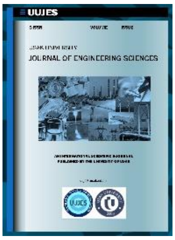

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Research article

A MACHINE VISION SYSTEM FOR GEAR TEETH DEFECT DETECTION

*Pevril Demir Arı[1], Fatih Akkoyun[2]**

[1]*Faculty of Engineering, Mechanical Engineering Deparment, Demokrasi University, Izmir, Türkiye*
[2]*Faculty of Engineering, Mechanical Engineering Deparment, Demokrasi University, Izmir, Türkiye,*

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Abstract

Gears, one of the indispensable components used in the industry, are mechanical elements that ensure efficient energy transmission, altering the speed and torque of rotational movements. The reliability and durability of gears directly affect the overall performance of related systems. Recently, gear manufacturing has been nearly fully automated with the help of advanced technology. However, it is common to assess the quality of a gear via traditional methods. The conventional quality control techniques for gear quality determination cause many difficulties, such as time-consuming and user-dependent measurement errors. In short, these conventional measurement methods decrease manufacturing speed. Today, Machine Vision Systems (MVS) offer the possibility to advance automated quality control systems. In this paper, to save time and reduce user-dependent errors, an automated gear evaluation system was developed for integration into a mass production line. The developed system has a rotating table, with gears progressing on the table at a controllable rotating speed. The gears are inspected for common defects such as missing teeth, rough surfaces, incorrect diameters, and other flaws. The detection process uses an MVS, programmed to differentiate perfect gears from defective ones through a vision system. The detected defective gears are automatically separated by pushing from the production line using compressed air via a pneumatic valve. This system enhances the efficiency of the production line and prevents defective gears from advancing to subsequent stages of production or assembly. As a result of the experiment, the standard deviation of both defective and perfect gears was measured below 1%, which is an indication of high measurement precision. The developed system provides high-speed quality control in mass production processes, thus aiming to increase efficiency by minimizing user-dependent measurement errors on mass production lines.

Keywords: *Gear, Rotary Table, Machine Vision System, Selecting and Sorting.*

*Corresponding author: Fatih Akkoyun
E-mail: fatih.akkoyun@idu.edu.tr

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1. Introduction

Gears are mechanical components that enable efficient energy transmission by changing the speed and torque of rotational movements [1]. They are widely used in many sectors, such as automotive, aviation, industrial machinery, aerospace, mining, renewable energy and consumer electronics [2–4]. The quality of gears, which are fundamental components in various machines and equipment, directly affects the performance and lifespan of the machines [5,6]. Gear wear is a serious damage to the tooth surfaces due to adhesion and abrasion under thermo-mechanical factors, and during this process, material transfer occurs from one tooth surface to another, which leads to serious failures. This wear can also cause the teeth of the gears to break [7,8].

In modern production processes, the demand for high precision and efficiency on production lines is continuously increasing. Quality control has become a critical factor to minimize losses and optimize resources by ensuring that only flawless products progress on the production line [9,10]. Today, with the rapid increase in production continuity, the need for mass production lines that minimize losses has become inevitable. Thanks to advancing technology, the integration of systems capable of automatic inspection and separation into production lines has become feasible [11–14]. Therefore, there is a frequent need for automatic inspection and separation solutions in the industry with the help of MVS [13,14]. Ning Gan and his friends designed a machine vision-based air-blowing sorting platform for the production of famous tea leaves. Famous tea is a pillar of the Chinese tea industry and must be processed using fresh leaves of consistent softness and size. However, equipment with high accuracy and efficiency for sorting fresh tea leaves (FTLs) is not available. Therefore, in their study, they designed a machine vision platform for sorting FTLs. The results of this study show that the designed platform can meet the small-scale production requirements for the famous tea, but it still cannot be said to be completely high-accuracy [14]. Wenju Zhou and his friends designed a rapid cork sorting system based on machine vision. In their work, an advanced deep learning method based on machine vision was adopted to detect the surface of cork and automatically classify them. The experimental results show that the system has high precision and requires less time to sort. However, it is suggested that the system should be faster [15]. Zhieng Lu and his friends, designed a winter-jujube sorting robot based on machine vision. This system, which they designed to sort special jujube grown in China according to their maturity, performed the sorting process by means of a robot arm. Image processing was also integrated into the robot arm. As a result of the study, they achieved high classification accuracy. They pointed out that the robot arm should be modified and the classification efficiency should be increased for future studies. In previous studies, it was revealed that there were some deficiencies in terms of high accuracy rates, speed, and efficiency [16]. Parnian Rezaei and his friends designed, developed and tested an automatic sorting machine to select and separate sunburned pomegranates. Sunburn is a common problem in the marketing of pomegranates and approximately 30% of the harvested pomegranates are affected by this condition. In this study, three new image processing algorithms are proposed to detect sunburn. As a result, sunburned pomegranates were sorted by these methods, but different accuracy rates were obtained in each algorithm [17].

In this study, a gear seperation quality checking system produced using MVS, which is more efficient, has higher speeds and stability, and reaches higher accuracy rates in terms of classification, was designed by taking these deficiencies into account. The study presents the development of a system for monitoring gears moving on a rotating table according to their defect status using a machine vision system and separating defective ones through a pneumatic valve. The gears moving on the rotating table are intended to be inspected for common defects such as missing teeth, rough surfaces, incorrect diameters, and other flaws. The inspection process is carried out using an advanced MVS positioned to view the rotating table, which monitors and analyzes the gears in real-time. In short, this study designed a separation system using a pneumatic valve to detect defective gears with MVS and separate them on a production line. By minimizing losses on production lines, it aims to increase efficiency. This approach is intended to contribute to significant progress in automatic production processes and to provide a practical solution to one of the industry's critical challenges.

2. Material and Method

MVS is integrated with a computer and designed to be programmed to distinguish flawless gears from defective ones. The system is calibrated to recognize specific features of flawless gears, such as the complete number of teeth, smooth surfaces, and correct diameters. When the MVS detects a defective gear, it sends a signal through the microcontroller to the pneumatic valve. This solenoid valve uses compressed air from a compressor to separate the defective gear from the rotating table. The flawless gears continue to progress on the line. This automated process not only enhances the efficiency of the production line but also is expected to significantly reduce the likelihood of defective gears advancing to subsequent stages of production or assembly.

The flowchart of the system is shown in Figure 1. In general, the image is processed by the IPC and an actuation command is transferred to the microcontroller with respect to processed image result. The signal generated by the microcontroller triggers the relay, which then activates the pneumatic valve to separate the defective gears from the rotating table.

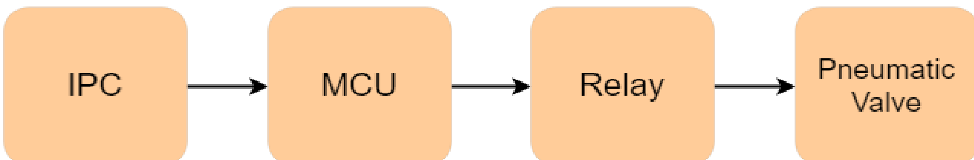
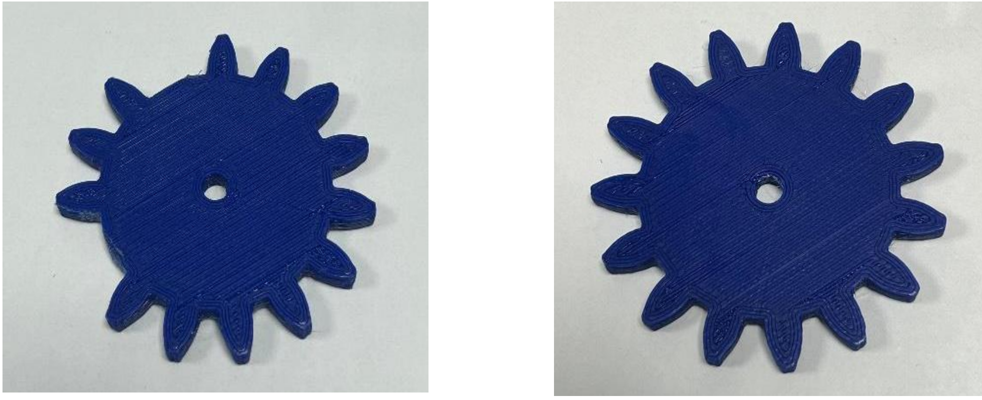


Fig 1. General structure of the system

A three-stage system is developed for the classification of gears as defective or perfect and their separation using image processing techniques. In the first stage of the system, an image preprocessing step is applied to the image taken from the camera. In the second stage, the gears in the environment are detected, and data related to the gears are transferred to the information database as either defective or non-defective. In the final stage, using the dataset, defective gears are separated while non-defective gears continue to progress. In this study, gears moving on the rotating table are detected for common defects such as missing teeth, rough surfaces, incorrect diameters, and other flaws, and these defective gears are separated.



(a) (b)

Fig 2. The gears a) defective, b) perfect

The image processing process begins with the acquisition of the image. The image, converted into a digital signal, is enhanced through preprocessing. Then, with the segmentation phase, gaps and background noises are eliminated. The boundaries of gears are determined by the contouring process. With data extraction, dimensions, shape, color, texture, and defects are measured. Subsequently, the gears are classified based on their characteristics. Finally, the gears are characterized with respect to the quality control parameters.

The first step in image processing is acquiring a digital image with a digital camera. The next stage after obtaining the digital image is preprocessing. Preprocessing involves subjecting the obtained digital image to certain preliminary processes to achieve a more successful result before using it. These processes can be categorized under the subheadings of image enhancement, image restoration, and image compression. In image processing steps, one of the color spaces applicable to pixels and the most commonly used is RGB (Red, Green, Blue), obtained by the combination of the three primary colors. The other system is Monochrome (black and white). Here in this study, RGB images are converted to the HSV to separate the target objects from the background.

Operations in image processing are performed on pixels, which are the smallest units that constitute the image. First, the digitized image is converted to grayscale to clean up noise. Then, additional filters are applied, including capturing the image, cleaning up noise, adjusting brightness, darkness, and correct color, sharpening and blurring the image, resulting in new images through necessary algorithms. Thanks to the illumination light, the reflected image from the object reaches the image center inside the camera. The analog signals obtained by the imaging sensor which are converted to digital signals and compared with the defined values in the control center. Depending on whether the measurement outputs are within tolerance values or not, a signal is generated, determining whether the controlled part is correct or not. These stages are indicated in Figure 1, sequentially.

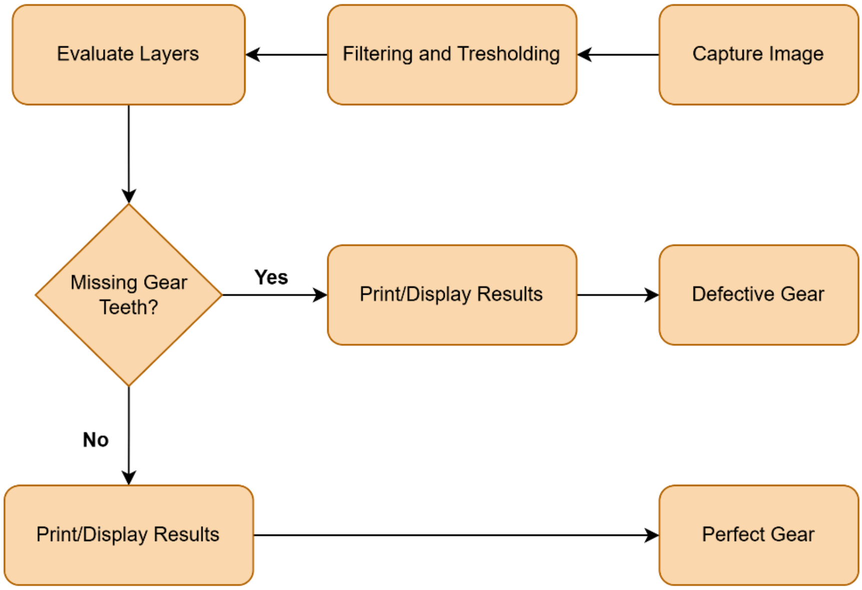


Fig 3. Stages of the Method

This system includes high-resolution lighting with a diffuser and cross-type lighting method, fast image processing with an IPC featuring Intel CPU, a product feeding unit, a rotary table product transport system with a stepper motor plexiglass optical table, control of sorting valves via PC/MCU with locally designed electronic units, monitoring of products on the rotary table with a machine vision system, and exit lines (roller conveyor lines).

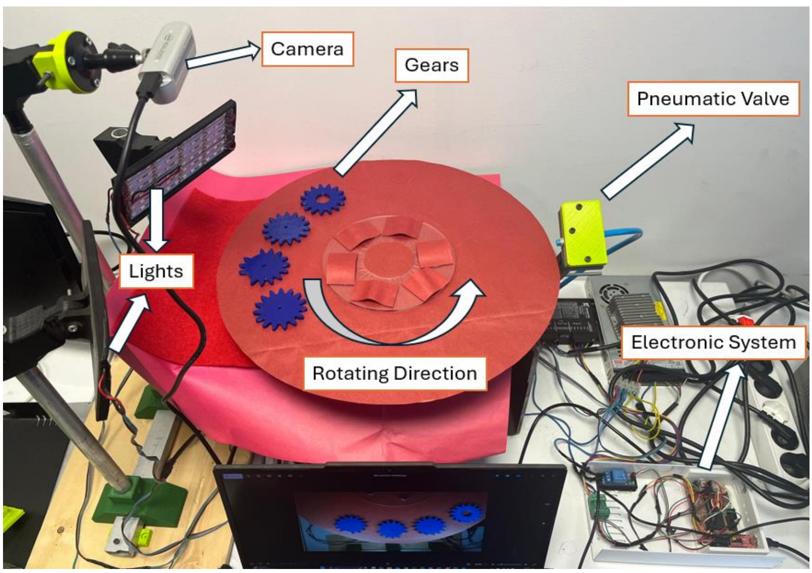
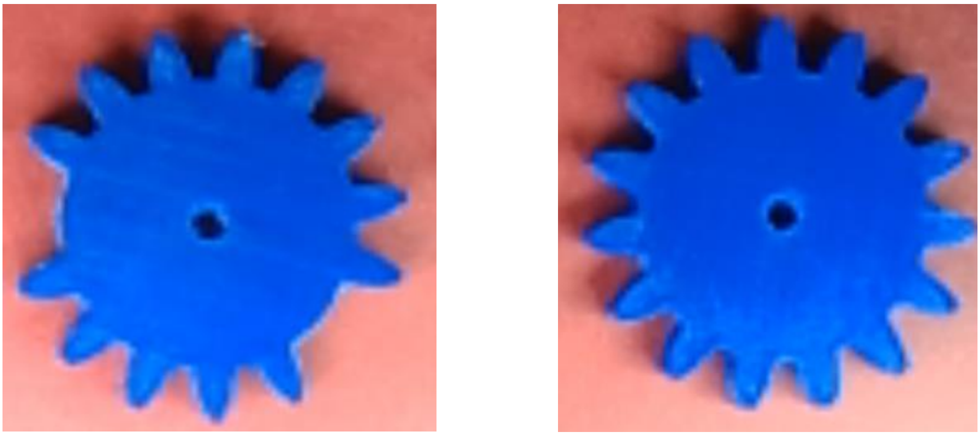


Fig 4. Top View of the System

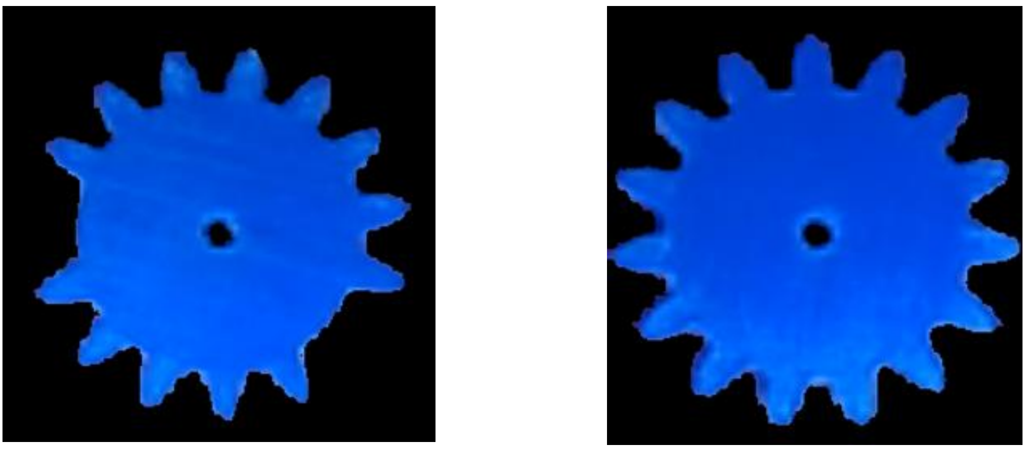
3. Results and Discussion



(a) (b)

Fig 5. Actual Image, a) Defective Gear, b) Perfect Gear

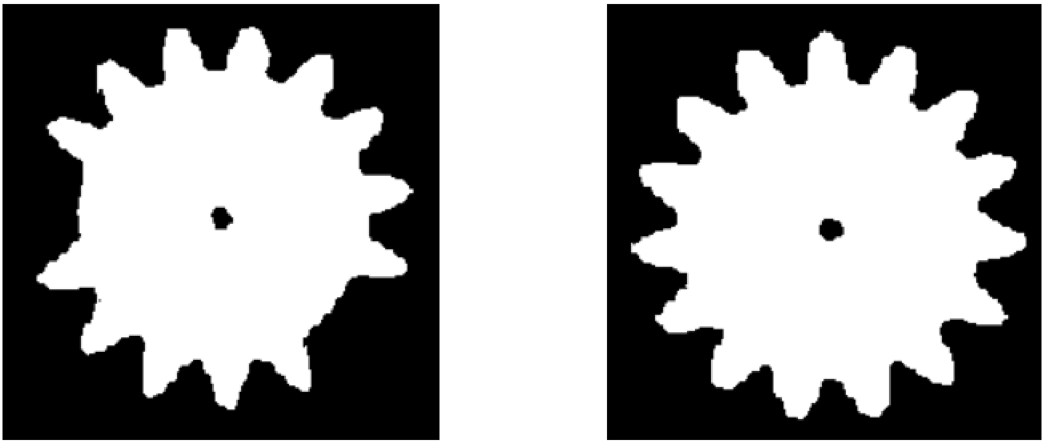
In the experiment, 3D-printed gears are used to evaluate the accuracy of the system. The 3D computer models of the gears are obtained from the SolidWorks Gear Library. These models are converted to stereolithography (STL) files for 3D printing. The converted models are printed using additive manufacturing technology with PLA materials. Figure 5 shows actual images of a perfect and defective gear.



(a) (b)

Fig 6. Masked Image, a) Defective Gear, b) Perfect Gear.

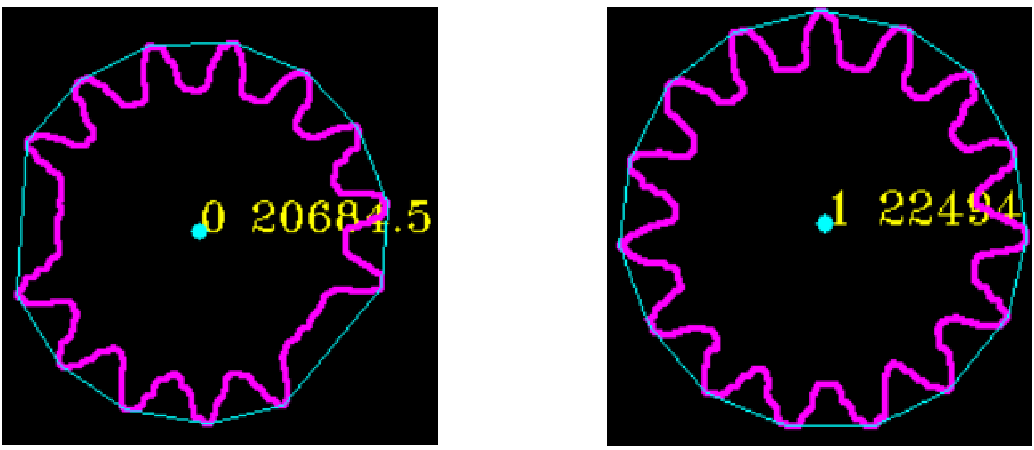
Figure 6 shows the masked version of the defective and perfect gear. Here, a background-free output is obtained. Since the gears used as subjects were blue, the camera software was created to only see blue objects. The top of the rotary table is also covered with a dark material to prevent light from reflecting. Thus, high accuracy outputs were obtained during the testing process. To measure the accuracy of the vision system, both gears were picked up and released 10 times.



(a) (b)

Fig 7. Processed Image, a) Defective Gear, b) Perfect Gear

Figure 7 shows the masked image passed through the threshold value and assigned the values "0" and "1". A value of 0 shows the background, while a value of 1 shows the gears. An attempt was made to isolate it from other lights in the environment. To measure the accuracy of the vision system, both gears were picked up and released 10 times.



(a) (b)

Fig 8. Processing Output, a) Defective Gear, b) Perfect Gear

Figure 8 shows the area output of the defective and perfect gear. On the left is the area of a defective gear with missing teeth, and on the right is the area of a perfect gear. An attempt was made to isolate it from other lights in the environment. To measure the accuracy of the vision system, both gears were picked up and released 10 times. The graphs in figures 9, 10 and 11 were created from the outputs obtained by taking and releasing both gears 10 times.

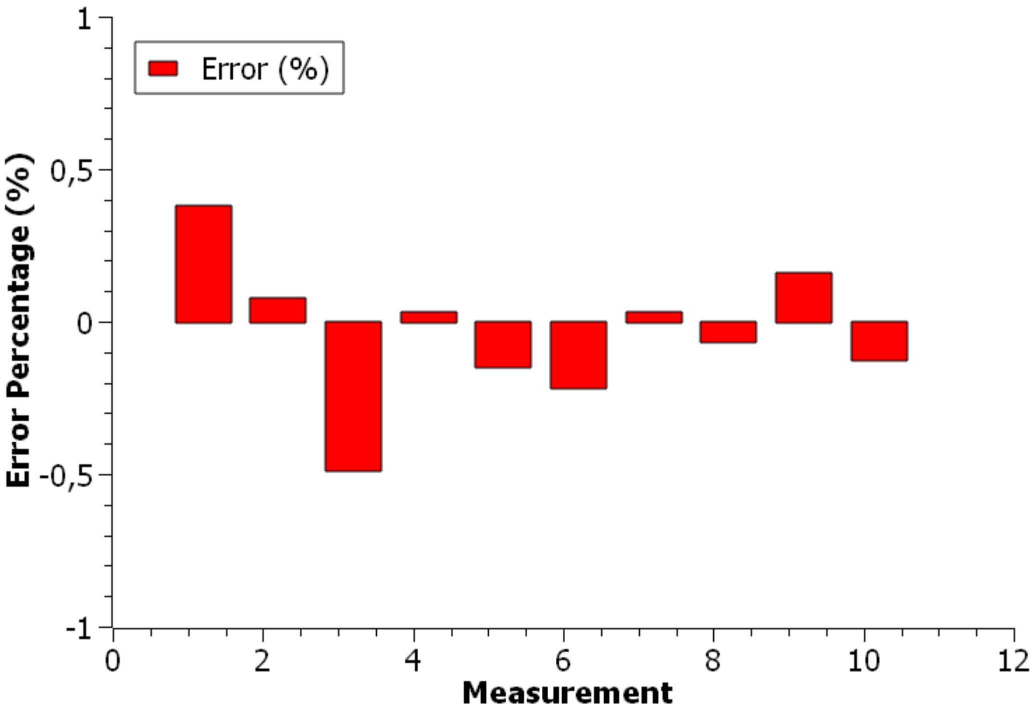


Fig 9. Error-Measurement Ratio for Defective Gear

Figure 9 presents the defect rate of gears, with a focus on the occurrence of missing teeth. To assess the reliability and consistency of these measurements, a defective gear was subjected to a series of 10 tests. The results of these repeated measurements are depicted in Figure 10, which provides a detailed representation of the findings from each individual test.

The statistical analysis of the repeated measurements revealed that the standard deviation for the defective gear was less than 1%. This low standard deviation reflects a high degree of consistency in the defect measurements, indicating that the defect rate of the gear is both stable and reproducible. The minimal variation observed supports the accuracy and precision of the measurement process, thereby validating the reliability of the defect assessment.

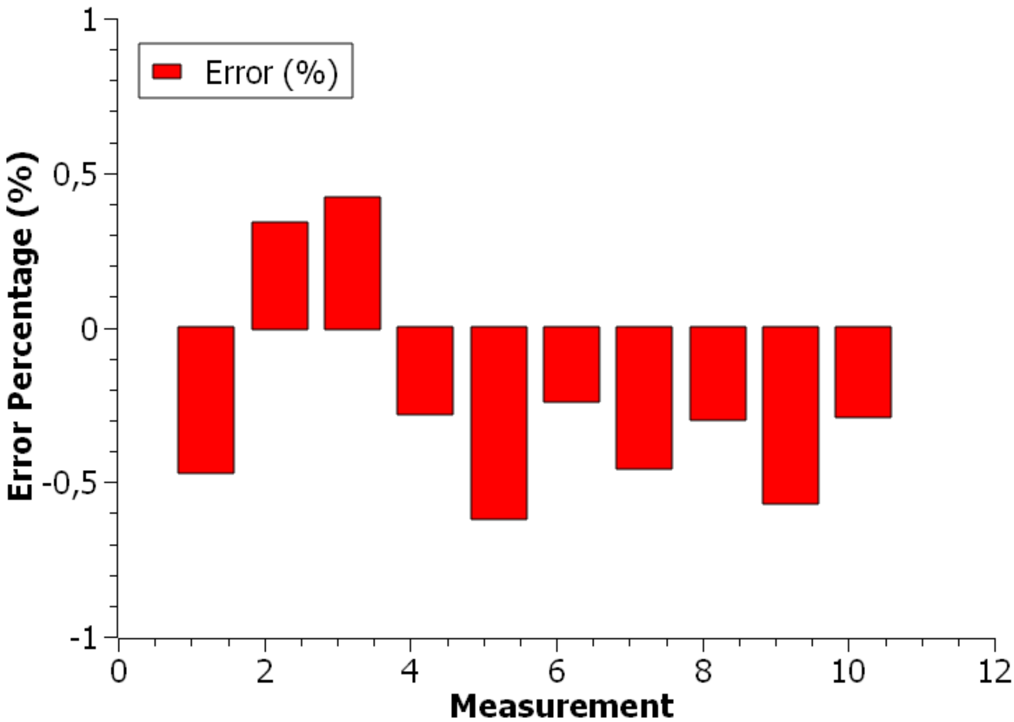


Fig 10. Error-Measurement Ratio for Perfect Gear

Figure 10 provides a detailed account of the accuracy rates and measurements for the perfect gear. The figure shows the error rate of defect-free gears based on the empirical data obtained. The perfect gear tests are conducted in a series of 10 tests, with the results from these trials being systematically represented in Figure 10. The analysis of these repeated measurements revealed a standard deviation of less than 1% for the ideal gear. This high accuracy reflects a high degree of measurement precision and consistency, underscoring the robustness and reliability of the assessment process for the perfect gear.

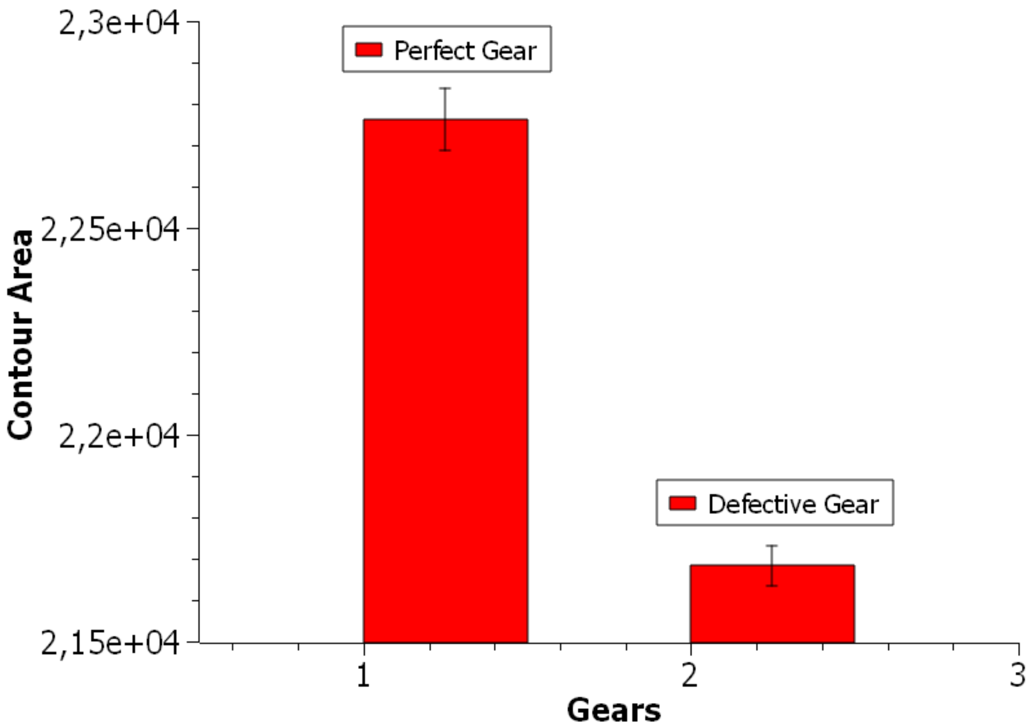


Fig 11. Measurements results for perfect and defective gears

In the experiments, two gears were used to evaluate the accuracy of the MVS in differentiating defective and perfect gears. Each gear evaluation stage was repeated ten times to obtain results for repetitive measurements, which are presented in Figures 9 and 10 for defective and perfect gears, respectively. The standard deviation for the defective gear is found to be below 1%. The perfect gear deviation is measured to be below 1%. The difference between the averaged results is found to be around 5%, which allows the MVS to differentiate between defective and perfect gears. The comparison result, including averaged data with the standard deviation for defective and perfect gears, is given in Figure 11.

The accuracy of the system, reflected by a standard deviation of less than 1%, is closely tied to the efficacy of the image processing step the image processing step is a cornerstone of the defect detection process, contributing significantly to the system's overall accuracy and reliability. This step involves the acquisition of high-resolution digital images, preprocessing to enhance clarity, segmentation to isolate the gear from the background, and contour detection to identify defects such as missing teeth and rough surfaces. By converting the RGB images into HSV color space, the system eliminates background noise, ensuring precise feature extraction. This multi-stage approach minimizes false positives and negatives, thus enhancing the precision of defect classification. The robust image processing framework directly influences the consistency of the results, as evidenced by the standard deviation of less than 1% in defect detection.

4. Conclusion

This study focuses on the development and implementation of an automatic gear separation system for use in a production line. The system consists of a rotating table, a high-resolution MVS, computer-based image processing software, and a pneumatic separation system.

The developed system has successfully passed various testing and calibration stages. The camera and image processing software were able to detect defects such as missing teeth, rough surfaces, and incorrect diameters with high accuracy. The pneumatic valve effectively separated defective gears from the rotating table and removed them from the production line.

During the testing phases, the system accurately distinguished between flawless and defective gears, and the separation of defective gears was completed smoothly. This demonstrates that the system is both reliable and efficient.

Future implementations may involve adapting the system for a wider range of gear types and testing it in diverse industrial environments. Potential applications include the automotive, aerospace, and heavy machinery industries, where stringent quality control is essential. Furthermore, the system scalability offers opportunities for broader adoption in automated manufacturing processes.

In conclusion, this study provides an effective solution for automating quality control in production processes. The developed automatic gear separation system enhances the efficiency of the production line and improves overall product quality by preventing defective gears from advancing to subsequent stages of production or assembly. It is believed that this system will provide significant progress in the integration of quality control and automation in modern industrial production processes.

5. Conflicts of Interest

The authors declare no conflict of interest.

6. Acknowledgments

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7. Author Contributions

Conceptualization, Fatih Akkoyun; Methodology, Fatih Akkoyun and Pevril Demir Arı; Formal analysis, Pevril Demir Arı; Writing, Fatih Akkoyun and Pevril Demir Arı. Both authors have read and agreed to the published version of the manuscript.

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