VNUHCM Journal of Engineering and Technology 2026, 9(2): 2841-2848

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Research article

Application of Image Processing for Quality Control in V-bending Processing

Quoc-Nguyen Banh [1,2,*], Hoang-Son Pham [1,2], Huu-Tai Pham [1,2], Anh-Son Tran [1,2], Minh-Tuan Ho [1,2]

ABSTRACT

The V-bending process, a fundamental operation in mechanical fabrication for components ranging from intricate electronic parts to heavy-duty automotive frames, faces a persistent challenge in achieving dimensional precision due to the phenomenon of springback. Springback, defined as the elastic recovery of sheet metal after the forming load is removed, is influenced by a complex interplay of variables such as material thickness t, yield strength σ_y, and elastic modulus E. Traditional quality control methods rely heavily on manual angle gauges or visual inspection, which are inherently subjective, time-consuming, and prone to significant human error. While high-precision Coordinate Measuring Machines (CMM) offer micron-level accuracy, they are often too labor-intensive and slow for high-volume production environments, typically requiring 30 to 60 minutes for a single part inspection, thus making 100% quality checks impractical. This study proposes an automated, non-contact measurement system utilizing digital image processing and computer vision to bridge this gap. The methodology employs a Raspberry Pi camera module to capture high-resolution images, which are processed through a rigorous multi-stage pipeline. Initial preprocessing involves a 5x5 Gaussian filter to suppress high-frequency industrial noise while preserving critical structural edges. Subsequently, the Canny edge detection algorithm is implemented, utilizing gradient computation, non-maximum suppression to thin edges, and hysteresis thresholding to ensure robust boundary identification. These refined edge pixels are then mapped into a ρ, θ parameter space via the Hough Transform to extract the dominant linear features of the V-profile. Experimental results on a 90-degree specimen demonstrate exceptional performance, achieving a minimal angular error of only 0.025 degrees with a processing time of under 10 seconds. This approach provides a cost-effective alternative to CMM, facilitating real-time data acquisition for smart manufacturing feedback loops and machine learning models to predict and compensate for springback.

Key words: Angle measurement, Canny edge detection, Hough transform, V-bending process

[1]*Faculty of Mechanical Engineering, Ho Chi Minh City University of Technology (HCMUT), 268 Ly Thuong Kiet Street, Ho Chi Minh City, Vietnam.*

[2]*Vietnam National University Ho Chi Minh City, Ho Chi Minh City, Vietnam*

Correspondence

Quoc-Nguyen Banh, Faculty of Mechanical Engineering, Ho Chi Minh City University of Technology (HCMUT), 268 Ly Thuong Kiet Street, Ho Chi Minh City, Vietnam.

Vietnam National University Ho Chi Minh City, Ho Chi Minh City, Vietnam

Email: bqnguyen@hcmut.edu.vn

History

- Received: 21-08-2024
- Revised: 24-09-2024
- Accepted: 13-04-2026
- Published Online: 25-05-2026

DOI : https://doi.org/10.32508/vnuhcmj-et.v9i2.1432

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INTRODUCTION

In V-bending process, spring back shows the elastic recovery of sheet metal which is being affected by numerous factors like thickness, tool's geometry, material properties and processing parameters. Furthermore, severe spring back is a major issue in metal V-bending process, eliminating spring back is a challenging task, it can be controlled and minimized [1–4]. Spring back can be described as the difference between two angle values measured on the bend part after finishing the V-bending process. There are several methods using machines and equipment that have been used to measure the spring back in experimental analysis. Most of the studies have used coordinate measuring machine (CMM) and profile projectors [5] for the main equipment. Newer technologies, such as non-contact measurement methods utilizing laser [6] and image processing, have good potential as they allow measurements to be made without touching the bent part. Digital image processing technology is a field of computer applications which transfer the image into a form of data matrix and store them in the computer or show the application on computer. With image processing, the dimensions of specific parts can be obtained by camera, and it is easy to measure these parts based on data and assessment whether they are within tolerances. Measurement based on edge detection is used for dimension inspection using image processing.

In the quality control of V-bending process, ensuring precise angle measurement of product is important. This journal explores an image processing approach for measuring the angle of a V-bending workpiece. This technique hinges on two key processes, which are pattern recognition and feature extraction.

Pattern recognition is a fundamental concept dating back to the 1940s when Warren McCulloch and Walter Pitts introduced the groundwork for artificial neural networks [7]. These early neural networks laid the foundation for image processing to pattern recogni-

Cite this article : Banh Q N, Pham H S, Pham H T, Tran A S, Ho M T. **Application of Image Processing for Quality Control in V-bending Processing.** VNUHCM J. Eng. Technol. 2026; 9(2): 2841-2848.

tion. Roberts [8] offers one of the first methods for detecting edges. The method is famous for its simple, but the downside is its sensitivity to noise. To over this problem, in the 1960s Prewitt and Sobel took gradient calculation into account which had opened a whole new path for computer vision. Years later, the structured edge detector (SED) was published and focused on detecting line and circle shape. At the same time, Canny combined several techniques to meet the requirements of precision edge detection, and soon became a big hit in the edge detection field. The Canny method is rated over the SED by the generality, robustness, and the ability to handle noise. As image quality has improved in the 21st century, zero-crossing based and learning-based methods have emerged, offering potential for further advancements, though they remain under active development.

Feature extraction, a crucial step following image processing techniques like edge detection, has evolved significantly since its early roots. Early algorithms often prioritized line detection due to its common in images. Circle detection followed, enabling measurement of radius and center points. Research continues extracting more complex shapes. However, for the purpose of calculating angles in this journal, the focus will be on line detection. Initially, methods like Roberts offered in 1963 focused on basic edge detection. While these methods might have hinted at potential applications for line detection, they were not specifically designed for it. A significant leap came in the 1970s when Hough Transform, developed by Paul Hough, was applied to detect lines [9] . Alternative approaches for efficiency include template matching, which compares pre-defined shapes to image regions. The evolution of machine learning has also led to novel methods capable of real-time shape detection.

Measuring spring back is a difficult yet valuable task in V-bending quality control. Digital image processing is a promising approach tool to automatedly compute angles. For that reason, the feature needs to be extract is line, and Hough transform is the proper technique. To minimize the drawback of Hough transform, which consumes a lot of computational resources, Canny edge detection will be the key for the balance between accuracy and noise reduction. The following sections discuss how the algorithms are going to be applied with an experiment verification at the end. The outcome shows positive result with remarkable processing time.

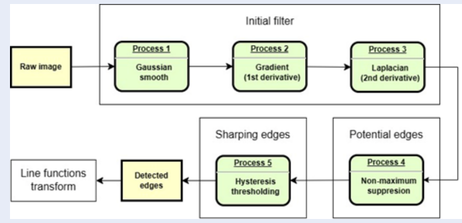

Figure 1: Edge detection algorithm [Source: The authors]

PROPOSED ANGLE MEASUREMENT METHOD

Figure. 1 demonstrates all the steps for detecting edges. An image of the specimen will be captured by raspberry pi camera module 2. The image is then converted to grayscale and smoothen by Gaussian filter. The gradient strength and direction of each pixel is then computed in the smoothed image. The exact position of the targeted pixel can be determined based on zero-crossing method. In non-maximum suppression process, several sets of edges will be grouped together and the group that has the most useful information will move to the next step. Thresholding is then done on the potential edges using hysteresis. In hysteresis, two upper and lower limits are used. This leads to three cases, all pixels below the lower threshold are discarded. The pixels above the upper threshold or the adjacent pixels, which lie between those thresholds, are considered edges. Finally, a line detection algorithm will be applied to find the required edges and calculate them by slope formula.

Edge Pixels Detection

To prepare for the derivative, Gaussian smooth is required. To remove the noise in the grayscale converted image with a 5×5 Gaussian filter [10] . This step is crucial as the Laplacian operator, which will be used later to detect edges, is extremely sensitive to noise. Increasing the size of the filter matrix will decrease the noise of the image. However, some important edges will be lost so the 5×5 is a compatible size for most cases.

An image will be divided into many 5×5 sub-regions, which contents pixels valued from 0 to 255. The gradient operator works with one sub-region at a time and computed the intensity and direction of each pixel in that sub-region. While the first order derivative can identify the position by setting a threshold, the second order derivative will be used to find the "sure-edge" pixels by zero-crossing method. The result from both processes will be combined to determine the final long edges. In real-world edges, its orientation tends to be horizontal, vertical, or diagonal. Therefore, all the calculated gradient direction will be categorized into those four directions. This will boost computational efficiency and make the edge linking process easier. Applying the Sobel operator in [11] , the gradient and direction of the pixels can be determined according to the magnitude of in horizontal direction and vertical direction. Gradient direction is always perpendicular to edges. Later, the direction of the pixels will be categorized to vertical, horizontal, or the two diagonal directions. Following by Laplacian operator [12] , even the smallest change in intensity will be recorded and marked as edge pixel.

Edge Pixels Enhancement

Although a great amount of noise has been filtered out, the remaining ones are still biased data. A punch of high intensity pixels is sitting next to each other which means the current edges are not actually a single line. The solution here is to apply non-maximum suppression to thin the edges and increase the consistency of the angle estimation. By using the result from the previous step, the gradient magnitude will be non-maximum suppressed in the gradient direction. Like the approach in [13] from page 81 to 83, the system will process every sub-region and remove blurry pixels.

Theoretically, the shape detection stage does not need that many edge pixels to form a line function. Thus, in the next step only the strong edge pixels will be kept by considering the slope of the zero-crossing. As mentioned in [13] from page 53 to 55, a single threshold is difficult to create a consistent output. The fluctuation of the taken image will lead to broken edge contour which is called streaking. Hence, hysteresis thresholding is the suitable technique to deal with the problem of streaking. The pixels which lie between these two thresholds are labeled as edges or non-edges based on their connectivity. If a pixel in this range has a neighbor that has already been classified as an edge, then the current pixel is also classified as an edge.

Line Detection

From the initial image, the edge detection algorithm has extract a minimum amount of pixels that have all the information for the line detection step. Therefore, Hough transformation (HT) will be used to detect line from the remaining pixels. The image goes through so many filter stages because HT is very sensitive to noise. Every possible line functions will be scanned, recorded, and the output shows the most repeated lines.

Figure 2 presents the process of extracting angle from an image. Firstly, the output of the edge detection algorithm in Figure. 1 becomes the input of the Hough transform algorithm. Implementing from [14] , all line function will be recorded in the form of (θ_K, ρ_K).Next, the most dominant lines will be separated from the weak ones according to the number of pixels that belong to that line. Finally, the angle of the intersecting lines is determined using slopes of the lines.

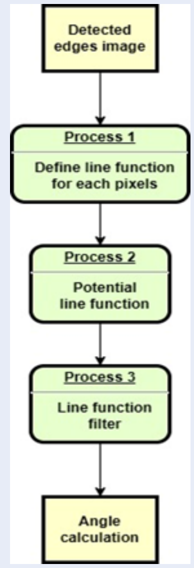

Figure 2: Houghline transform algorithm [Source: The authors]

From the previous procedure, the input image has been filtered, the unwanted edges are set to black, and the main pixels are in white color. During the line detection process, only the white pixels will be used to form line functions. HT requires all pixels to have the same coordinate, and it must be as close as possible to the white pixels in order to archive a precise outcome. Therefore, from the left to right the first white pixel that coincides with the vertical line will be the Oy axis, and similarly the Ox is obtained from bottom to top direction.

The system first identifies corner pixels, which are the intersection points of edges in the image. This is achieved by considering both the gradient direction and the neighboring pixels. The Hough line transform method [9] is then employed to calculate the normal parameters for a line, using one pixel chosen from the corner points and another from a set of white pixels. Since many pixels might be nearly colinear, they are rounded to the same line function for efficient counting by the computer.

Next, statistical analysis is performed to identify the most frequently occurring line functions. All pixels belonging to these lines are then subjected to linear regression [15] to determine the best-fit lines. This process aims to identify the bending angle of the 90-degree specimen. If two parallel lines are detected, one will be discarded. Only pairs of lines with angles close to 90 degrees are used for the final average angle calculation.

EXPERIMENTAL VERIFICATION

Experimental Result

Figure 3: Captured input image [Source: The authors]

For experimental purposes, a view of a V-bending specimen is first printed on plain paper to create a test image for the system. The specimen itself has a 90-degree bending angle. Subsequently, the camera raspberry pi module 2 positioned vertically above the paper captures an image, which is then used as the input for the system (Figure 3). This camera offers a resolution of 3280 x 2464 pixels, with each individual pixel size of 1.12 μm x 1.12 μm. The distance between the camera and the paper is 100 mm in order to get the sharpest image. This distance minimizes blur and allows the camera to capture fine details. Additionally, the lighting is arranged around the camera, avoiding direct contact with the specimen in the center. Direct light can block out the true edges due to glare and shadows. Furthermore, a brighter background can contribute to a significant reduction in image noise, enhancing overall image quality. Although Figure 3 exhibits good overall quality, shadows are present in the background. To address this, further image processing will be applied.

Prior to applying detection algorithms, a Gaussian filter is employed to smooth the entire image, with a particular focus on softening the specimen's edges. As illustrated in Figure 4, the bending area exhibits clearly defined edges to the human eye. However, computer vision algorithms can be sensitive to rapid color changes. Therefore, Gaussian filtering serves as a crucial pre-processing step to prepare the image for subsequent operations like Sobel, Laplacian,

Figure 4: Zoomedinput image [Source: The authors]

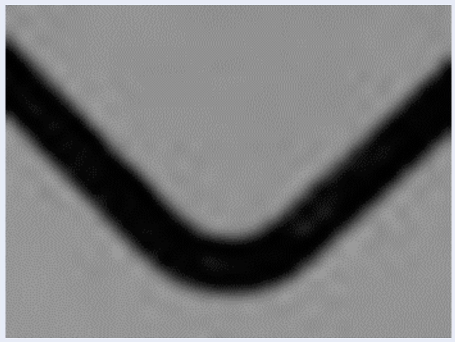

Figure 5: ZoomedGaussian smooth image [Source: The authors]

and Hough transform, which rely on accurate edge information. Figure 5 is the result after multiplying the image with a 5 x 5 Gaussian filter kernel. Compared to Figure 4, the filter effectively removes a lot of confusing pixels, but some detail of the edges also loses. Thus, the next process will focus on detecting and sharpening the edges.

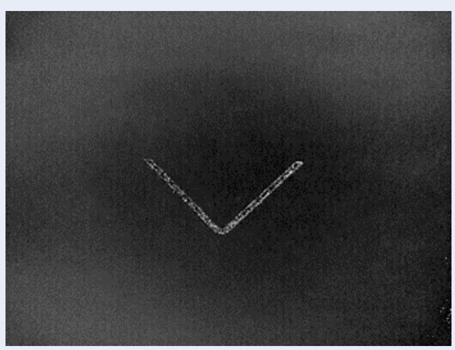

Figure 6: Sobel operation [Source: The authors]

The Sobel operator is applied to calculate the image gradient magnitude and direction at each pixel, aiding in edge detection. In Figure 6, the resulting image highlights pixels with strong intensity gradient in white. While unwanted background edges are present, increasing the threshold to eliminate them would also risk removing important details of the main specimen. This is the first glance of the computer vision, and it needs to collect enough information. Since these background edges will be revisited later, the current focus is on catching as many true edge pixels as possible. Consequently, a small amount of noise in this stage is acceptable.

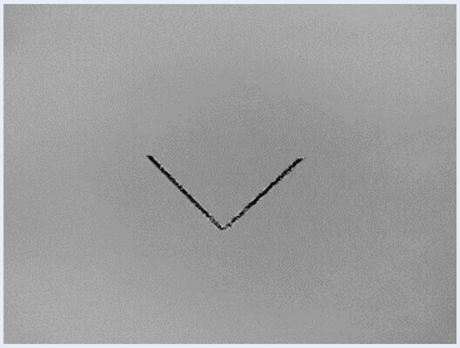

Figure 7: Laplacian operation [Source: The authors]

This process takes a step further than the previous one by computing the rate of change of the gradient. Besides the zero-crossing method, threshold method will be also taken into account. Basically, if the rate of change in gradient of a pixel equals zero and it goes through the zero-point steep enough, it will be marked as white pixels. As a result, Figure 7 only detects pixels around the specimen and not even including any noise pixel. This process does not require detecting every edge pixel, the Sobel filter has already shown the shape of the edge of the specimen. Therefore in Figure 7, there are fewer white pixels as compared to Figure 6, but the reliability of these pixels is really high. This is essential for the hysteresis threshold process as it will use the white pixels in Laplacian operation as a reference for edge refinement.

At this point, the all the non-edge pixels are suppressed to black. Although in Figure 6 the white edges are standout from the image, the background is still in grey color with various intensity. Thus, this step will not only detect long edges, but it also set the non-processing pixels to black. Consequently, Figure 8 presents the sharpened edges image and forms potential lines that ready to be detected. Zooming into

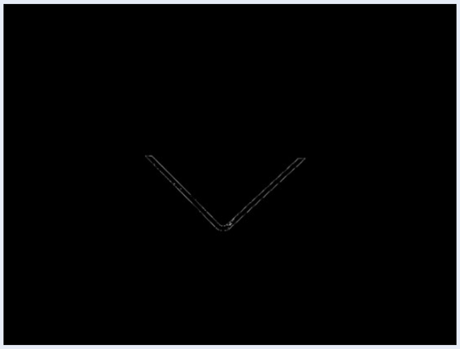

Figure 8: Non-maximum suppression [Source: The authors]

Figure 9: Zoomed Sobel operation [Source: The authors]

Figure 10: Zoomed non-maximum suppression [Source: The authors]

the Sobel operation image, Figure 9 is hard to point out the edge line of the specimen. The background has uneven pixels intensity, many white pixels gather without contributing to a true edge, and the thick edge areas overlap with many pixels. Looking at Figure 10, the background and inner area of the specimen are mostly black, the edges are thin and comprise of co-linear pixels. Additionally, the intersecting point has become more consistent and easier to detect.

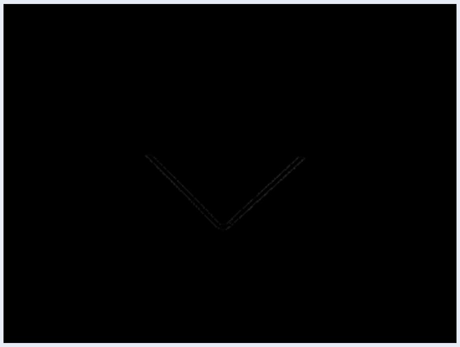

Figure 11: Hysteresis thresholding [Source: The authors]

The goal is to eliminate all the background edges in order to maximize computer resources. Therefore, isolation of the specimen's edges during pre-processing has achieved by hysteresis thresholding, as shown in Figure 11. Compared to Figure 8, the number of pixels has reduced noticeable. From the beginning of 8 megapixels, the image is only left with white pixels, which is around 2000 pixels for the line detection to work with.

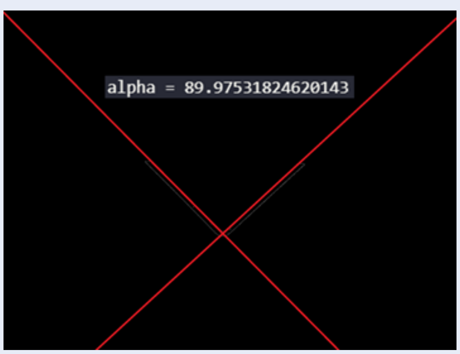

Figure 12: Output image [Source: The authors]

Figure 12 shows the angle of the two red lines. Indeed, HT detects four most appearing line in Figure. 11, which occurrence is higher than 400 times. After consideration, the image is left with two lines inside the specimen, and the final angle is computed at 89.975 degrees. The entire process including filters and angle calculations is under 10 seconds.

Result Discussion

The implemented approach successfully detected straight lines within the input image. The Laplacian of Gaussian filter was employed for edge detection, followed by the Hough Line Transform for angle calculation. Notably, the achieved accuracy yielded an error margin of only 0.025 degreed for the detected angle. To account for this minimal error, several factors require further investigation. Firstly, potential optimizations within the system's firmware could contribute to improved accuracy. Secondly, the camera placement during image acquisition might introduce slight variations. Finally, the inherent tolerance of the printed specimen itself could be a source of error.

CONCLUSION

To sum up, the implemented method demonstrates acceptable accuracy. The experimental result has removed the background around the specimen. The inside of the specimen is also filtered, and the edges are sharpened to the finest quality. The HT has shown its effectiveness after the filter process. For this method to work on a real V-bending specimen, some adjustment will be made to suitable for the quality control process of V-bending. In some cases, the outer angle is more important than the inner one or vice versa. It depends on the requirements of the manufacturing process. Overall, this is a great steppingstone to a fast and cost-effective spring back measurement. Further development efforts will focus on enhancing the system's reliability.

COMPETING INTERESTS

The author(s) declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

Nguyen Banh Quoc: Conceptualization, Writing – original draft preparation, Project Administration.

Son Pham Hoang: Methodoloy, Validation, Formal analysis, Visualization.

Tai Pham Huu: Validation, Investigation, Data curation.

Son Tran Anh: Software, Writing – review and editing, Supervision, Funding accquisition.

Tuan Ho Minh: Methodology, Writing – review and editing, Supervision.

Abbreviation	Full Name
AI	Artificial Intelligence
CMM	Coordinate Measuring Machine
CNC	Computer Numerical Control
GD&T	Geometric Dimensioning and Tolerancing
HT	Hough Transform
ISO	International Organization for Standardization
LoG	Laplacian of Gaussian
MES	Manufacturing Execution System
FEM	Finite Element Method
QC	Quality Control
ROI	Region of Interest
RSM	Response Surface Methodology
SED	Structured Edge Detector
VMM	Vision/Video Measuring Machine

NOMENCLATURE

ACKNOWLEDGEMENTS

This research is funded by OISP under grant number SVOISP-2023- CK - 02. We acknowledge Ho Chi Minh City University of Technology (HCMUT), VNU-HCM for supporting this study.

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VNUHCM Journal of Engineering and Technology 2026, 9(2): 2841-2848

Open Access Full Text Article

Bài báo nghiên cứu

Ứng Dụng Xử Lý Ảnh vào Kiểm Soát Chất Lượng trong Quy Trình Chấn V

Bành Quốc Nguyên [1,2,*], Phạm Hoàng Sơn [1,2], Phạm Hữu Tài [1,2], Trần Anh Sơn [1,2], Hồ Minh Tuấn [1,2]

TÓM TẮT
Quá trình chấn V được sử dụng rộng rãi trong chế tạo các sản phẩm hàng ngày. Do đó, quy trình kiểm soát chất lượng của quá trình chấn V cần phải chặt chẽ hơn. Các phương pháp kiểm tra góc chấn truyền thống thường dựa vào kiểm tra trực quan hoặc thước đo góc nên tốn rất nhiều thời gian và dễ xảy ra sai sót. Đề tài khám phá các phương pháp xử lý ảnh để đo góc tự động của các sản phẩm chấn V. Trước tiên, sản phẩm sẽ được chụp bằng máy ảnh. Sau đó, thuật toán phát hiện cạnh Canny được sử dụng để xác định các cạnh trong bức ảnh. Các cạnh này sẽ được trích xuất thành các phương trình đường thẳng thông qua thuật toán biến đổi Hough. Thông qua phân tích các đường thẳng được trích xuất, góc chấn V được tính toán. Cách tiếp cận này cung cấp một giải pháp thay thế cho các phương pháp kiểm soát chất lượng truyền thống với độ chính xác và hiệu quả cao hơn. Kết quả có tính ổn định cao với một khoảng sai số do góc đặt máy ảnh hoặc chất lượng của mẫu kiểm tra. Tóm lại, đề tài cung cấp giải pháp đo góc tự động với độ tin cậy cao giúp kiểm soát chất lượng chấn V bên cạnh các phương thức có độ chính xác cao như máy đo tọa độ (CMM).

Từ khoá: Quá trình chấn V, kiểm tra góc chấn, thuật toán phát hiện cạnh Canny, thuật toán biến đổi Hough

[1]*Khoa Cơ khí, Trường Đại học Bách khoa Tp.HCM (HCMUT), 268 Lý Thường Kiệt, Phường Diên Hồng, Thành Phố Hồ Chí Minh, Việt Nam*

[2]*Đại học Quốc gia Thành phố Hồ Chí Minh, Phường Linh Xuân, Thành phố Hồ Chí Minh, Việt Nam*

Liên hệ

Bành Quốc Nguyên , Khoa Cơ khí, Trường Đại học Bách khoa Tp.HCM (HCMUT), 268 Lý Thường Kiệt, Phường Diên Hồng, Thành Phố Hồ Chí Minh, Việt Nam

Đại học Quốc gia Thành phố Hồ Chí Minh, Phường Linh Xuân, Thành phố Hồ Chí Minh, Việt Nam

Email: bqnguyen@hcmut.edu.vn

Lịch sử
- Ngày nhận: 21-08-2024
- Ngày sửa đổi: 24-09-2024
- Ngày chấp nhận: 13-04-2026
- Ngày đăng: 25-05-2026

DOI : https://doi.org/10.32508/vnuhcmj-et.v9i2.1432

Trích dẫn bài báo này: Banh Q N,Pham H S,Pham H T, Tran A S, Ho M T. **Ứng Dụng Xử Lý Ảnh vào Kiểm Soát Chất Lượng trong Quy Trình Chấn V**. VNUHCM J. Eng. Technol. 2026; 9(2):2841-2848.