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3D measurement vision system using reflection for machine tools

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Abstract

The proposed paper introduces a 3D vision system that harnesses the capabilities of mirrors. This visionary system is designed to capture three distinct images, achieved through the strategic arrangement of three cameras and two mirrors. These images are the building blocks for facilitating three-dimensional reconstruction, ushering in a new era of depth perception in imaging technology. The paper also presents the development of a dedicated autofocus stage and a motor control system. The motor control unit is ingeniously built around the Raspberry Pi, showcasing the system's adaptability and versatility. Furthermore, the user interface (UI) is constructed using Node-Red, which offers user-friendly web-based control. The implications of this measurement system have potential applications spanning various industries. One particularly promising application is within the field of manufacturing. This system can measure even the most hidden areas, such as the obscured rear parts of objects, where conventional viewing angles fall short. In manufacturing, precise measurements are paramount, and the proposed 3D vision system, with its multifaceted design and innovative technologies, promises to revolutionize the way these measurements are taken. As this paper and the associated system advance our understanding of 3D imaging, it is clear that the proposed system holds significant potential in improving the accuracy and efficiency of measurements in manufacturing, ultimately contributing to enhanced product quality and process optimization.

Engineering, Measuring instrument, Tool, Visual inspection

1. Introduction

In recent technological advancements, the integration of Computer Numerical Control (CNC) systems in manufacturing processes has significantly contributed to automated machining and production. CNC tools, vital components in these processes, play a crucial role in shaping specific parts with precision and repeatability. However, the use of damaged CNC tools can lead to various problems, including overheating, equipment damage, and errors affecting the entire system. Therefore, it becomes imperative to develop a system that can diagnose tool damage effectively.

This paper introduces a novel 3D diagnostic solution for CNC tools, departing from traditional image-based solutions. While traditional 3D scanners come with a hefty price tag, often exceeding $1000 for industrial-grade equipment, this proposed system offers a cost-effective alternative. The system aims to provide diverse views of CNC tools for precise diagnostic information, overcoming the limitations of existing 3D scanning methods vulnerable to light reflection and refraction.

To address these challenges, the proposed system utilizes a 3D vision system employing mirrors and a sophisticated motor control unit based on Raspberry Pi. The system captures three distinct images through strategic camera and mirror arrangements, enabling three-dimensional reconstruction. The use of mirrors allows the system to measure challenging areas, such as obscured rear parts of objects, which conventional viewing angles struggle to reach. The motor control system, built around Raspberry Pi, ensures adaptability and versatility, while the Node-Red-based user interface offers a user-friendly web-based control mechanism.

The potential applications of this cutting-edge system extend across various industries, with a particularly promising impact on manufacturing. Precision measurements are critical in manufacturing, and the proposed 3D vision system, with its multifaceted design and innovative technologies, promises to revolutionize the way measurements are taken. The use of mirrors for image capture, coupled with Raspberry Pi-based motor control and a web-controlled interface, adds an unprecedented level of flexibility and ease of use to this technology.

As the paper progresses, it delves into the challenges faced by conventional 3D scanning methods, highlighting their vulnerabilities to light reflection and refraction. The paper then introduces the concept of Neural Radiance Fields (NeRF) [1,-6] as a promising alternative due to its ability to depict light reflection accurately. NeRF's advantages, including ease of dataset creation and representation of continuous space for natural view transitions, are discussed. Despite NeRF's longer processing times, the paper proposes a feasible application in the industrial sector for real-time rendering systems.

In summary, this research aims to construct a 3D diagnostic system for CNC tools, utilizing a cost-effective approach with a single manual focus camera and NeRF technology. The proposed system demonstrates commendable performance in analyzing the external state of CNC tools economically and effectively. This approach is anticipated to find practical utility in small-scale manufacturing or environments with budget constraints, providing an innovative solution for CNC tool diagnostics.

2. Proposed Methodology

2.1 Hardware description

The proposed method involves positioning two mirrors and three cameras to obtain images of the unseen areas from the cameras through the reflection in the mirrors. In this setup, cameras with adjustable focal lengths are controlled using DC motors due to the variations in focal length and field of view depending on the camera's position. Figure 1 illustrates the process of measuring a solid end mill, showcasing two mirrors reflecting the top surface of the solid end mill, captured by three cameras in action. This method can find practical applications in tasks requiring high precision measurements. By utilizing mirrors to expand the field of view and capturing images from multiple angles through multiple cameras, it becomes possible to scrutinize detailed information about the target object. This is particularly advantageous for measuring small objects or objectswith intricate shapes. Moreover, the ability to adjust the camera's focus adds flexibility to measurement tasks across various environments. By automatically adjusting the focus using DC motors, users can maintain accuracy in the measurement process while operating efficiently. The hardware is installed in a clean environment and is not integrated into the actual manufacturing system but rather deployed for proof of concept purposes.

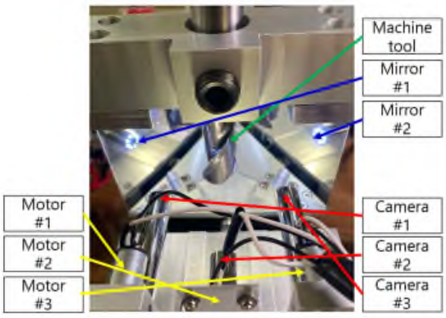

Figure 1. Proposed Hardware (Mirrors, Cameras, DC motors) for test-bed.

2.2. Software description

To establish a seamless integration between the cameras and DC motors, a connection was established with the Raspberry Pi. This intricate setup involved attaching gears to the focus ring of the manual focus camera and the DC motor, enabling changes in the camera's focus with the rotation of the DC motor. The automated focus feature of the DC motor and its impact on the captured images were implemented through Node-Red, as depicted in Figure 2. Utilizing three cameras in tandem allowed the system to acquire three distinct images in a single measurement session, amplifying the efficiency and depth of data collection.

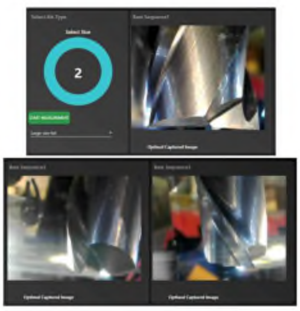

Figure 2. Proposed Software (User Interface with Node-red)

2.3. 3D reconstruction results

Figure 3 depicts the three-dimensional reconstruction results achieved using NeRF. The cost of the applied system, at less than $1000, indicates the feasibility of building an economical and effective 3D diagnostic system. However, the approximately 1-2 minutes required for image pre-processing and 3D rendering pose challenges with performance matric [7-9] for real-time rendering system implementation. The proposed method can help improve product quality by measuring machine tools through 3D Rendering.

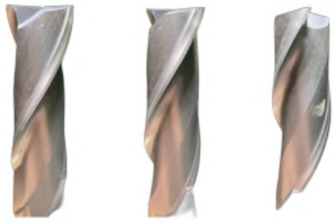

Figure 3. Reconstruction Results

3.Conclusion

This paper introduces an 3D diagnostic system for CNC tools, using mirrors and a Raspberry Pi-based motor control unit to overcome traditional 3D scanning limitations. The system enables precise measurements and three-dimensional reconstruction in challenging manufacturing areas. Exploring NeRF technology as an alternative to conventional 3D rendering, the paper highlights its potential for real-time rendering in industrial applications. The cost-effective approach, employing three autofocus camera and NeRF, performs well in analyzing CNC tool states. In conclusion, this research offers an accessible and efficient solution for CNC tool diagnostics, promising improvements in accuracy and efficiency for manufacturing processes.

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References

[1] T. M¨uller, A. Evans, C. Schied, A. Keller 2022, Instant neural graphics primitives with a multiresolution hash encoding, ACM Transactions on Graphics (ToG), **41**, no. 4, pp. 1-15,

[2] Mildenhall, B., Srinivasan, P. P. , 2021, Tancik, M., Barron, J. T., Ramamoorthi, R., Ng, R., "Nerf: Representing scenes as neural radiance fields for view synthesis", Communications of the ACM, **65**, 199-106.

[3] Mildenhall, B., Srinivasan, P. P., Tancik, M., Barron, J. T., Ramamoorthi, R., Ng, R. 2021, Nerf: Representing scenes as neural radiance fields for view synthesis, Communications of the ACM, **41**, no. 1, pp. 99-106.

[4] Jonathan T Barron, Ben Mildenhall, Matthew Tancik, Peter Hedman, Ricardo Martin-Brualla, and Pratul P Srinivasan, 2021. Mip-nerf: A multiscale representation for anti-aliasing neural radiance fields. In Proceedings of the IEEE/CVF International Conference on Computer Vision, pp. 5855–5864.

[6] K. Deng, A. Liu, J. Zhu, D. Ramanan 2022, Depth-supervised nerf: fewer views and faster training for free. In Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition, pp. 12882–12891,

[7] A. Horé and D. Ziou, "Image Quality Metrics: PSNR vs. SSIM. 2010. 20th International Conference on Pattern Recognition, pp. 2366-2369.

[8] Zhou Wang, A. C. Bovik, H. R. Sheikh, E. P. Simoncelli 2014, Image Quality Assessment: From Error Visibility to Structural Similarity, IEEE Transactions on Image Processing, **13**, no. 4, pp. 600-612,

[9] Zhang, R., Isola, P., Efros, A.A., Shechtman, E., Wang, O. 2018, The unreasonable effectiveness of deep features as a perceptual metric, In Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, pp. 586–595,