Detection of Flaws in Machine Parts Using Ultrasonic Sensors

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Abstract

Several billions of machine parts are being manufactured per day in different parts of the world. Recalling the fact that only some things are perfect and considering just 2% of the average error rate we get millions of defective products. Some are crucial objects, which if used defective can cause mass destruction or fatality to human life. Some parts get errors in them while they are being transported from one place to another, hence a sophisticated mechanism is required for their testing. Some methods include the utilization of Artificial Intelligence with the help of camera vision which in turn results in an expensive approach to resolve the issue. This paper provides a new, and economical prospect with the usage of Ultrasonic Sensors and provides a brief on how precise error detection could be achieved using these sensors. A 3D Point Cloud is generated from the distance data points captured and then compared with the ideal object.

Keywords: 3D Point Cloud, Camera Vision, Ultrasonic Sensors

1. Introduction

The manufacturing industry, with its expansive scale, produces several billions of machine parts each day across the globe. Despite advancements in technology and rigorous quality control measures, an average error rate of 2% results in millions of defective products entering the market. The presence of such defects, especially in critical components, can lead to catastrophic failures, posing significant risks to human life and safety. These defects can originate not only during the manufacturing process but also during the transportation and handling of the parts.

The need for an effective and efficient mechanism for flaw detection in machine parts is paramount. Traditional methods often rely on complex systems involving artificial intelligence and camera vision. While these methods can be highly effective, they are also expensive and resource-intensive, making them less accessible for widespread use, especially in smaller manufacturing setups.

This paper introduces an innovative and cost-effective approach for detecting flaws in machine parts using ultrasonic sensors. Ultrasonic testing offers several advantages, including the ability to detect internal and surface flaws, non-destructive evaluation, and relatively low operational costs. By generating a 3D point cloud from the distance data captured by the sensors, our method provides a detailed comparison with the ideal object, ensuring high precision in error detection.

The proposed system leverages the principles of ultrasonic wave propagation and reflection to identify discrepancies in the structure of machine parts. This approach not only enhances the accuracy of flaw detection but also streamlines the inspection process, making it more efficient and economical. The integration of ultrasonic sensors for flaw detection represents a significant advancement in quality control, promising to reduce the incidence of defective products and improve overall safety and reliability in various industries.

2. Methodology of Proposed Work

2.1 Using Computer Vision

An AVI of PCBs for defect detection, classification and localization using image processing techniques such as mathematical morphology and template matching were investigated by Malge P. S. and Nadaf R. S. (2014). A computer vision system for the detection of missing fasteners on steel stampings was introduced by Killing, Surgenor et al., 2009. A neuro-fuzzy image classification algorithm was made and compared with a threshold-based classifier [1-3]. It was reported that once optimized, the neuro-fuzzy classifier depleted in a less abrupt fashion when the input significantly varied from the trained data. Klein, Masad et al. (2014), suspected early bearing failures and tests using image processing techniques applied to time-frequency representation (TRF) of the vibration signals. The four-stage system was developed to detect and classify bearing failure signs based on the vibration signals.

There are 4 basic principles for finding the faults,

1. **Image Acquisition**: High-resolution cameras capture detailed images of machine parts from multiple angles.
2. **Preprocessing**: Images are enhanced to highlight relevant features, such as reducing noise and adjusting contrast.
3. **Feature Extraction**: Algorithms identify specific features indicative of defects, like cracks and surface irregularities.
4. **Classification and Detection**: Machine learning models, particularly convolutional neural networks (CNNs), classify and detect defects based on the extracted features. These models are trained on large datasets of labelled images, enabling accurate defect identification.

Numerous studies validate computer vision's effectiveness. Tsai and Hsieh (2012) achieved over 95% accuracy in detecting surface defects in steel strips using deep learning [4]. Zhao et al. (2017) demonstrated that deep learning-based systems could identify casting defects with high precision, outperforming traditional inspection methods. The integration of 3D imaging techniques further enhances detection capabilities, successfully applied in inspecting complex components like turbine blades and automotive parts.

With 3 major advantages which are, high precision, automation and speed, and non-destructive nature which makes us rely on this method but on the downside some crucial drawbacks are high cost, complexity, and environmental sensitivity.

2.2 Using Ultrasonic Sensors

It is not mandatory to be able to provide high accuracy in some cases and is more important to have the devices to be cost-effective in a few cases. That is where ultrasonic sensors come into the picture making the process economical. Nonetheless, even this approach comes with a cost of time and accuracy. The test object is first kept on a turn table and the sensor measures distance from a fixed point in XY-Axis. After a 360-degree rotation of the turn table, the ultrasonic sensor [5-7] moves perpendicularly along the Z-Axis barely 2-3 dings of a stepper motor. The dings could be chosen as per the accuracy requirement. The apparatus is shown in Fig. 1 and Fig. 2 which consists of,

- 1x Arduino Mega
- 2x Stepper Motor
- 1x Ultrasonic Sensor
- 1x Motor Shielding for Arduino
- 8x Male-to-Male Jumper Wires
- 4x Male-to-Female Jumper Wires

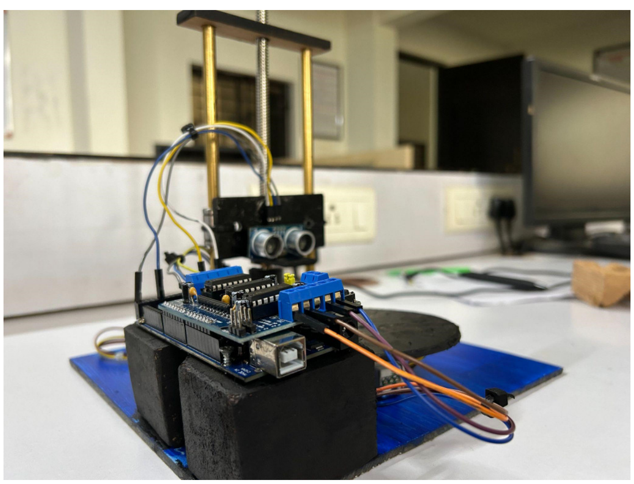

Fig. 1

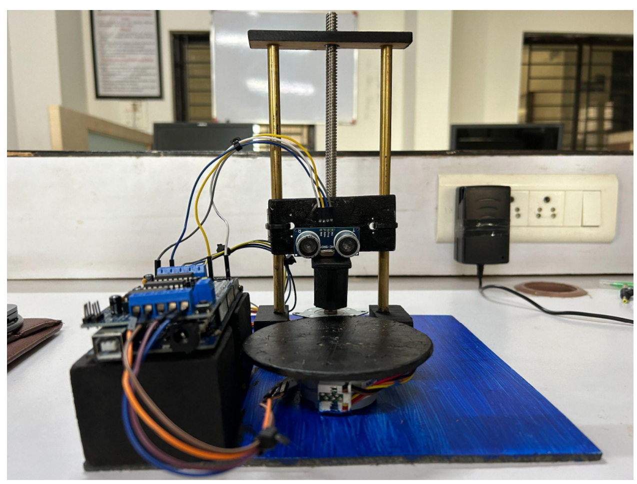

Fig. 2

Fig. 1 and Fig. 2, represents the apparatus design

3. Results

The test was done on a toy shaped like a farmer shown in Fig. 3 which was considered as the ideal defect less object and then the farmer toy's height was reduced using a filer from the top. Thereby, making it a defective piece with faults that could not be seen or felt with the naked eye. Fig. 4 shows the 3D image generated of the ideal object shown in blue color which took about 30 mins to generate. Fig. 5 represents the erroneous farmer toy's 3D-generated image in red color. Comparing Fig. 4 and Fig. 5, no such major changes could be noticed hence Fig. 6 is generated showing where the error is in red color and the yellow region represents that there is no error.

Fig. 3 *Farmer Object*

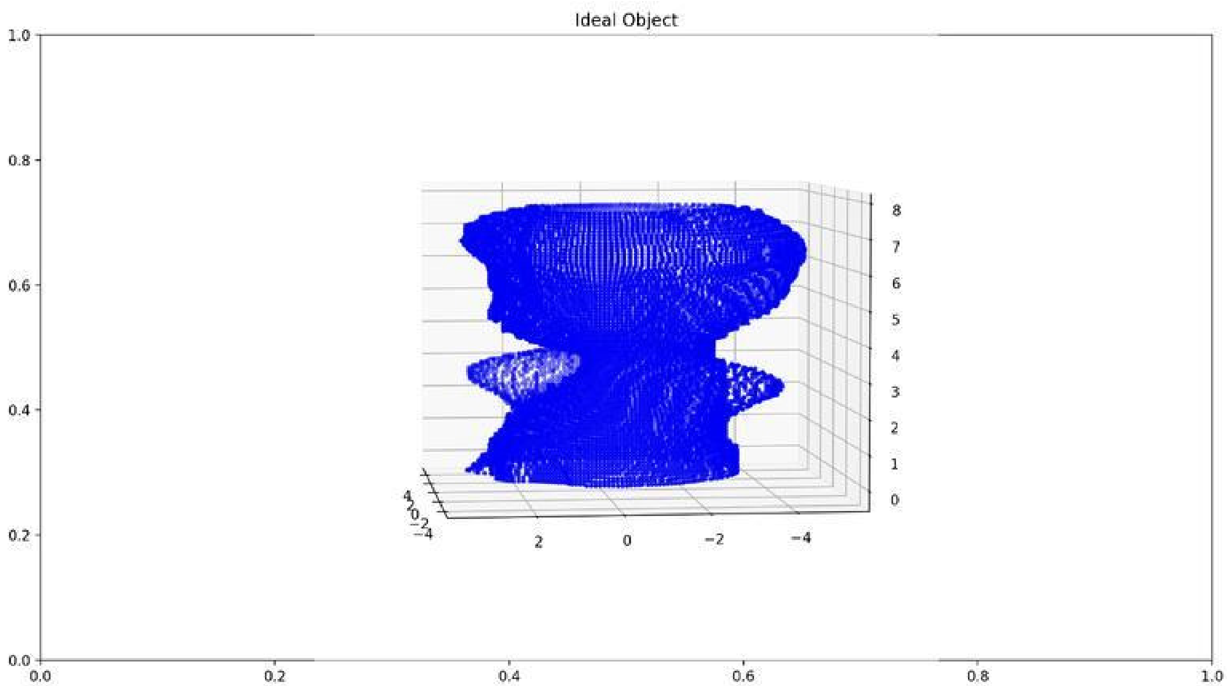

Fig. 4 *3D Image of Ideal Object*

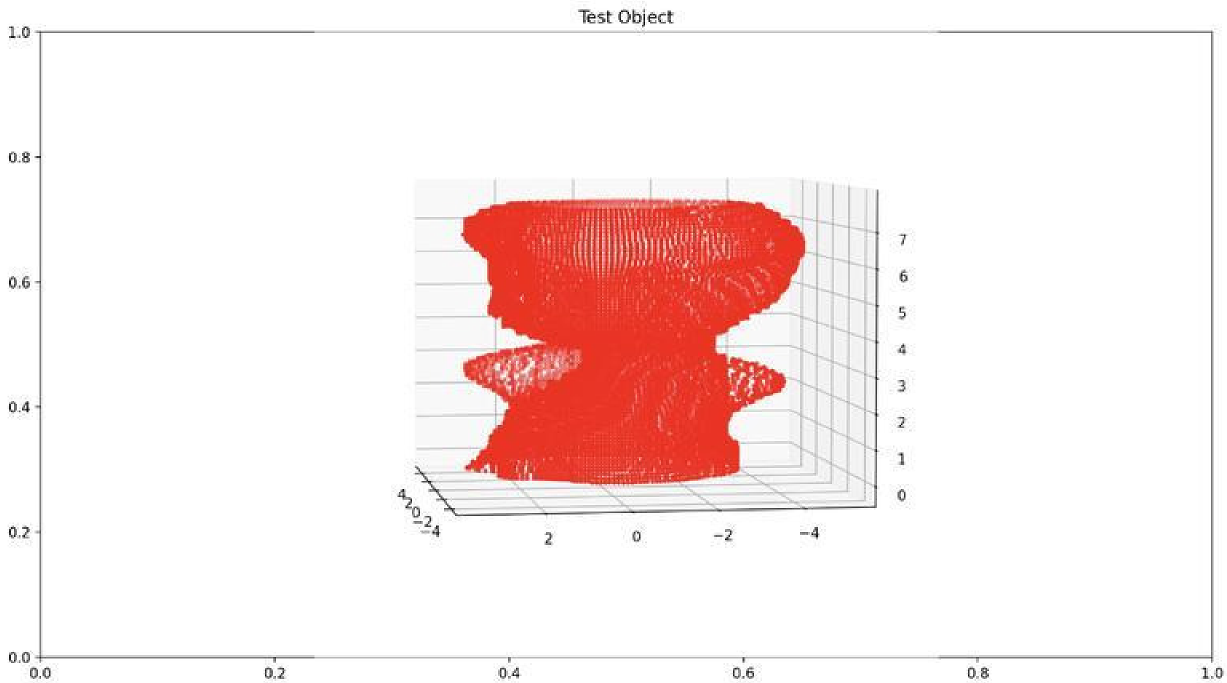

Fig. 5 *3D Image of Test Object (Erroneous)*

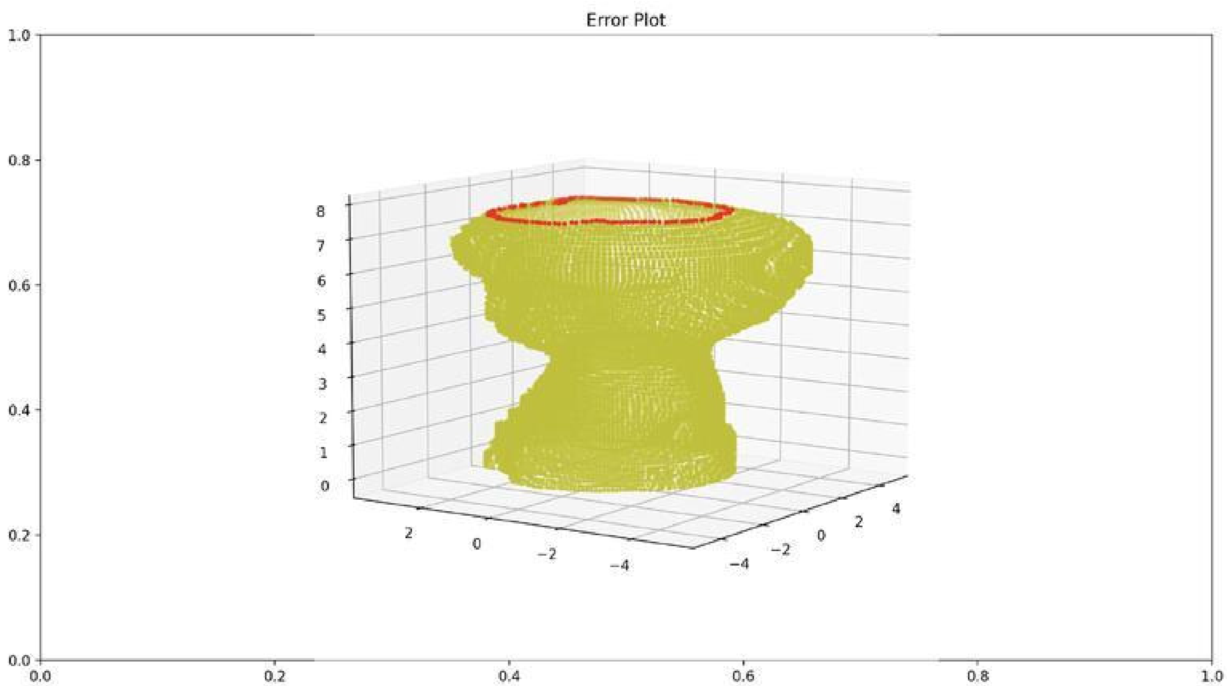

Fig. 6 *Image of Plot Showing Erroneous Points*

4. Conclusion

The rapid pace of global manufacturing results in the production of billions of machine parts daily, with an inevitable error rate leading to millions of defective products. Ensuring the quality and safety of these parts, especially critical components, is paramount to preventing potential catastrophic failures. Traditional methods of flaw detection, particularly those involving computer vision and artificial intelligence, offer high precision but come with substantial costs and complexities, limiting their accessibility for widespread use.

This paper introduces a novel, cost-effective approach for flaw detection using ultrasonic sensors. By generating a 3D point cloud from distance data captured by the sensors, this method allows for a detailed comparison with an ideal object, ensuring high precision in error detection. Ultrasonic testing not only detects internal and surface flaws but also offers non-destructive evaluation at a relatively low operational cost.

The proposed system demonstrates significant advantages, including high accuracy, efficiency, and economic feasibility, making it suitable for various industrial applications. Experimental results, such as those obtained from testing a modified toy object, validate the system's capability to detect subtle defects that are not visible to the naked eye. The comparison of 3D images generated for both ideal and defective objects highlight the system's precision in identifying discrepancies.

In summary, the integration of ultrasonic sensors for flaw detection represents a significant advancement in quality control. This method promises to reduce the incidence of defective products, thereby enhancing overall safety and reliability in the manufacturing industry. Future research and development could further optimize this approach, making it even more robust and adaptable to a wider range of industrial applications.

5. References

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