Quality Inspection of PVC Shoe Chopsticks: A Research Study

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Abstract

In the past decade, the advancement of artificial intelligence technology has led to substantial growth in industrial automation. However, most manufacturing industries are still at the stage of physical labor automation, especially in the area of product inspection, where manual inspection is predominantly used. Taking a PVC shoe chopstick factory as an example, the production line operates 24 hours a day, but quality inspection requires employees to conduct checks on the next working day. This approach makes it difficult to promptly address any defects that occur during production. By incorporating computer vision technology into the PVC production line to track and measure products, it is possible to reduce the defect rate in production and decrease the personnel costs and time delays associated with manual inspection.

Keywords: Computer Vision, Product Inspection, Quality Control, Labor Cost.

1. Introduction

The Taiwanese plastics industry has a development history spanning over 50 years, establishing a comprehensive industrial chain from upstream naphtha cracking to downstream plastic product processing. Polyvinyl chloride (PVC) is a critical material within this industry, and Taiwan was once the second-largest producer globally. However, increasing competition from China and other Southeast Asian countries has led to a decline in Taiwan's competitiveness in terms of scale. Although some companies continue to operate by leveraging advanced molding and processing technologies, maintaining both product quality and price competitiveness remains a significant challenge. Furthermore, the majority of Taiwanese plastic manufacturers are small and medium-sized enterprises (SMEs), which face substantial barriers to adopting Industry 4.0 initiatives. While many stakeholders understand and express interest in these innovations, they often lack the necessary resources and initial investments. This challenge is particularly pronounced in traditional industries, where the concept of technological innovation remains relatively unfamiliar. Moving forward, the development of plastic products will prioritize environmental sustainability and product quality, necessitating innovative approaches to enhance production standards.

The PVC shoe chopsticks investigated in this study are produced using an extrusion machine [1]. The manufacturing process involves melting granular PVC raw materials combined with additives and extruding the molten material through a mold to create continuous tubular products, where the mold defines the final product shape. Quality inspection for PVC shoe chopsticks is primarily conducted during the first and second stages of processing on the production line, focusing on parameters such as product dimensions (length and width), bending angles, and quantity statistics. This study aims to develop an automated inspection system to replace manual inspections, enhance product quality, and meet the demands of industry standards and market competitiveness.

2. Research Framework and Methodology

After capturing images on the production line, the inspection process is divided into three parts: image grayscale binarization, contour extraction with the drawing of the target object's bounding rectangle, and quality inspection. The quality inspection consists of three components: measurement of the target object's length and width, detection of bending angles, and quantity statistics with inspection reporting. The inspection framework is illustrated in Fig. 1.

2.1. Measuring the Dimensions of the Target Object

The principle of scale ratio [2] is used to calculate the actual spatial distance as the ratio between the image distance and the specified reference distance. This method, also known as the Pixel Ratio per Metric, determines the target object's actual dimensions based on the pixel size of a reference object. The process involves selecting the target object within the image and applying the scale ratio principle to calculate its actual dimensions.

2.2. Pipe Bending Angle

After applying Canny edge detection [3] on the image, the bounding rectangle of the contour is calculated using OpenCV's bounding rectangle API. In this study, the method is based on selecting the largest contour by pixel size. First, the set of contour points is obtained, and the rectangle's parameters—x, y, w, and h—are returned. Using the positions of the four contour points, circles and lines are drawn to outline the target object's bounding rectangle.

After determining the position of the bounding rectangle, three points are selected to calculate the angle of the target object.[4] First, the vector calculation for points A, B, and C is performed using formulas (2a, 2b, and 2c). Then, the cosine rule is applied using formula (2d). Finally, the angles between vectors AB and AC are individually calculated.

$$\mathrm{AB} = (b.x - a.x, b,y - a,y) \tag{2a}$$

$$\mathrm{AC} = (c.x - a.x, c,y - a,y) \tag{2b}$$

$$\cos A = (\mathrm{AB}*\mathrm{AC})/(|\mathrm{AB}| * |\mathrm{AC}|) \tag{2c}$$

$$\cos A = (\mathrm{b*b} + \mathrm{c*c} - \mathrm{a*a})/(2*\mathrm{b*c}) \tag{2d}$$

2.3. Quantity Count

Since the bounding rectangle of the target object is already drawn using FindContours [5] during the measurement of the object's length and width, the quantity statistics are directly obtained by traversing all the bounding rectangles to count the number of target objects in each image.

2.4. Inspection Reportt

After completing the three types of inspections, Power Query retrieves the inspection data, analyzes it, and displays the results on the report UI, including the quantities of defective and non-defective products, inspection time, and the status of the cutting machine.

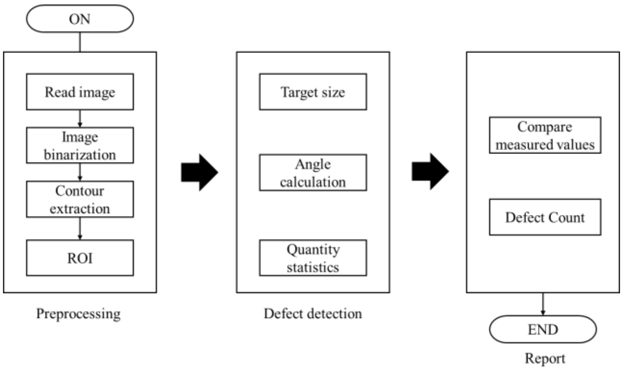

Fig. 1 Research Framework

3. Results and Discussion

In this study, we performed image recognition on production line images. The final results provide information on the target object's dimensions, processed bending angles, quantity statistics, and reports.

3.1. Target Object Dimensions

The primary inspection focuses on whether the cutting machine at the extrusion process's final stage can perform cutting according to the set angle. The results are shown in Fig. 2.

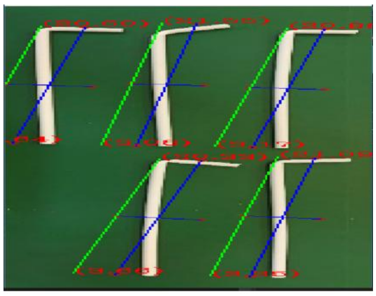

Fig 2 Dimensional Inspection Results

3.2. Processed Pipe Bending Angle

Since the shoe chopsticks are straight pipes after cutting, they require bending to be considered finished products. Therefore, measuring the bending angle, as shown in Fig, 3, serves as the final quality inspection step.

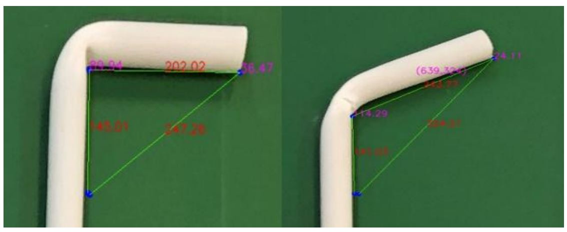

Fig 3 Bending Angle Inspection

3.3. Quantity Statistics

After the inspection is completed, the production quantities for each batch need to be statistically recorded, as shown in Fig. 4.

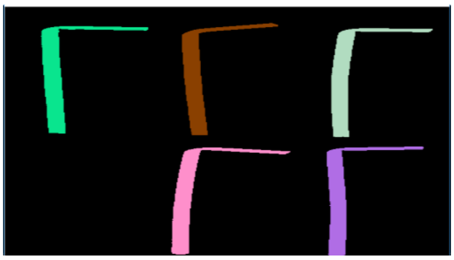

Fig 4 "Quantity Statistics"

3.4. Inspection Report

Since the first three tasks are all results of image recognition processing, a report is necessary to provide users with a clear understanding of the current production line status. This report enables monitoring of the shoe chopsticks' production quality and allows users to determine whether the production line machinery needs to be halted based on defect results. When defects in the shoe chopsticks occur, they are immediately displayed in the report, as shown in Fig. 5.

Inspection Report					
Target Quantity	Qualified Quantity	Unqualified Quantity	Yield Rate	Cutting Machine Status	Last Inspection Time
500	200 / 500	300 / 500	Low	Warning	Thu Jun 24 03:26:49 2024

Updata

a. Inspection Report

PVC-width	3.64	PVC-length	20.5
PVC-width	3.66	PVC-length	20.33
PVC-width	3.08	PVC-length	21.55
PVC-width	3.17	PVC-length	20.96
PVC-width	3.25	PVC-length	21.09
PVC-width	3.64	PVC-length	20.5
PVC-width	3.66	PVC-length	20.33
PVC-width	3.08	PVC-length	21.55
PVC-width	3.17	PVC-length	20.96
PVC-width	3.25	PVC-length	21.09
PVC-width	3.64	PVC-length	20.5
PVC-width	3.66	PVC-length	20.33
PVC-width	3.08	PVC-length	21.55
PVC-width	3.17	PVC-length	20.96
PVC-width	3.25	PVC-length	21.09

b. PVC Inspection Data

Fig 5 Inspection Report

4. Conclusion

This study successfully developed an automated quality inspection method for PVC shoe chopsticks by integrating computer vision technology into the production line. The proposed method addresses challenges in traditional manual inspections, such as high labor costs, inspection delays, and the inability to promptly identify production defects.

The method consists of three core steps: measurement of target object dimensions, bending angle detection, and quantity statistics. Through grayscale binarization, contour extraction, and advanced image processing techniques, the inspection method achieves high precision in defect detection and generates real-time inspection reports.

The findings demonstrate that the application of this method not only improves product quality and reduces defect rates but also provides actionable insights through detailed reports. These insights enable operators to monitor production line performance and make timely adjustments, ensuring compliance with industry standards and maintaining market competitiveness.

Future research directions may focus on expanding the method's applications, such as handling more complex product shapes, inspecting multiple production lines, and integrating with Industry 4.0 frameworks to further enhance production efficiency and quality control.

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Authors Introduction

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