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The Measurement of Different Mechanical Components using Machine Vision and Digital Image Processing

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Abstract

Machine vision system is a technology that employs a computing device to inspect, evaluate, and identify still or moving parts. Post the acquisition of the image, it is processed, analysed and measured by various computer software in determining various characteristics. The role of machine vision in accurately measuring the dimensions of complex parts is inevitable. In this study an attempt has been made to accurately measure the dimensions of the boat shaped structure of the single way tool post which is used in machining process and in measuring the indentation diameter of the specimen used in Brinell Hardness. DMV 001 camera was used, and various lighting intensities and techniques have been employed during the image acquisition. A plethora of sensors and a myriad of lighting has been used to enhance the best possible way to acquire the image. Enumeration of the dimensions is made through MATLAB software. The dimensions of the boat structure were found to be 3.794 cm and of the indentation was found to be 1.8 mm. This study underscores the importance of continued research and development in machine vision systems to fully realize their potential in industrial applications.

Keywords: *Machine vision, Image acquisition, Image processing, Brinell Hardness, Single way tool post.*

1. INTRODUCTION

Machine vision is revolutionizing the field of mechanical engineering, particularly in the precise measurement of dimensions. This technology, which involves the use of cameras and computer algorithms to interpret visual data, offers unprecedented accuracy and efficiency in quality control and manufacturing processes. In mechanical engineering, accurate dimensional measurement is critical to ensuring that parts and assemblies fit together correctly, perform as intended, and meet stringent industry standards. Machine vision systems utilize high-resolution cameras to capture detailed images of components. These images are then processed using sophisticated software algorithms that can detect and measure features such as length, width, height, and diameter with micron-level precision. Unlike traditional contact measurement methods, such as callipers and micrometres, machine vision is non-contact, reducing the risk of damaging delicate parts and allowing for measurements to be taken at high speeds. The integration of machine vision into manufacturing lines enables real-time inspection and dimensional verification. This ensures that defects are identified and corrected promptly, minimizing waste and rework. Furthermore, machine vision systems can be programmed to handle a wide variety of parts and measurements, providing flexibility and adaptability in dynamic production environments. The application of machine vision extends beyond basic dimensional checks. It can be used for complex tasks such as surface defect detection, assembly verification, and robotic guidance. As technology advances, the capabilities and accuracy of machine vision systems continue to improve, making them an indispensable tool in the arsenal of modern mechanical engineering, driving efficiency, precision, and innovation.

The collection of papers reviewed provides a comprehensive understanding of the significant advancements and applications of machine vision technology across various industries. Javaid et al. [1] delves into the crucial role of machine vision (MV) within the framework of Industry 4.0. The paper highlights how MV technology, through automated image inspection, evaluation, and identification using digital sensors and advanced optics, enhances manufacturing productivity and precision. By identifying twenty critical applications of MV, the study emphasizes its contributions to inventory control, quality assurance, and error reduction. The authors argue that the integration of MV into Industry 4.0 practices leads to substantial improvements in operational efficiency and manufacturing quality. Melvyn et al. [2] provides an in-depth survey of machine vision technology. The paper offers a historical review of the field, tracing its development from early innovations to current state-of-the-art systems. It reflects on significant progress made over the years and explores how machine vision has evolved to address complex industrial and scientific challenges. The study also discusses current technologies, including advanced imaging and processing techniques, and provides perspectives on future directions for research and development in machine vision. This comprehensive review underscores both the achievements and ongoing challenges in the field. Eshkevari et al. [3] presents a novel heuristic segmentation approach designed to enhance the detection of dimensional defects in glass vials. The paper addresses limitations of traditional defect detection methods by introducing an advanced image processing framework that integrates multiple algorithms. This new approach demonstrates significant improvements in both accuracy and computational efficiency, outperforming conventional techniques. The study highlights the method’s ability to offer greater reliability and faster processing times, making it a valuable tool for quality control in manufacturing. Che et al. [4] focuses on a vision-based system for the real-time measurement of workpiece diameter during the turning process. The proposed method enhances both accuracy and efficiency compared to traditional measurement techniques. The results indicate that the vision system significantly improves monitoring capabilities, leading to better process control and quality assurance. The paper demonstrates how real-time diameter measurement can contribute to more precise and efficient manufacturing operations. Laigang Zhang et al. [5] explores an image recognition approach for accurately determining the size of mechanical parts. The authors propose a method that leverages advanced image processing techniques to measure mechanical components with high precision. Their research shows that this approach offers improvements over traditional measurement methods, providing reliable and precise size assessments. The study suggests that the image recognition system has potential benefits for quality control and manufacturing processes, with recommendations for further exploration to enhance accuracy and broaden applicability. Torabi et al. [6] introduces a high-precision imaging and measurement system designed for inspecting the wheel diameter of railroad vehicles. The paper highlights the effectiveness of the system in detecting deviations and ensuring accurate maintenance of railroad wheels. The advanced imaging techniques employed in the system significantly enhance measurement accuracy compared to traditional methods. The study underscores the value of the proposed system for railroad vehicle maintenance and quality control, while suggesting areas for future research to explore potential enhancements and broader applications. S. Sathiyamoorthy [7] examines the implementation of machine vision technology across various industrial settings. The paper discusses specific applications where machine vision is utilized, including defect detection, dimensional measurement, and process monitoring. Results demonstrate that machine vision significantly improves accuracy, speed, and consistency in industrial operations. The study concludes that adopting machine vision technology offers substantial benefits for optimizing production processes and ensuring product quality. The paper also provides suggestions for future advancements and applications in the field. Zohdy et al. [8] reviews recent advancements and applications of machine vision technology in scientific and industrial domains. The authors highlight how machine vision enhances automation, quality control, and data analysis, with a focus on its effectiveness in defect detection, measurement, and process monitoring. The study illustrates that machine vision significantly improves operational efficiency and accuracy across various applications. The paper concludes by discussing emerging trends and potential future developments, offering insights for further research and broader implementation.

Collectively, these studies illustrate the transformative impact of machine vision technology on enhancing manufacturing processes, improving accuracy, and optimizing quality control. The ongoing advancements and diverse applications of machine vision underscore its growing significance and potential for future innovation in various industrial and scientific fields.

2. PROBLEM STATEMENT

While machine vision systems have demonstrated effectiveness in various measurement applications, there is limited research specifically addressing their use for precise measurements of boat-sized components in single-way tool posts and Brinell hardness specimens. Existing research often lacks a comparative analysis of the accuracy and efficiency of machine vision systems versus traditional measurement techniques for these specific tasks.

Despite advancements in machine vision technology, accurately measuring the length of boat-sized components in single-way tool posts, as well as determining the indentation diameter of Brinell hardness specimens, remains challenging. The primary problem is the lack of comprehensive studies evaluating the precision and reliability of machine vision systems for these specialized measurements. This research aims to address this gap by assessing the accuracy of machine vision in these applications, comparing its performance against traditional measurement methods, and identifying potential improvements to enhance measurement precision and efficiency in industrial settings.

3. EXPERIMENTAL COMPONENTS

3.1 Camera

The front-end camera uses CMOS or CCD sensors to translate images from the surrounding environment or from a focused object into pixels. There are two kinds of cameras used in machine vision: line scan and area scan cameras. An image sensor with 640 × 480 or 1280 × 960 pixels in width and height is used for area-scan. A long and extremely narrow sensor with 2000 × 1 or 8000 × 1 pixels is used for line scanning. When the full image is captured at once or when it is difficult or undesirable to accurately manage the scene's movement in relation to a line scan sensor, area-scan cameras work best. Ideally, area-scan cameras are used. When very high continuous resolution is needed or when capturing continually moving objects or scenes, line scan cameras work best.

3.2 Sensors

3.2.1 CCD Sensors

CCD sensors are valued for offering an excellent price-to-quality ratio. However, their detection spectrum is limited to visible elements only. A notable drawback is their heightened sensitivity to glare and the sharp increase in parasitic electrons as temperatures rise. As a result, cooling is often required to minimize thermal noise. It is worth mentioning that advancements in CCD technology have significantly improved their quality, bringing them closer to the standards of CMOS sensors while still remaining affordable.

3.2.2 CMOS Sensors

CMOS sensors are generally more costly than CCD sensors but come with notable advantages. They provide superior image quality, even though the latest CCD technologies have begun to close this gap. Additionally, CMOS sensors are well-suited for low-light imaging, ensuring that reduced lighting conditions do not hinder performance. They also offer faster readout speeds than most CCD sensors and consume less energy.

Furthermore, specialized lighting setups, such as dome and backlighting, have been implemented. The intensity of these lights has been adjusted through software to optimize illumination. The camera is securely positioned on a high-precision Haiser model stand, allowing for precise adjustments to the camera’s alignment and height based on specific requirements.

4. DATA REDUCTION

The focal length can be determined by using the Eq.1

$$Focal\ length = \frac{(Sensor\ size\ x\ Working\ Distance\ )}{Field\ of\ View} \quad (1)$$

Field of View is the object area which is imaged by the lens. It should cover all features that are to be inspected with tolerance for alignment errors. The magnification is the ratio between sensor size and focal length and it can be calculated by using Eq.2

$$Magnification\ (m) = \frac{Sensor\ Size}{Focal\ Length} \quad (2)$$

Where focal length can be determined by using Eq. 1.

5. METHODOLOGY

The paper examines two cases. The first involves a boat-shaped structure used in single-way tool posts, characterized by its distinctive curved shape resembling a boat. Typically made from high-strength materials such as hardened steel or carbide, it is designed to securely hold various cutting tools during machining operations. The curved shape enhances stability and reduces tool deflection and vibration, which are essential for achieving high precision and fine surface finishes. The dimensions of these parts are calculated using machine vision systems. The use of image processing in this context allows for precise measurement of the component's size, significantly improving the accuracy and consistency of the measurements compared to manual methods.

The second case focuses on finding the indentation diameter in a Brinell hardness test specimen. In this method, a specific force is applied to the surface of a component, resulting in the formation of an indentation. The depth of this impression indicates the hardness of the component. Brinell hardness tests are widely used in the industry to measure material hardness. The traditional method involves measuring the depth or area of an indentation left by an indenter of a specific shape, under a specific force for a set time. However, this method has accuracy limitations. To improve accuracy, the proposed system measures material hardness by analysing the diameter of the indentation using image processing. Images of the component are captured and analysed to measure the indentation diameter, enhancing measurement accuracy and product quality.

5.1 Image acquisition of boat structure used in single way tool post

In this study, a machine vision system was configured to measure the length of boat-sized components in a single-way tool post. To ensure accurate measurement, the appropriate camera focal length and sensor size were selected.

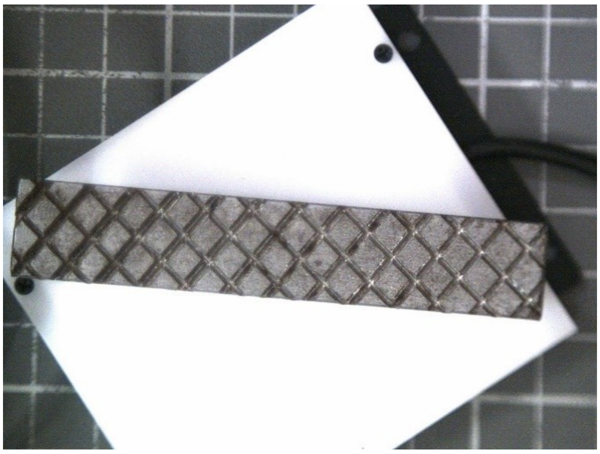

Figure 1. Pictorial view of the boat structure used in single way tool post

The camera used was a DMV 0001 with a 2 MP resolution (1600 x 1200 pixels). The system employed a LD 25 macro lens and doom lighting to enhance image clarity. The lighting setup included red with an intensity of 12, green with an intensity of 8, and blue with an intensity of 4, along with back lighting to reduce shadows. The camera stand used was a Haiser model, ensuring stability and precise alignment.

Initially there are various focal length of the cameras and standard sensor sizes. The focal length and sensor size is selected based on the dimensions of the specimen. Initially the focal length was fixed as 50 mm. Applying this in Eq. (1)

$$50\ mm = \frac{(6.4\ *\ 4.8\ \ x\ Working\ Distance\ )}{100\ *\ 30}$$

$$Working\ Distance = 781.25\ mm$$

For horizontal sensor size, Magnification can be found from Eq. 2

$$m = \frac{6.4}{50} = 0.12\ x$$

The focal length (f) can be determined using Eq. 1, where Sensor Size is 6.4 mm by 4.8 mm, and the field of view (FOV) is 100 mm by 30 mm. Rearranging the formula to solve for the Working Distance (W.D), with a focal length of 50 mm, the Working Distance for the horizontal sensor size was calculated as follows:

W.D=50 $\times \frac{100\times 30}{6.4\times 4.8} =$ ≈781.25 mm (78.1 cm)

The aspect ratio of the images was 4:3, and the magnification (m) was calculated as using Eq.2

$$m = \frac{6.4}{50} = 0.12\ x$$

Each millimetre in the object space corresponded to 16 pixels in the image. The doom lighting height was set at 33 cm. This setup was designed to provide accurate and consistent measurements of the boat-sized components, with considerations for alignment errors and feature coverage.

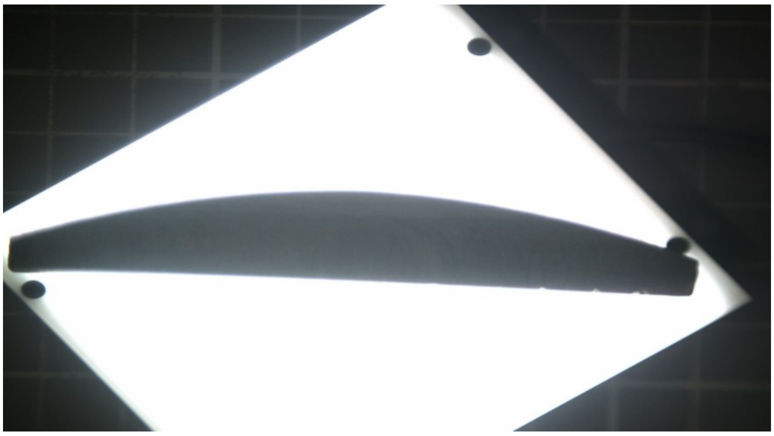

Figure 2. Image Captured with Backlighting

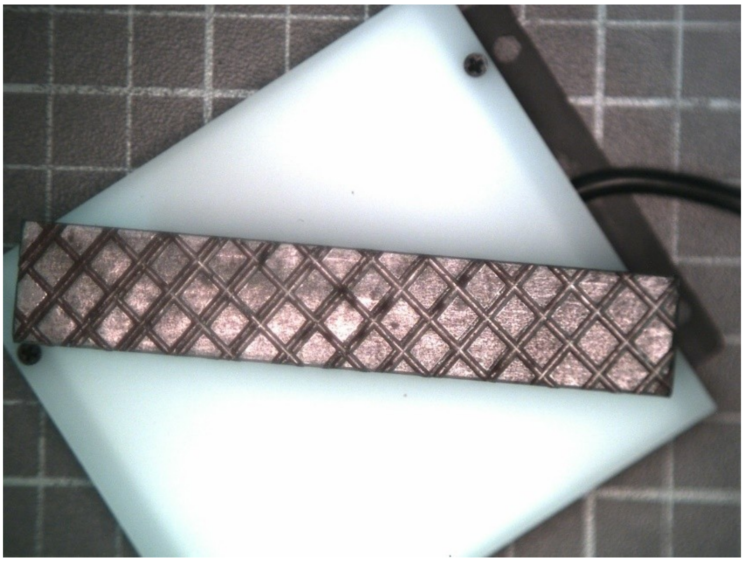

Figure 3. Image Captured with Doom Lighting

5.2 Measuring the indentation diameter

In this study, a machine vision system was employed to accurately measure features of the object, utilizing various camera and lighting configurations. An area-scan camera with a high resolution of 1600 × 1200 pixels was selected to capture detailed and comprehensive images of the object in a single frame, which is essential for ensuring that all features are captured simultaneously and minimizing alignment errors. The camera system was equipped with a 50 mm LD macro lens, chosen for its ability to provide precise focus and measurement of fine details such as the length and serration distance of the boat-sized components and the indentation diameter of the Brinell hardness specimens. The macro lens facilitates close-up imaging with high accuracy, which is critical for achieving the necessary measurement precision.

The focal length for the lens was set at 50 mm, calculated using the same formula, where the sensor size was 2.4 mm × 1.3 mm and the field of view (FOV) was 40 mm. This setup led to a working distance of approximately 641.025 mm, rounded to 700 mm for practical use. The sensor size of 6.4 mm × 4.8 mm (1/2 inch) was utilized, with a magnification of 0.16x, derived from Eq. 2.

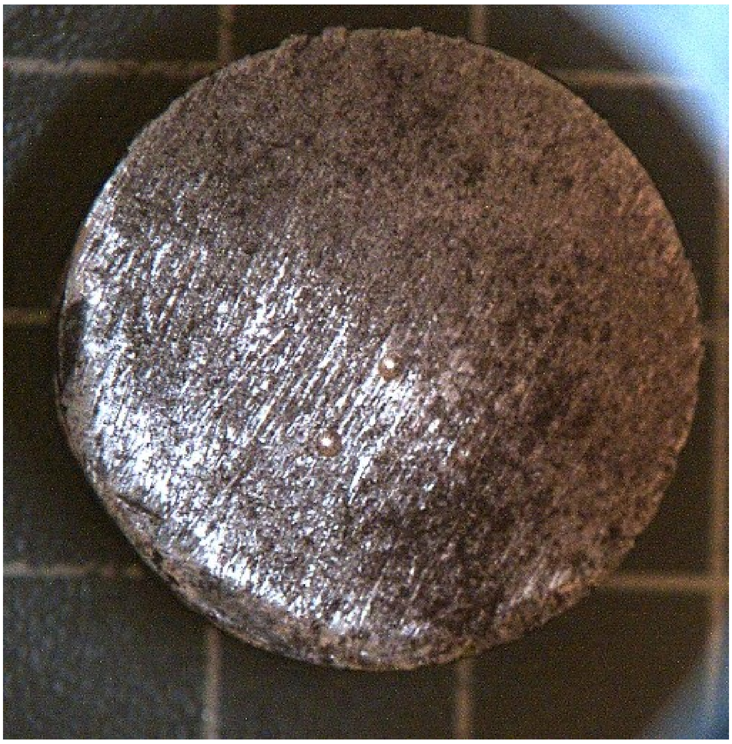

Figure 4. Image Captured with Doom Lighting

The number of pixels per millimetre was 40, resulting in a pixel size of 0.025 mm (25 micrometres), ensuring precise measurement and detailed imaging of the object features. RGB dome lighting, bar lighting, and back lighting were employed to enhance image clarity and feature detection, with specific RGB intensities adjusted for optimal illumination: backlight with CH1 set to 0 and CH2 to 9. The area-scan camera was preferred over a line scan camera because it captures the entire image field at once, making it suitable for inspecting stationary objects where precise control over movement is challenging. This approach minimizes the risk of alignment errors and ensures that all features within the field of view are imaged simultaneously. The combination of a high-resolution area-scan camera, a macro lens, and appropriate lighting provided a robust setup for accurate and reliable machine vision measurements.

Figure 5. Image Captured with Bar Lighting

Figure 6. Image Captured with Bar and Back Lighting

6. RESULT AND DISCUSSIONS

6.1 Determining the dimensions of boat structure using MATLAB

The captured image was analysed using MATLAB software. Using various tools of the software, the pixels were found. Using the formulae, the dimensions were found.

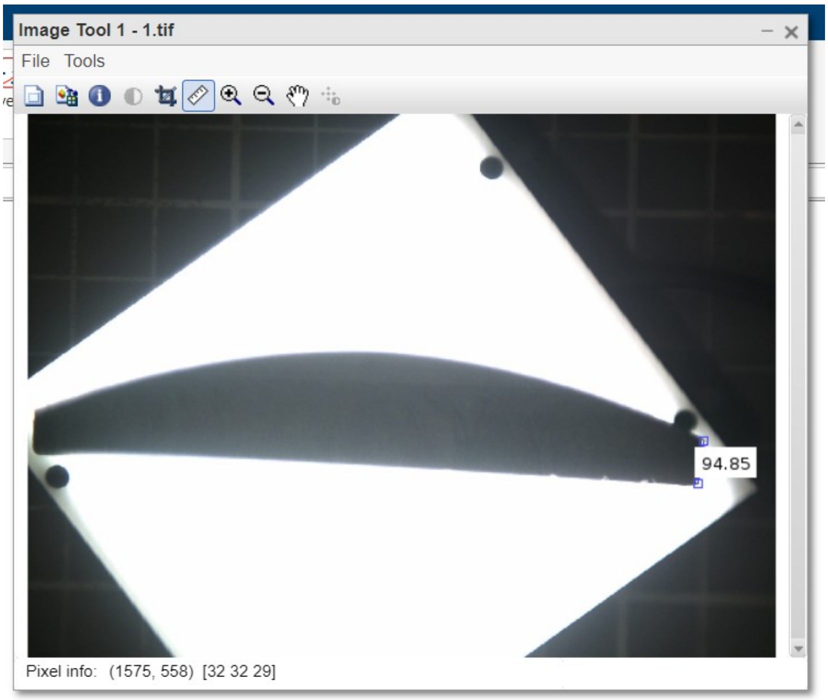

Figure 7. Enumeration of dimensions using MATLAB

$$\frac{Pixels}{mm} = \frac{Sensor\ Size}{Resolution} == 6.4/1600 \quad = 0.004 \text{ pixels/mm}$$

94.85 pixels is found in first image using MATLAB

The dimension of first image = $0.04 * 94.85 \quad = \quad 3.794\ cm.$

Thus, image of the boat by various lighting such as Doom lighting at 33cm, Angular Lighting with Fluorescent light have been successfully taken and the dimensions of the boat shaped structure can be calculated by using the MATLAB software. The variation of the dimensions when it was measured with physical measurements can be analysed and the anomalies could be found. When measuring physically using Vernier Calliper, the dimension was found to be 3.6 cm. Thus, a variation of 5.38 % was found when measuring it physically

6.2 Enumeration of diameter of indentation using MATLAB software

The captured image was analysed using MATLAB software. Using various tools of the software, the pixels were found. Using the formulae, the dimensions were found.

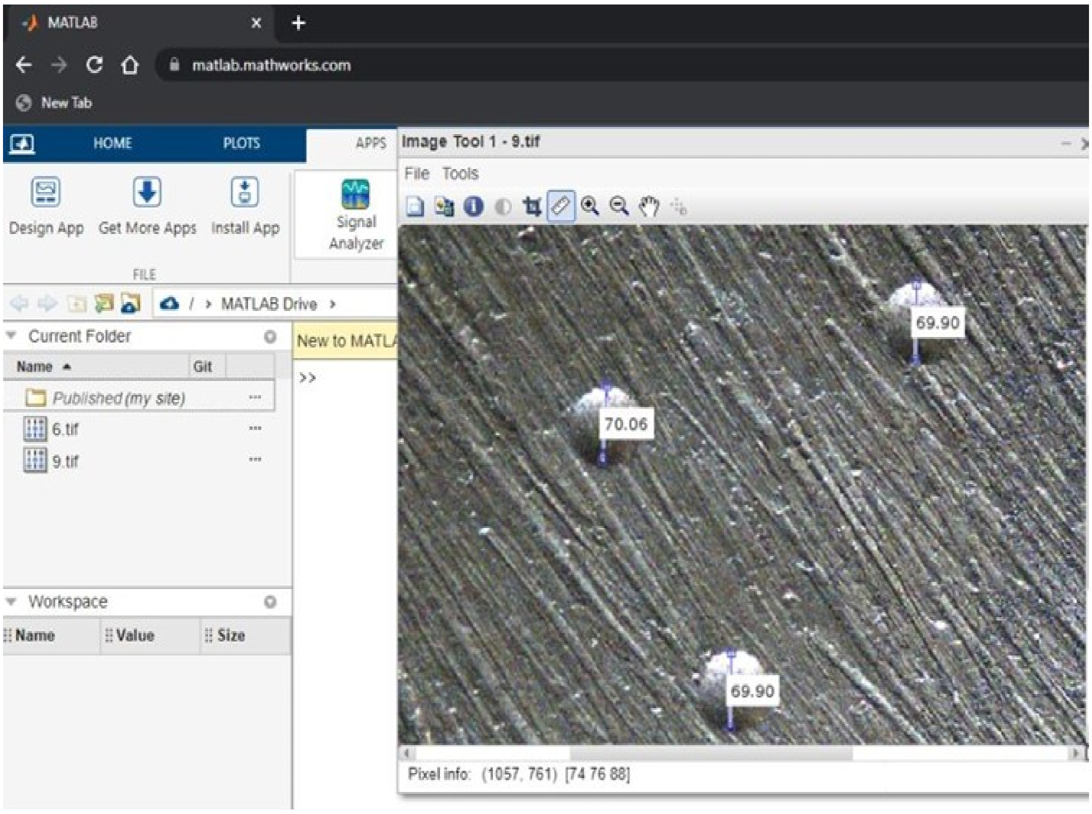

Figure 8. Enumeration of indentation diameter using MATLAB software

$No. of\ pixels = 69.89$

$Size\ of\ 1\ pixel = 1/40 = 0.025\ mm$

$Diameter\ of\ the\ hole = 69.89\ x\ 0.025 = 1.8\ mm$

The diameter of indentation obtained from MATLAB is 1.8 mm which is between the standard diameter range used in Brinell Hardness which range from 1 to 2.5 mm. This process of measurement is easy when compared to the conventional method which involves measuring through microscope. It is laborious and prone to error. The proposed method, eliminates the possible errors associated with the measurement. The diameter measured through the conventional method is 2 mm which is 10 % more than the value obtained using machine vision.

7. CONCLUSION

This research demonstrates the effective use of machine vision systems for precise measurements of boat-sized components in single-way tool posts and indentation diameters in Brinell hardness specimens.

- The machine vision system showed high accuracy in measuring boat-sized components, with a 5.38% variation compared to traditional methods, demonstrating improved measurement precision.
- Machine vision allows for non-contact measurements, reducing the risk of human errors and inconsistencies found in manual processes.
- In Brinell hardness testing, machine vision provided a more precise measurement (1.8 mm) compared to the traditional 2 mm method, with a 10% variation, proving its reliability.
- By automating the measurement process, machine vision systems reduce the errors associated with manual measurements, enhancing consistency across tasks.
- The integration of advanced imaging techniques into machine vision systems offers potential for industrial applications, improving measurement accuracy and operational efficiency.
- The research lays the groundwork for future implementation of machine vision systems in industrial settings, promoting broader use for enhanced precision and reliability in mechanical measurements.

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Declaration of Competing Interest

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