed to classify the character by the extracted features (row and column) [5-9]. The activation function has the characteristics of continuity, differentiability and non-decreasing monotony. There are several activation functions used in neural network. Binary sigmoidal and bipolar sigmoidal are generally used in neural network training. The binary sigmoidal which has a normalized range [0 to 1] and bipolar sigmoidal which has a normalized range [-1 to +1] are used in backpropagation training. They are defined as:

Binary sigmoidal

$$f(x) = \frac{1}{1+e^{-x}} \tag{6}$$

Bipolar sigmoidal

$$f(x) = \frac{2}{1+e^{-x}} - 1 \tag{7}$$

where

x is the input data and

$f(x)$ is the activation function

Among the activation function binary sigmoidal is used in this paper. Since the range of Binary sigmoidal is smaller than that of bipolar sigmoidal and since the binary sigmoidal requires less computation, the binary sigmoidal is used as the activation for all neurons

The network is trained using backpropagation algorithm. The training involves three stages. They are as follows:

1. The feedforward of the input training pattern
2. The calculation and backpropagation of the associated error
3. The adjustment of the weights

During feedforward, each input neuron receives an input signal. Each input neuron transmits the signal to each hidden neuron which, in turn, applies the activation function and passes it on to each output layer. Each output layer applies activation function to obtain the network output. The activation function is explained.

The network output is compared with the target value and the appropriate error is computed throughout the training. All weights are updated simultaneously. The weight v_{ij} between input and hidden layer and w_{jk} between hidden layer an output are updated using [9] :

$$w_{jk}(new) = w_{jk}(old) + \Delta w_{jk} \quad (8)$$

$$v_{ij}(new) = v_{ij}(old) + \Delta v_{ij} \quad (9)$$

where Δv_{ij} and Δw_{jk} are increments.

Backpropagation training algorithm is explained and executed in 10 simple steps as listed below [9]:

1. Initialize the weights randomly.
2. If stopping condition is false then execute 3 to 10.
3. For training in each training pair with x:t; execute 4-9.
4. Hidden layer neuron is denoted as Z_j, it is calculated by taking $f(z_{inj})$. The z_{inj} is calculated using v_{oj}, x_i and v_{ij}.
5. Output layer neuron is denoted as Y_k, it is calculated by taking $f(y_{ink})$. The y_{ink} is calculated using w_{ok}, Z_j and w_{jk}.
6. Computing the error δ_k for each output neuron.
7. Computing the error δ_j for each hidden neuron.
8. The weights are updated based on the error.
9. Testing for stopping condition.

A simple feed forward neural network is proposed to identify the various types of illegible marking of symbols as shown in Figure 13. The network consists of 75-input neurons, 6-output neurons and 1- hidden layer of 20 neurons The 50 row sums (P_{h1}... P_{h50}) and 25 (P_{v1}...P_{v25}) column sums of the extracted feature are used as input to the networks. The network is trained using a backpropagation training algorithm. The cumulative error versus epoch characteristics of the training is shown in Figure 14 to 16. The learning parameters are chosen as given in Table 3 to 5: The tables summarie details, such as, training time and the number of misclassifications.

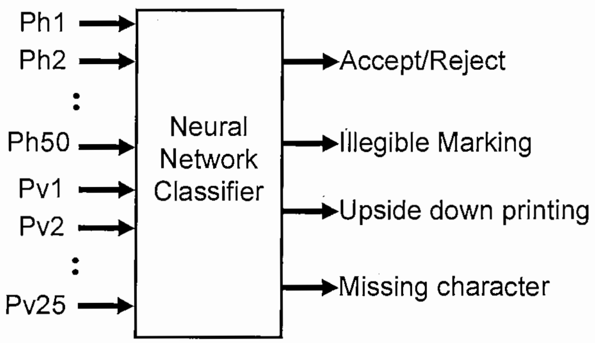


Figure 13: Neural Network Configuration for three Illegible Group and Accept/Reject Classifications.

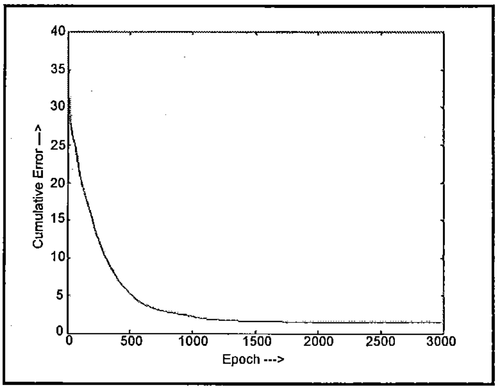


Figure 14: Cumulative error versus epoch plot for first classifications (Accept/Reject) only.

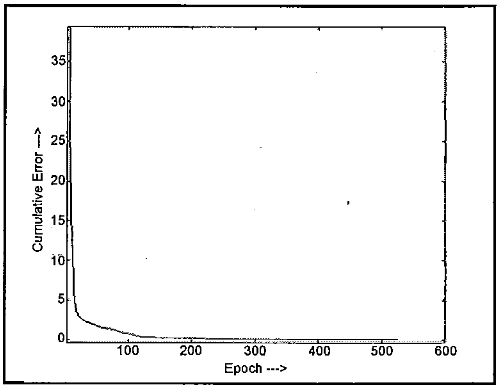


Figure 15: Cumulative error versus epoch plot for four classifications (Without Logo).

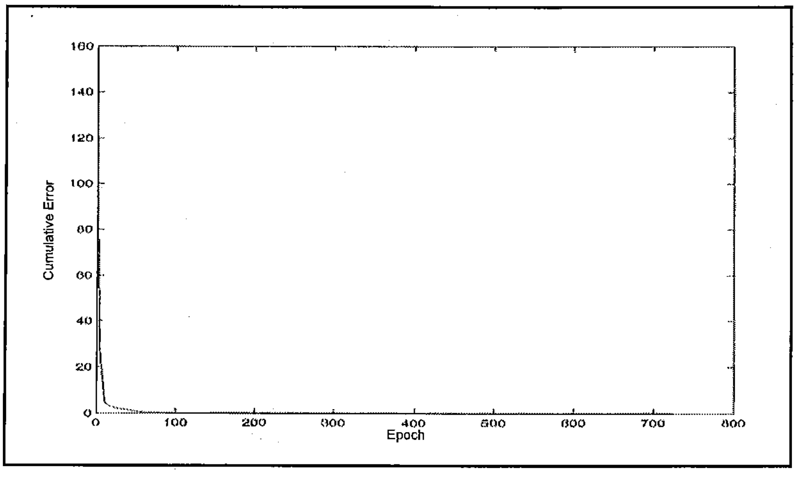


Figure16: Cumulative error versus epoch plot for four classifications (with logo).

Table 3: Data (without logo) trained for first classifications (Accept or Reject) only.

BackPropagation Algorithm Output neurons: 1 Activation function: (2/ (1+e^{-x}))- 1 Maximum no. of epoch: 3000 No. of trained samples: 400	$q_h = q_o = 1.0$ Hidden neurons: 20 Momentum factor: 0.4 Training tolerance: 1.5		Input neurons: 75 Learning rate: 0.01 No. of samples: 628 Testing tolerance:0.1
Best No.	Epoch	Time	% Misclassification
1	2999	322 sec	4.13

Table 4: Data (without logo) trained for four classifications.

BackPropagation Algorithm Output neurons: 6 Activation function: (2/ (1+e^{-x}))- 1 Maximum no. of epoch: 2000 No. of trained samples: 400	$q_h = q_o = 1.0$ Hidden neurons: 20 Momentum factor: 0.87 Training tolerance: 0.01		Input neurons: 75 Learning rate: 0.25 No. of samples: 628 Testing tolerance:0.01
Best No.	Epoch	Time	% Misclassification
1	642	55 sec	0

Table 5: Data (with logo) trained for four classifications.

BackPropagation Algorithm Output neurons: 6 Activation function: (2/ (1+e^{-x}))- 1 Maximum no. of epoch: 2000 No. of trained samples: 400	$q_h = q_o = 1.0$ Hidden neurons: 20 Momentum factor: 0.87 Training tolerance: 0.01		Input neurons: 75 Learning rate: 0.25 No. of samples: 655 Testing tolerance:0.01
Best No.	Epoch	Time	% Misclassification
1	724	62 sec	0

CONCLUSION

This paper focusses on IC chip marking inspection setup for industrial quality control. Simple procedures were carried out for preprocessing and extracting feature (zoning and profile projection) for the marking of symbols. Fuzzy logic is applied for the marking inspection of IC chips. The concept of fuzzy rule base is applied to a two level zoning of marking. The application of fuzzy rule base offers 99% successful result. Training is not needed in fuzzy logic marking inspection. Since there are only two zoning features used in this work, setting the membership parameter are easy. Another artificial intelligence technique is neural network. A feedforward neural network (backpropagation) configuration, has been developed to classify the marking based on projection profile. Training was performed with logo and without logo. The training classifications were of two types: first was the training for the output 'Accept or Reject' and the second for further classifications of illegible group. Between the two artificial intelligence techniques, neural network is found to be faster and the recognition rate is comparatively higher than fuzzy logic. Even though the training time in either of the technique is higher, example, 55 to 62 for 400 samples but the testing time is found to be 0.7 to 0.8 secs per chip. It is envisaged that this package is highly useful in semiconductor industries for verifying the character marking.

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