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THE APPLICATION OF IMAGE PROCESSING FOR IC CHIP INSPECTION

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Abstract

In recent years, there has been an increasingly high demand for integrated circuit (IC) chips, due to the rapid growth of the electronics industry. However, the manufacturing process of these chips is susceptible to various defects, which can significantly impact their performance and reliability. To ensure the production of high-quality IC chips, it is therefore essential to develop an effective and automated defect detecting method using image processing. This project proposes the usage of image processing techniques to automate the inspection of IC chips. The research involves collecting a dataset of digital images of IC chips, including both normal and defective chips, through the use of a digital microscope. Six IC chip models, namely LM358P, LM741CN, 4558D (DIP8), 4558D (DMP8), SN74LS08N and HD74LS153P were used. The Optical Character Recognition (OCR) was conducted using EasyOCR in Python to read the markings on the IC chip while image processing was performed with OpenCV to identify potential missing pins on an IC chip. The EasyOCR algorithm resulted in an average character error rate of 6.90% across six different IC chip models. The pin detection algorithm was tested on the six different IC chip models on four different backgrounds, which were black, white, green, and blue. It was concluded that except for white, all the other backgrounds resulted in a 0% error rate, while the white background did not provide enough contrast compared to the IC chip pins, resulting in an error rate of over 25% for four IC chip models. The missing pin detection test was performed with five different pin configurations on a black background, with a 0% error rate. In conclusion, this research proves that image processing is an effective method to automate IC chip inspection.

Keywords: IC inspection, Image processing.

1. Introduction

The term "integrated circuit" (IC), also known as "microelectronic circuit", "microchip" or "chip" refers to an assembly of electronic components constructed as a single unit that consists of miniature active components, such as transistors and diodes, and passive parts, such as capacitors and resistors, coupled by thin substrates made of semiconductor material, typically silicon [1].

All integrated circuits are polarised, meaning that each pin has a specific function and position, requiring the inclusion of an indicator on the IC package to show which pin is the primary pin. On the majority of IC packages, this is indicated by a dot or a notch. Once the primary pin has been located, each subsequent pin is located anticlockwise to each other.

The packaging of an IC chip is the case that encapsulates the chip, typically made of ceramic or plastic. There are three major packaging techniques, namely wire bonding, flip chip and tape-automated bonding [2]. Markings will then be printed on top of the casing to indicate the type and model number of the IC chip.

However, these markings can be very small and hard to read, making the task of sorting IC chips difficult. Besides that, after prolonged usage, or reuse of the IC chips, cracks may form on the casing and legs may break off, possibly making it unusable. However, these defects are hard to observe with the naked eye. Therefore, it is proposed that image processing be used to help identify and inspect the condition of an IC chip. Image processing is a set of computer techniques that can be used to analyse, enhance, compress and reconstruct images.

The primary components to image processing are importing, analysis and showing an output. The importing of an image is when an image is captured through the use of scanning or digital photography while the analysis and manipulation of the image are accomplished using various specialized software applications. Finally, the output involves outputting the image to primarily a monitor or printer [3].

In a paper by Lu et al., the authors discussed using image processing to automatically detect pin defects for IC chips [4]. They used OpenCV and a corner detection algorithm was first applied to the image of the chip. This was to detect the corners of the chip and calculate the inclination and positioning of the chips, as they were not fixed.

Next, a feature detection algorithm was applied. Scale-Invariant Feature Transform (SIFT), Speeded-Up Robust Features (SURF), Features from Accelerated Segment Test (FAST) and Oriented FAST and Rotated BRIEF (ORB) algorithms were tested. It was concluded that SIFT and SURF have good performance on the chip due to the ability of the algorithm to detect features at different scales and resolutions but are not as effective at detecting corners and edges.

FAST and ORB algorithms have better performance on the corner detection of the chip pins, but FAST is more likely to detect features along the edges of an object in an image, which leads to redundant feature points to be extracted and affects the determination of the pin corners. The proposed algorithm used the Harris corner detection method to locate the target points of the chip pins, with the aid of the geometry information of the feature points obtained from SURF.

Furthermore, IC chip markings have also been shown to have certain defects, thus a marking defect inspection method was proposed by Nagarajan et al. [5]. They researched using Optical Character Recognition (OCR) in conjunction with a feed forward neural network.

The images are first converted to 256-bit greyscale, and a threshold filter was applied on top to convert them to binary images. Next, feature extraction was performed on the binary images, in which they tested four different techniques, namely zoning, projection profile, moments and contour profile. Of the four techniques, the conclusion was projection profile could maintain the lowest processing time whilst being suitable for real-time marking inspection applications.

Another similar marking defect inspection method was proposed by Yang et al. [6], where they discussed image pre-processing, marking location, character segmentation and feature extraction. After obtaining the data of the features on the IC chip, the data was used in a neural network for defect identification. The neural network researched was the Back Propagation Neural Network (BPNN), which is a supervised neural network, with three layers consisting of an input layer, output layer and hidden layer. Overall, the system managed to recognize an IC marking of 20 characters in just 130 ms, with a maximum recognition rate of 98.5%.

In addition, a study on marking and pin defects on recycled IC chips was conducted by Ghosh et al. [7]. Aspects of the IC chips that were checked were country of origin mismatch, marking imperfection, indent mismatch, texture mismatch and bent or corroded pins.

A CNN architecture-based classification method for the detection of corroded and bent IC pins from RGB and depth map images as an alternative to X-ray was proposed. Bent pins were identified through the use of a depth map and 3D image reconstruction alongside machine learning, where three techniques were tested, which were Support Vector Machines (SVM), k-Nearest Neighbours (KNN) and Convolutional Neural Networks (CNN).

In a study conducted by Asadizanjani et al. [8], two approaches to detect defective ICs, which were image processing and artificial neural network (ANN)-based algorithms, were explored. For the image processing technique, they used Hough transform and Sobel filter to filter and identify cracks on the IC chip.

However, it was concluded that not all defects could be detected using this approach, such as colour variations, and thus addition of an ANN was proposed. The model was trained with images of chips with and without defects using MATLAB and found that the ANN model was more susceptible to detecting various types of defects.

Moreover, in a study by Yang et al. [9], YOLOv3 was used, which is a real-time object detection system that can detect objects in images and videos. It is based on a deep neural network and uses a single convolutional neural network (CNN) to predict bounding boxes and class probabilities directly from full images in one evaluation. This was used to detect defects in the silicon chips, not IC chip packages, but it should be applicable for IC chips as well.

Zhang et al. [10] developed an image processing system to detect defects in printed circuit boards (PCB) based on colour threshold segmentation. The defect they aimed to detect is the solder paste conditions on the solder pads. It was concluded that the colour threshold segmentation method they developed had an accuracy rate of 99.4% for detecting solder pads and an incorrect detection rate of 0.4%. For solder paste, the accuracy of detection was 99.3% with an incorrect detection rate of 0.03%.

Besides detecting defects, OCR algorithms can also be used to classify IC chips by reading the markings on the IC chips which contains the model number. Research conducted by Vedhaviyassh et al. compared the use of two OCR techniques, EasyOCR and TesseractOCR to read the text on license plates [11]. Their research concluded that EasyOCR resulted in more than 95% accuracy for predicting the number plate when compared to Tesseract OCR which has only resulted in 90% accuracy. Hence, EasyOCR outperforms Tesseract OCR in object recognition whilst being efficient in real time prediction.

The goal of using image processing for IC chip inspection is to detect defects on the IC chips that may not be visible to the naked eye or may be difficult to detect manually. Image processing can also streamline and automate the process. Therefore, the process will not be subject to human error. This results in improved quality control of used IC chips and helps to reduce the risk of building a circuit with a defective chip.

2. Research Methods

Figure 1 shows a flowchart of the proposed IC chip inspection algorithm. The process begins with image acquisition from the digital microscope. The image of the IC chip is then processed using OpenCV.

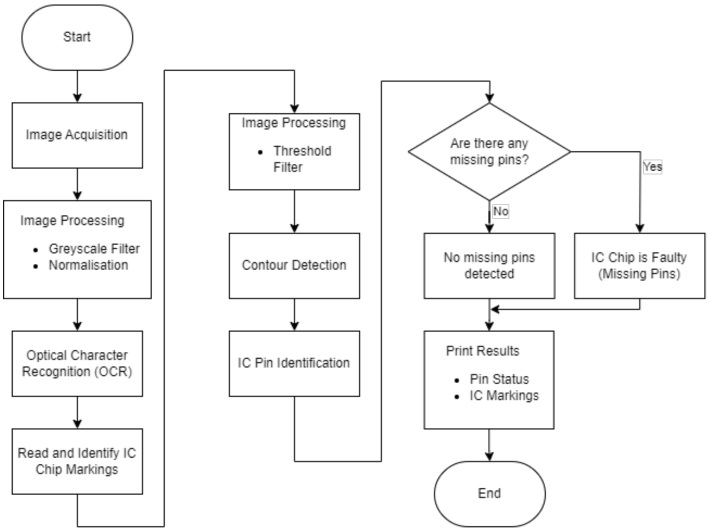


Fig. 1. Flowchart of the IC chip inspection algorithm.

A greyscale filter is applied to the image and the image is then normalized to make the range of values of pixel intensity of the image to fill the whole 0 to 255 values in the greyscale spectrum. This is to ensure that the brightest part of the image is always 255 and the darkest part of the image is always 0, enabling the threshold filter results to be consistent.

After normalisation of the image, Optical Character Recognition (OCR) is performed, which reads and identifies the markings on the IC chip. A threshold filter is then applied to convert the pixels in the image above a predetermined intensity to white, and the rest to black. This is to improve the accuracy of the contour detection algorithm in detecting the pins, as the pins are a lighter colour compared to the body of the IC chip.

After that, contour detection is applied to detect the contours of the pins. After that, the program checks if there is consistent spacing between each pin. If there is not, then the IC chip has missing pins, and the program will determine and draw the estimated location of the missing pins on the IC chip image. Lastly, the program will print out if the IC chip has any missing pins and the IC chip markings.

2.1. Optical character recognition (OCR)

In this project, EasyOCR plays a pivotal role in automating the recognition and interpretation of textual information on the IC chips. EasyOCR is a powerful OCR library that specializes in extracting text from images and converting it into machine-readable text. After extracting and reading the IC chip markings, the IC chip can be identified. The OCR also assists in pin detection, as the region where the text is detected by the OCR algorithm can be excluded from the region of interest in the pin detection algorithm, increasing their accuracies.

2.2. Pin detection

Pin detection was performed by first finding contours, which are connected components in the image by using the 'cv2.findContours' function. Next, 'cv2.RETR_EXTERNAL' is used to only use the extreme outer contours on the perimeter of the object, which is ideal for detecting IC chip pins. Next, the spacing between pins is calculated. The spacing is calculated by finding the difference in the x-coordinates of the centre of two pins. The lowest spacing calculated is then set as the reference spacing.

Next, spacing between pins with significantly greater spacing than the reference spacing, for this case it was set to 1.5 times, will be concluded to contain missing pins. The number of missing pins can therefore be calculated by Eq. (1), where n is the number of missing pins:

$$Size\ of\ Gap = n(Reference\ Gap) \tag{1}$$

The program uses the reference spacing to estimate the positions of the missing pins and then draw them, ensuring they are correctly spaced relative to the existing pins.

2.3. Project setup

This project uses a digital microscope, namely a YiZhan 48 MP model, which is used to capture an image of the IC chip placed under the microscope. A ring light is attached under the microscope which ensures there is consistent lighting on the IC chip. The microscope is then connected to a computer via its USB video output port. This is illustrated in Fig. 2. The computer obtains the image of the IC chip and processes it in PyCharm, where the algorithm is written in Python running on the PyCharm IDE. OpenCV, which is an image processing library, was used to preprocess the IC chip images and contour detection to identify missing pins. To read the IC chip markings, the EasyOCR library was used, which is also available in Python. The budget of this project is RM 500.

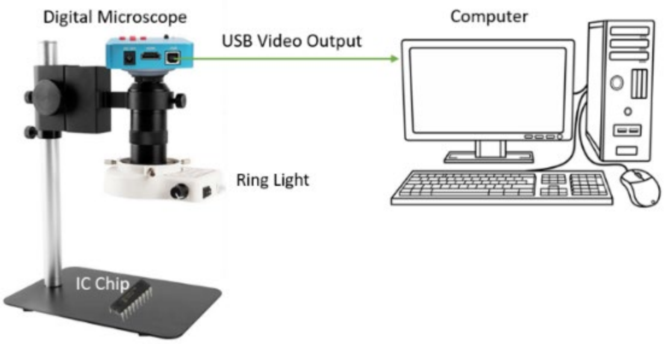


Fig. 2. Project setup.

3. Results and Discussion

The proposed algorithm in this paper was tested out on six different IC chip models, namely LM358P, LM741CN, 4558D (DIP8), 4558D (DMP8), SN74LS08N and HD74LS153P. The number of pins for each chip is shown in Table 1.

Table 1. List of IC chips and number of pins.

IC chip model number	Number of pins
LM358P	8
LM741CN	8
4558D (DIP8)	8
4558D (DMP8)	8
SN74LS08N	14
HD74LS153P	16

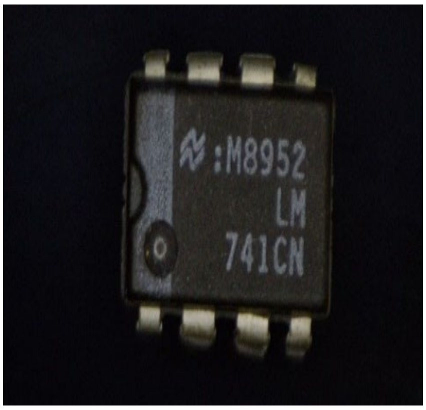
3.1. Optical character recognition (OCR) results

To test the EasyOCR algorithm, 5 images of each IC chip were taken for a total of 30 images, where the accuracy was calculated using the character error rate is given in Eq. (2):

$$Character\ Error\ Rate\ (\%) = \frac{Number\ of\ Characers\ Detected\ Wrongly}{Total\ Number\ of\ Characters} \times 100\% \quad (2)$$

The results of the EasyOCR accuracy for each IC chip model are tabulated and shown in Table 2. Since the project setup involves the use of a ring light, there is consistent lighting on the IC chip under external lighting conditions, causing the EasyOCR results to be identical for every 5 images taken for each IC chip. An example of the OCR results is shown in Fig. 3.

From Table 2, the LM358P and 4558D (DMP8) IC chip models had a CER of 0.00%, indicating that these models were recognized with perfect accuracy by the OCR system. The LM741CN and 4558D (DIP8) IC chip models had CER values of 8.30% and 7.70%, respectively. While these values are relatively low, they indicate that there were some recognition errors on certain characters. It was observed that these were primarily the ‘8’ in the 4558D model which was incorrectly identified as a ‘B”. This was also encountered in the LM741CN model, where the '7’ was incorrectly identified as a ‘Z’.



(a) **(b)**

Fig. 3. (a) Image of IC chip, (b) OCR results on IC chip image.

Table 2. Character error rate of EasyOCR for each IC chip.

IC Chip Model Number	Character Error Rate (CER) (%)
LM358P	0.00
LM741CN	8.30
4558D (DIP8)	7.70
4558D (DMP8)	0.00
SN74LS08N	11.11
HD74LS153P	14.29
Average	6.90

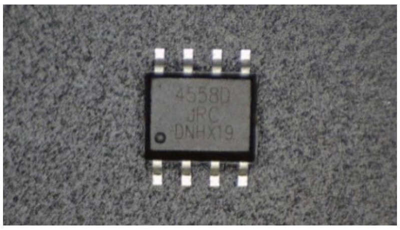
Next, EasyOCR results on the SN74LS08N and HD74LS153P resulted in higher CER values of 11.11% and 14.29%, respectively. This could be attributed to the font used for the markings on these models, causing difficulties in the EasyOCR algorithm to accurately identify the markings.

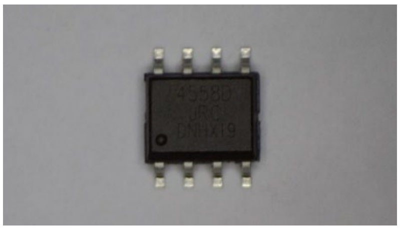
3.2. Pin detection results

Images used for the pin detection algorithm were tested on the same 6 models of IC chips, with 4 images for each model. The 4 images used different backgrounds, which were black, white, green and blue. Green, blue and black were chosen to replicate the colour of a PCB, whereas white was used to evaluate the proficiency of the algorithm in high contrast scenarios. An example of the images used are shown in Fig. 4, and the results of the example images are shown in Fig. 5, where the detected pins are highlighted with green borders.

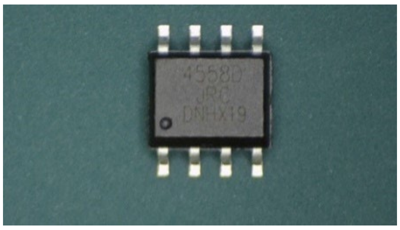
The accuracy of the pin detection algorithm was tabulated and shown in Table 3 by evaluating the pin error rate with Eq. (3):

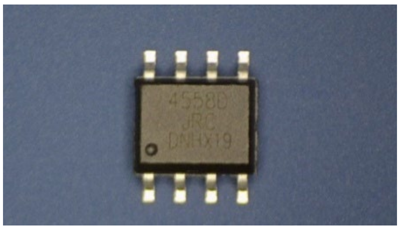
$$Pin\ Error\ Rate\ (\%) = \frac{Number\ of\ Pins\ Not\ Detected}{Total\ Number\ of\ Pins} \times 100\% \quad (3)$$





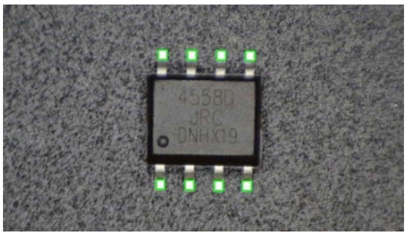
(a) **(b)**

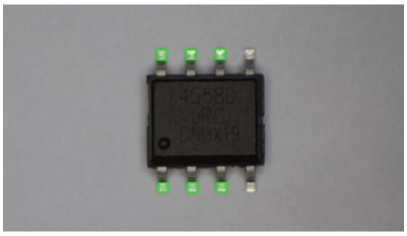




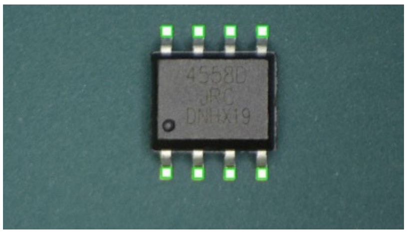
(c) **(d)**

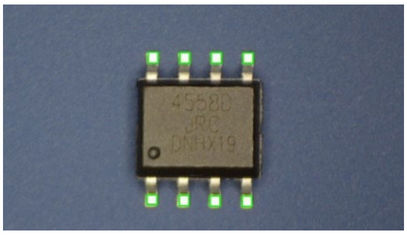
Fig. 4. (a) IC chip with black background, (b) IC chip with white background, (c) IC chip with green background, (d) IC chip with blue background.





(a) **(b)**





(c) **(d)**

Fig. 5. Results of pin detection algorithm on: (a) IC chip with black background, (b) IC chip with white background, (c) IC chip with green background, (d) IC chip with blue background.

From Table 3, the use of black, green and blue backgrounds resulted in an error rate of 0% for all the IC chip images tested. This means all the pins could be detected in the images. However, a white background causes a high pin error rate, especially for the LM358P, LM741CN, 4558D (DIP8) and 4558D (DMP8) models, which all returned a 25% or higher error rate.

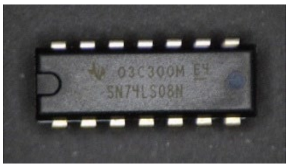
Table 3. Pin error rate of pin detection algorithm for each IC chip on different backgrounds.

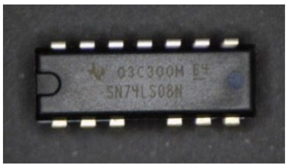
IC Chip Model Number	Pin Error Rate (%)			
	Background Colour			
	Black	White	Green	Blue
LM358P	0.00	25.00	0.00	0.00
LM741CN	0.00	25.00	0.00	0.00
4558D (DIP8)	0.00	50.00	0.00	0.00
4558D (DMP8)	0.00	25.00	0.00	0.00
SN74LS08N	0.00	0.00	0.00	0.00
HD74LS153P	0.00	6.25	0.00	0.00

This is caused by the lack of contrast of the background to the pins on the IC chip, as both are a light colour, causing difficulty for the algorithm to detect pins. Thus, it is recommended to avoid using a bright or light-coloured background when using the pin detection algorithm.

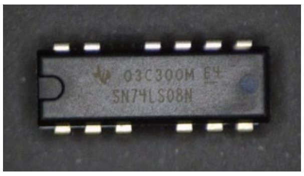
3.3. Missing pin identification results

The missing pin identification algorithm was tested using 5 images for each of the 6 IC chip models. All tests were conducted on a black background and the images varied in the number of missing pins. The scenarios included images with no missing pins, one missing pin, two missing pins, two side-by-side missing pins and three missing pins with two of them positioned side-by-side. These test scenarios are Illustrated in Fig. 6, with the results of the algorithm on the example images illustrated in Fig. 7. The potential missing pin locations are marked with a red dot.

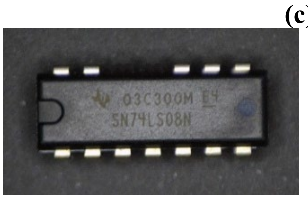


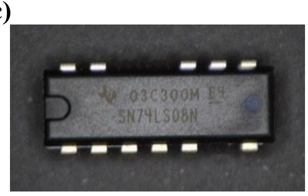


(a) **(b)**



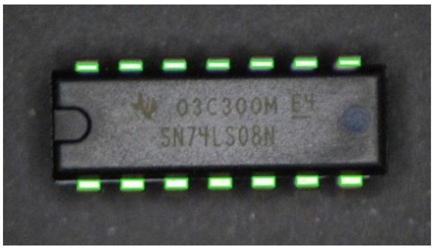
(c)



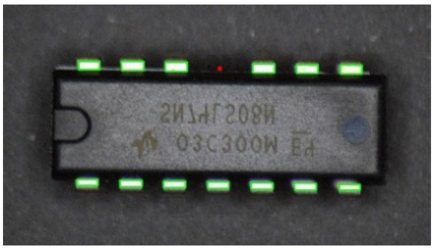


(d) **(e)**

Fig. 6. (a) IC chip with no missing pins, (b) IC chip with one missing pin, (c) IC chip with two missing pins, (d) IC chip with two side-by-side missing pins, (e) IC chip with three missing pins (two side-by-side).

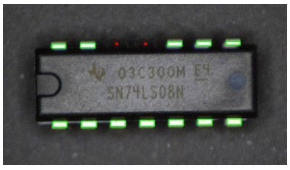


(a)

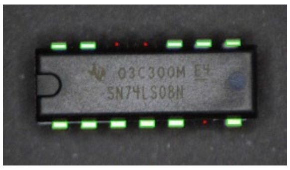


(b)

(c)



(d)



(e)

Fig. 7. Results of missing pin detection algorithm for: (a) IC chip with no missing pins, (b) IC chip with one missing pin, (c) IC chip with two missing pins, (d) IC chip with two side-by-side missing pins, (e) IC chip with three missing pins (two side-by-side).

The accuracy of the pin detection algorithm was tabulated and shown in Table 4 by evaluating the pin error rate by Eq. (4):

$$Pin\ Error\ Rate\ (\%) = \frac{Number\ of\ MIssing\ Pins\ Not\ Detected}{Total\ Number\ of\ Pins} \times 100\% \tag{4}$$

From Table 4, the missing pin identification algorithm resulted in a 0% error for all IC chip models tested and all missing pins configurations on a black background. The algorithm accurately identified the number of missing pins and the location of the missing pins on the IC chips. The algorithm also did not detect any false positives, especially on the images with no missing pins.

Table 4. Pin error rate of missing pin identification algorithm for each IC chip.

IC Chip Model Number	Pin Error Rate (%)				
	Configuration				
	No Missing Pins	One Missing Pin	Two Missing Pins	Two Side-by-Side Missing Pins	Three Missing Pins (Two Side-by-Side)
LM358P	0.00	0.00	0.00	0.00	0.00
LM741CN	0.00	0.00	0.00	0.00	0.00
4558D (DIP8)	0.00	0.00	0.00	0.00	0.00
4558D (DMP8)	0.00	0.00	0.00	0.00	0.00
SN74LS08N	0.00	0.00	0.00	0.00	0.00
HD74LS153P	0.00	0.00	0.00	0.00	0.00

4. Conclusion

In conclusion, this research aims to integrate image processing techniques into IC chip inspection. Missing pins on an IC chip and the IC chip model information were extracted using OpenCV and EasyOCR. The OCR resulted in an average character error rate of 6.9%, whereas the pin error rate for the missing pin algorithm was 0% when performed on a black background.

However, pin detection on a white background resulted in an error rate of over 25% for four IC chip models tested, suggesting that it is recommended to use a background with a higher contrast between the IC chip pins, such as black, green, or blue. Future recommendations are to increase the accuracy of the OCR by training it on a dataset of IC chips and adding more functionality to the algorithm to detect more defects such as IC chip cracks.

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