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An Improved Quality Inspection of Engine Bearings Using Machine Vision Systems

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ABSTRACT

The growth of an industry is mostly based on the quality of the product. When there is a fault in the manufactured product in a batch, the entire batch is rejected because of a single faulty product. Quality has become one of the important factors deciding the growth of the industry. Industries nowadays are being automated in every phase of the manufacturing process. Here, an automated system is developed for the inspection of the product developed for the automobile industry. The bearing is one of the parts that play a major role in the connections with the engine and the shafts. Therefore, the bearing has to be perfect, as faulty bearings will lead to greater damage regardless of others. In the automated system, the bearing is inspected for the missing operations in the product. The faulty product is rejected and would be checked for rework or to be scraped. The inspected products are then being sent for the packing process. Through the automated inspection system, the production rate of the product can be increased, also increasing the reputation of the industry. The objective of the present work is to develop a machine vision system for quality inspection of bearing efficiency. The LabVIEW-based approach is carried out for the implementation in current research work.

Keywords

machine vision system, engine bearings, quality inspection, fault detection, automated system

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Introduction

Today's world is looking for quality products, and supply and demand of such products is increasing drastically. The defective products are not accepted by the manufacturers as that would affect their market value. In order to avoid these problems, inspection of a product

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is required at the final phase of the manufacturing process. The inspection of the product is done either by human power or automated inspection by machine. The quality has become the crucial factor and is an important need for the customer. Product quality is determined at the manufacturing line where quality inspections are made either manually or through some automated systems. If an unprocessed product gets through without a quality check, it may lead to major issues where the industry could even lose the customer and their market value. The unfinished/defective part skipped to the packing session happens mainly because of human error. A survey on the automated inspection system is as follows: Jiang, Tasi, and Wang[1] have developed a system for the Integrated Circuits (IC) marking inspection using gray relation analysis where the performance of the system has proved to be 90 % efficient as compared with the other techniques in the gray scale analysis. Aytekin et al.[2] have proposed various methods with different evaluation criteria being conducted for the case of hexagonal fastener detection in railway routes. Using the evaluation of the performance of the various approaches, a new fused technique has been proposed. This method has been identified to be of low consumption cost. Chen and Wei[3] have explained that in an automated monitoring and inspection system, the sampling process has shown better results compared with theoretical and practical values in an online inspection system. Molleda et al.[4] have proposed a system to detect the transverse section of the rails, where four different laser range finders are used to detect the section of the rails. Here, the system has proved to be accurate as the experimental setup shown is repeatable. Fürtler et al.[5] have developed an image processing system with the help of digital signal processor architecture and field-programmable gate array architecture where the performance of the system is considered using the number of central processing units in the field-programmable gate array core. Liu, Zhou, and He[6] have introduced a technique to detect the status of the bogie block key using the visual inspection system. An integrated cascaded detection approach has been developed to inspect the defect in the bogie block key. The integrated cascaded technology has improved the speed of the visual inspection system. Sathiyamoorthy[7] has given the various types of machine vision systems (MVSs) for the development of automated inspection system, which would help in improving the production and reducing the scrap. Wang et al.[8] have designed a system to drill holes in the printed circuit board with an accuracy of 5 μm, which is drilled in 2.5 seconds. In the paper, the C# code is used to detect a number of 144 sub-images to position the drill for the hole. Ekwongmunkong, Mittrapiyanuruk, and Kaewtrakulpong[9] have given an automated system for the visual inspection system for cut quality in cubic zirconia. In their paper, the cut quality of the gemstone is identified by using three different techniques directly on the detected facets. Park and Kweon[10] have proposed a multiclass classification model to identify the defects of the cell surface. In their work, they developed a system that can detect the cell even under various luminances and various background textures. Gan and Zhao[11] have developed a system for the defect detection in liquid crystal display. A local binary fitting model is introduced to identify the contour of the image. This method has proven to be unsatisfactory for the practical application; therefore, a modified local binary fitting model was developed and was tested for the performance of the system to detect the defects in the liquid crystal display panel.

Based on the mentioned survey, we have found the motivation for the development of the automated inspection system for inspecting the products using the MVS. The error occurs because of unconscious or visual problems when a human is employed to inspect a large number of finished products. For example, in industries, the production rate per shift is 100,000 products, and a shift consists of 7 hours in which a laborer should be able to check 23 parts within a minute. In some cases, because of human nature, inspecting a greater number of products could lead to visual mistakes, leading to unfinished products given on the run. So, in order to eliminate this problem, MVS is used for the inspection of the finished parts. The objective of the proposed work is to develop an automated inspection system that would identify the defects in the product and increase the production rate in the industry. To achieve the objective of the proposed work, an automated system is developed to identify the defects in the bearing. In the present system, the identification of the fault is done using a camera, and image processing technique is used to identify the defect and reject the defective product. It will help in increasing the quality, which in turn will be reflected in the increase in the production rate.

Imaging Technique

The visual inspection is the more reliable and healthier noncontact-type fault detection technique. In order to automate the visual human inspection, a camera and its associated system are used. The camera that is used for acquiring the image is called a machine vision camera, which is mainly manufactured for vision application. The sensors used for machine vision cameras are of two types: charge-coupled device and complementary metal oxide semiconductor (CMOS). Charge-coupled device sensors are costlier than CMOS sensors. CMOS sensors are more reliable and cost less, which makes the visual automation cheaper. The size of the bearing ranges from 4 to 125 mm. The sensor size is very important while going for machine vision application. There are different sensor sizes available in the market such as 4 mm, 6 mm, 8 mm, 9 mm, and 16 mm in diagonal length, and the choice of lens is of the utmost importance. For example, according to the calculation, if the focal length is 8 mm and the sensor size is 1.27 cm, then the lens must be a 1.27 cm lens which is specified in the lens. If a 0.635 cm lens is used, then output image will look like a cropped image where the data can be missed out.

Proposed MVS

The MVS is one of the growing visual automation systems in the industry to enhance the quality of the product. The system consists of different parts that can be listed out as camera, lens, lighting, housing, sensing element, and rejection mechanism, etc. The bearing is the inspection element that moves on a conveyor at the speed of 1.2 seconds/bearing. Once the bearing has been sensed by the sensor, the trigger signal is given to the camera via Hirose cable, and the camera gets triggered and the image is stored in buffer. This image is then transported to the system through a universal serial bus (USB) communication medium. Whenever the image trigger signal is obtained by the system through the data acquisition card, the program will process the image. The processed image is checked for the missing operations. If there are no fault operations, then the bearing is given an "OK" signal. If the processed image consists of certain faulty conditions, then a "NOT OK" signal is given, and the signal is passed to a rejection system, where a pneumatic arm pushes away the bad product for rework or to be trashed.

Figure 1 shows the top view diagram of the MVS, which consists of two cameras: one is to capture the inner diameter of the bearing, and another camera is used to capture the outer diameter of the bearing.

To identify the missing operations in the bearing, concepts of the image processing are adopted. Implementations of new algorithms are done to identify the fault with high accuracy. The algorithm involves filtering, segmentation, and so on. The software used to develop this system is LabVIEW with Vision toolbox, which consists of both acquisition and image processing. Image acquisition is done through NI-IMAQdx file and further processing is done through vision assist. **Figure 2** shows the flow of the process involved in the detection of the missing operation.

Experimental Setup

The automated machine vision inspection system developed is shown in **figure 3**. The inspection of the product is done using the image processing technique in LabVIEW, where Vision and Motion toolbox is used. The image that is captured in the camera is passed to the LabVIEW program with the help of the USB communication.

FIG. 1 Proposed MVS.

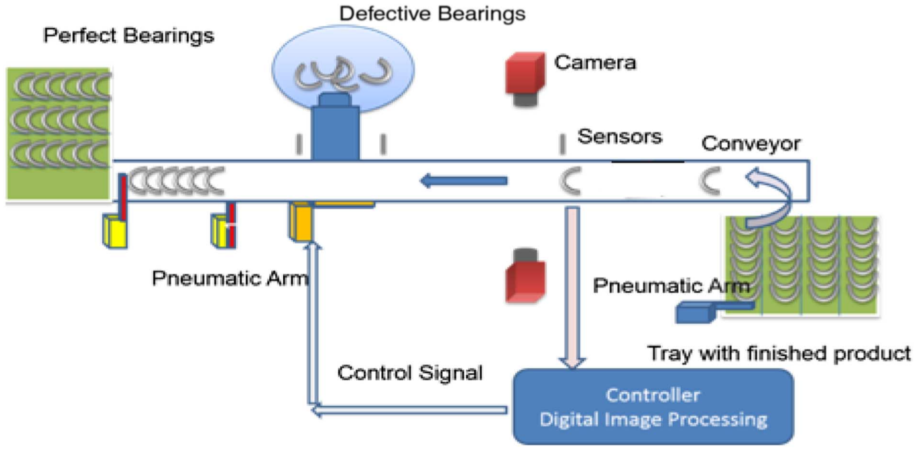


FIG. 2 Techniques involved in the detection of the missing operation.

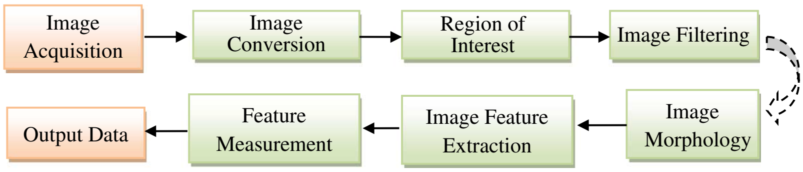
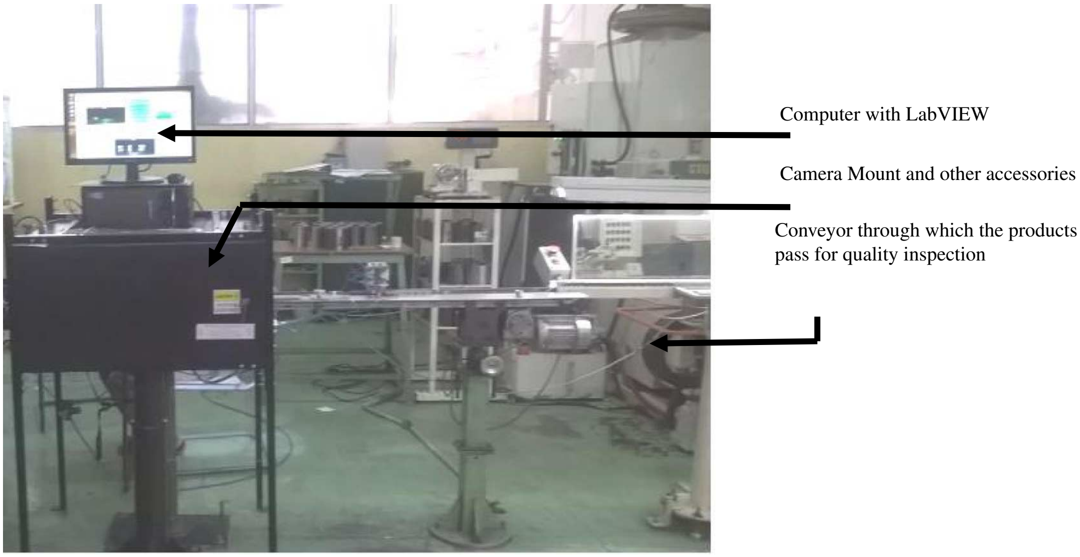


FIG. 3 Automated line with the MVS system in the industry.



The IMAQ-dx tool is used to grab the image into the program. Then the program is executed through the loops, where the different processing techniques for identifying the missing operation are processed. The processed image is checked for the missing operation. In case the product consists of no missing operation, then the system

FIG. 4 Front panel of the automated system when the bearing is passed through the camera.

gives an “OK” signal, and the product is passed for the next operation. If there are any missing operations in the product, the program sends a “NOT OK” signal to the rejection system with the help of the data acquisition system (DAQ), which intiates the rejection to push the defected product, preventing it from passing to the next operation.

The DAQ is a device that is used to convert the physical signal into a digital signal, which is then used to operate or trigger certain devices in the system. A LabVIEW-compatibile DAQ device is used as the signal data from the LabVIEW program. It is given as the input to the DAQ, and the output is given to the other devices such as rejection system. In this propsed system, the DAQ device consists of four input/output analog pins, eight input/output digital pins, and ground and supply pins. The DAQ requires 24 V input to operate. In this proposed system, the central processing unit that is used consists of an i3 sixth generation processor, a 4-GB random access memory, and a 1-TB Sata hard disk with a Windows 8 operating system. **Figure 4** shows the front panel of the image in the automated system.

Results and Discussions

The missing operations are being observed through the image acquired with the help of the camera. The captured image is passed to the LabVIEW through the USB communication, and the image is shown in the front panel graphical user interface of the system. The missing operations such as “HOLE,” “CHAMFER,” “NOTCH,” and “GROOVE” are detected in the bearing. In certain types of bearings, the previously mentioned operations may or may not be present depending on the locomotive and the installation location of the bearing. The bearings are passed through the automated system, which is installed in the production line of the industry.

CHAMFER OPERATION

In **figures 5**–**8**, there are the operations involved in the identification of the chamfer. The bearing, which is inspected to see if the chamfer is missing, will undergo all these steps to ensure the presence of the chamfer in the bearings. The missing of the chamfer in the bearing will lead to the rejection of the bearing from the line for rework.

FIG. 5 Image of bearing inspected for chamfer operation.

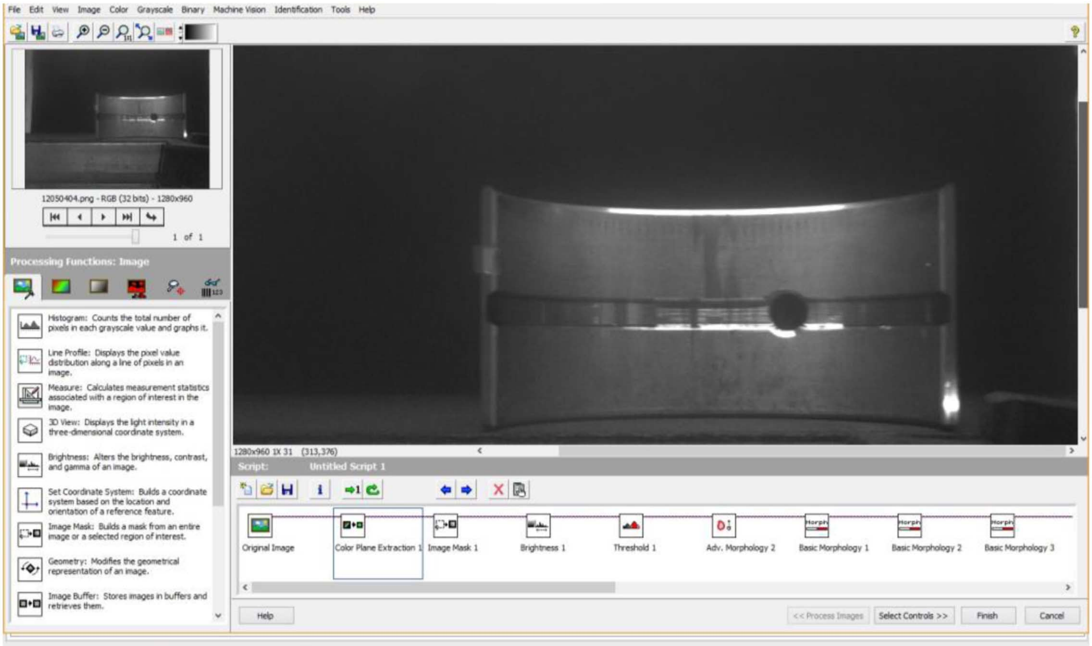
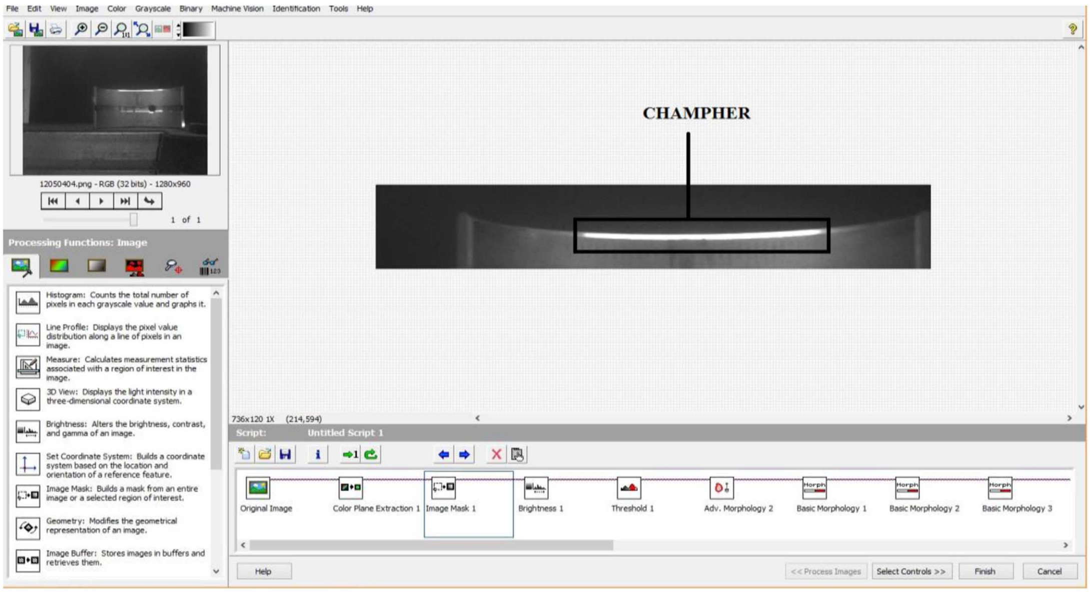


FIG. 6 Cropped image to identify the chamfer.



HOLE OPERATION

Figures 9–12 are related to the identification of the hole in the bearing. The image that is captured is masked to identify the region of interest. Then the image is converted with the help of the threshold where the hole is separated from the other operations. The hole is then processed by the morphological operation, where the hole

FIG. 7 Identification of the chamfer with the help of threshold.

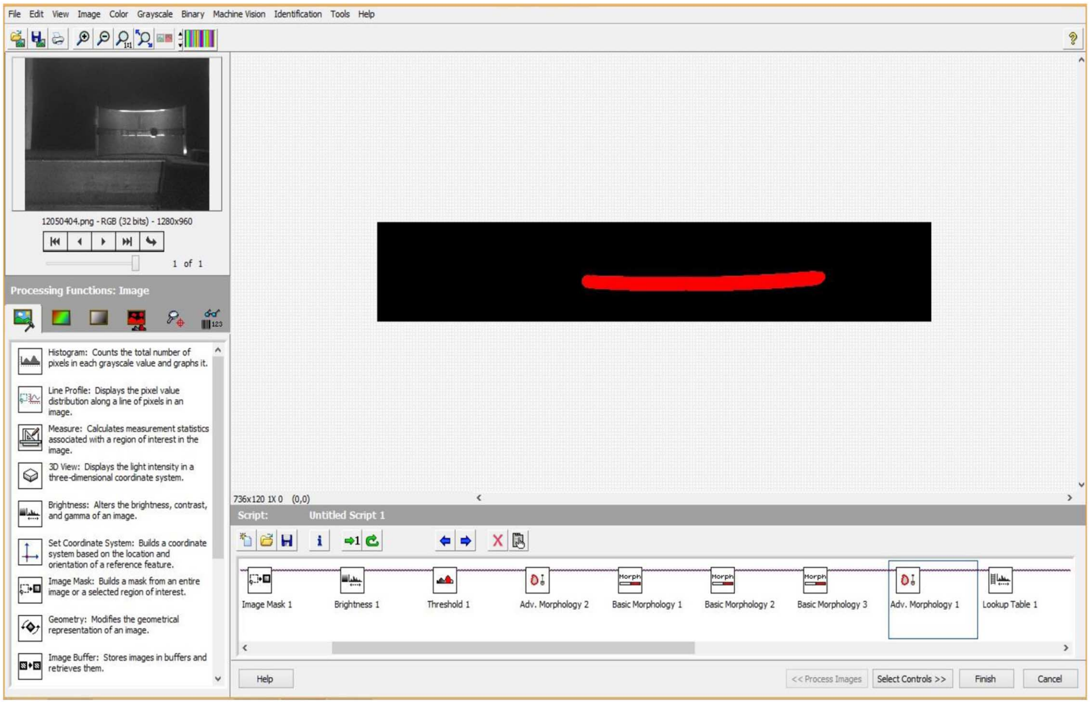


FIG. 8 Measurement of the chamfer to determine if the operations have been successfully done or if there are any miscalculations.

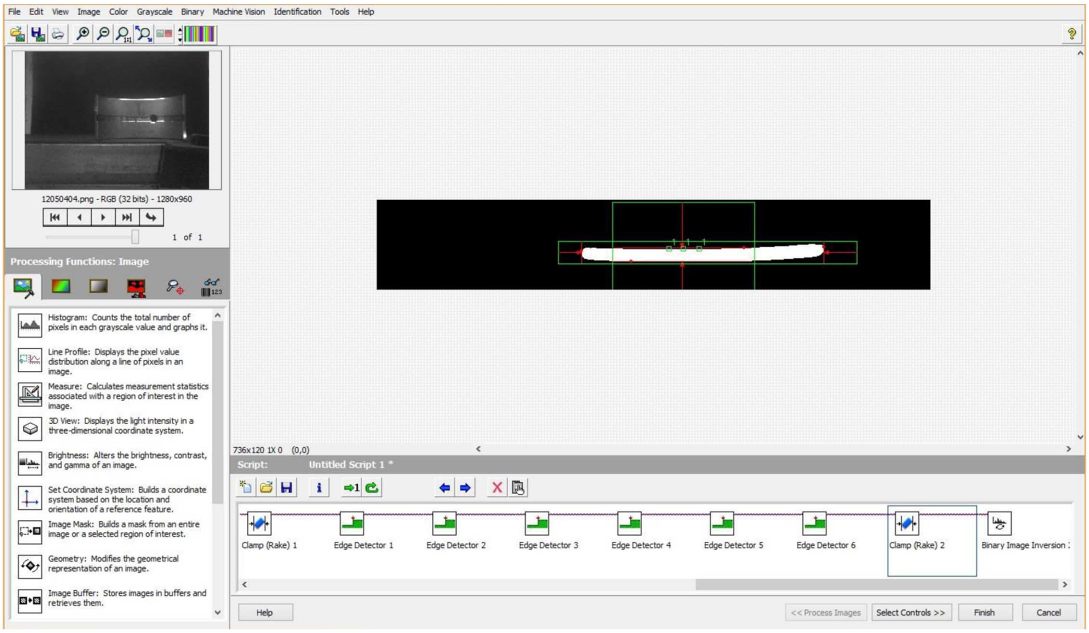


FIG. 9 Masking of the image to identify the hole operation in the bearing.

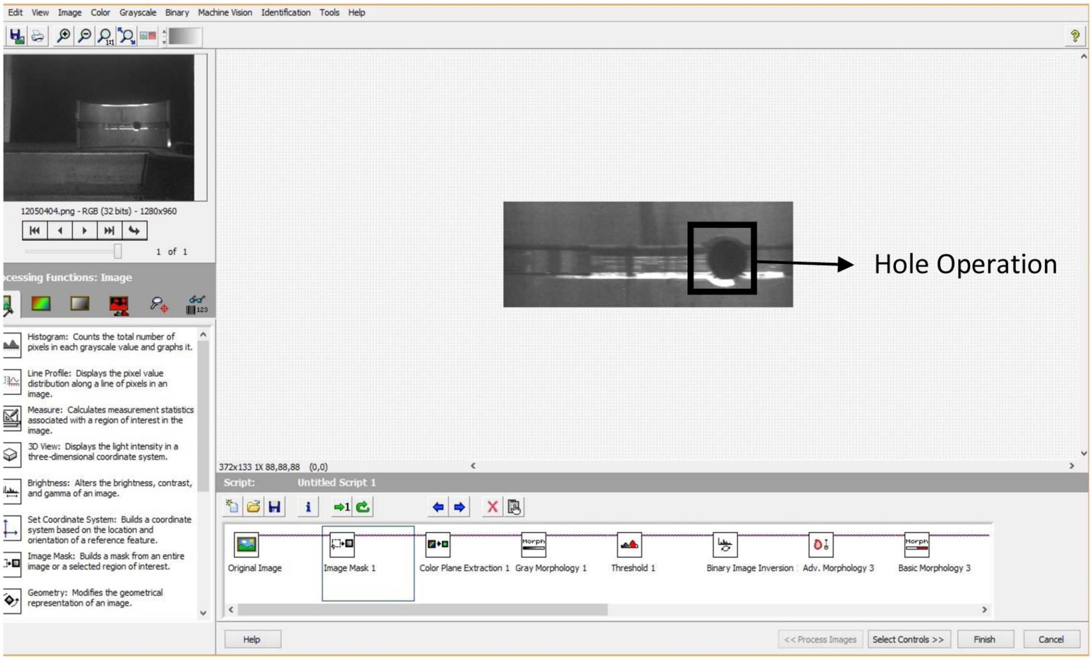


FIG. 10 Masked image is applied with a threshold to identify the hole.

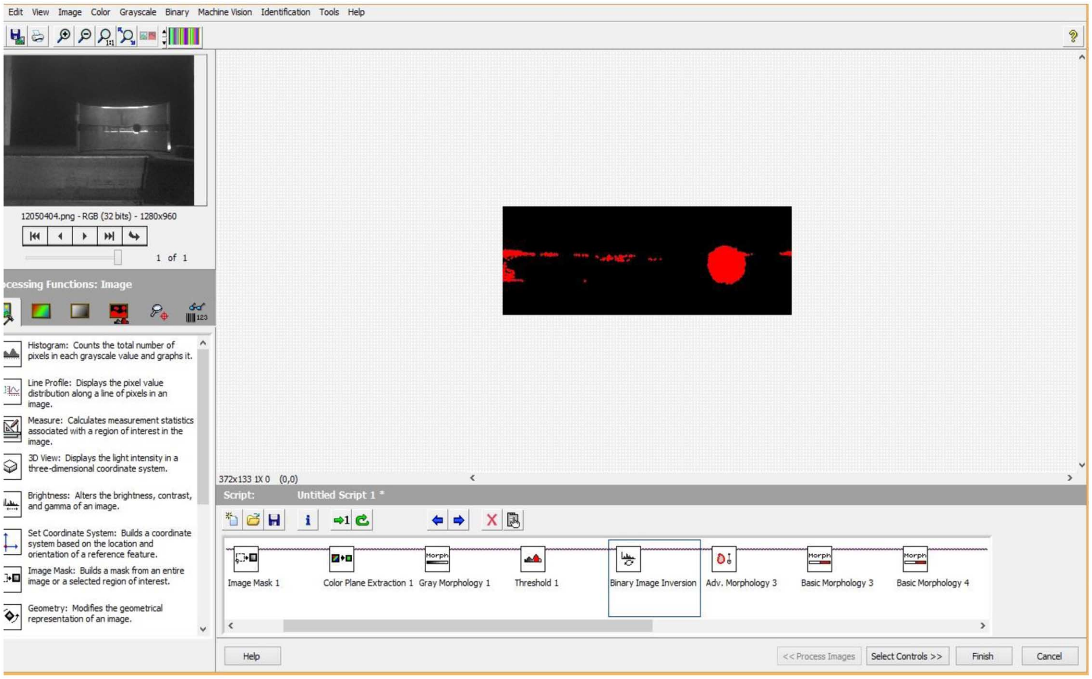


FIG. 11 Image is processed through basic morphology changes to make a perfect circle.

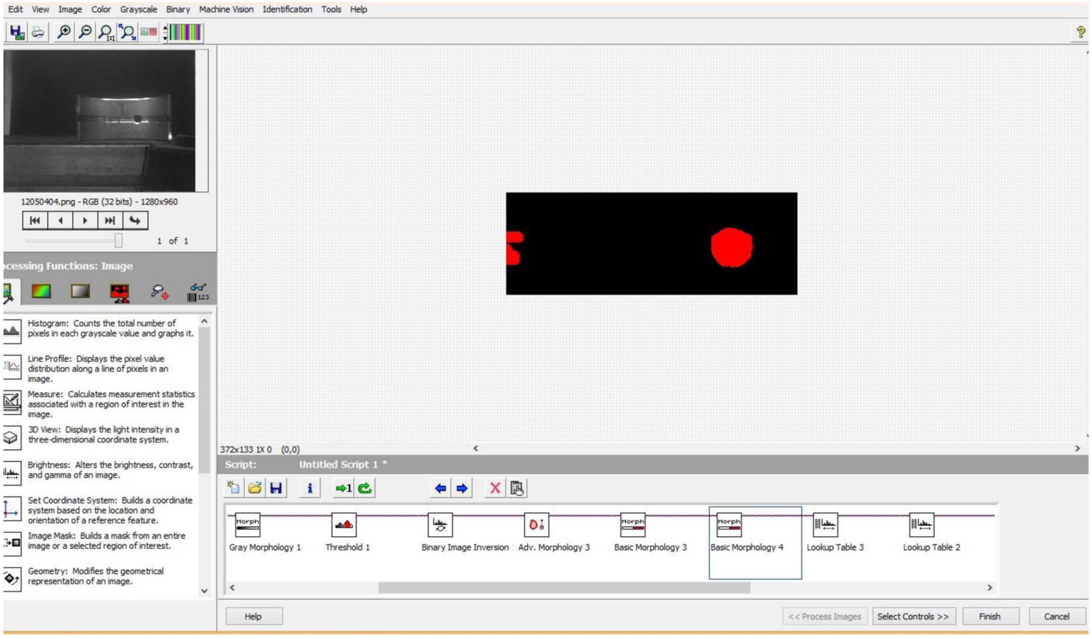
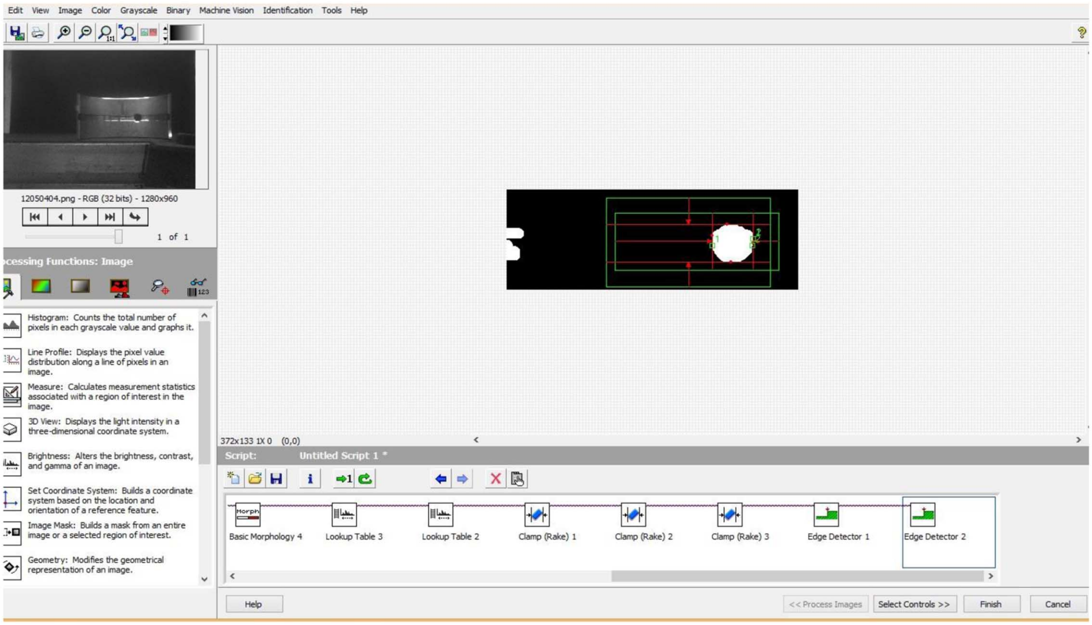


FIG. 12 Edge detection is applied for the circle with the values.



is completed into a perfect circle to mark the edges smoothly. To determine the edges of the hole, edge detection technique is used, and the edge of the hole is marked. The values of the edges are noted and are used in the processing of the hole in the system.

GROOVE OPERATION

The groove is one of the important operations in the bearing. The groove is the part that is used for the oil flow from the oil container to the engine parts. To identify the groove in the bearing, the bearing is first masked based

FIG. 13 Operation to identify the groove in the bearing.

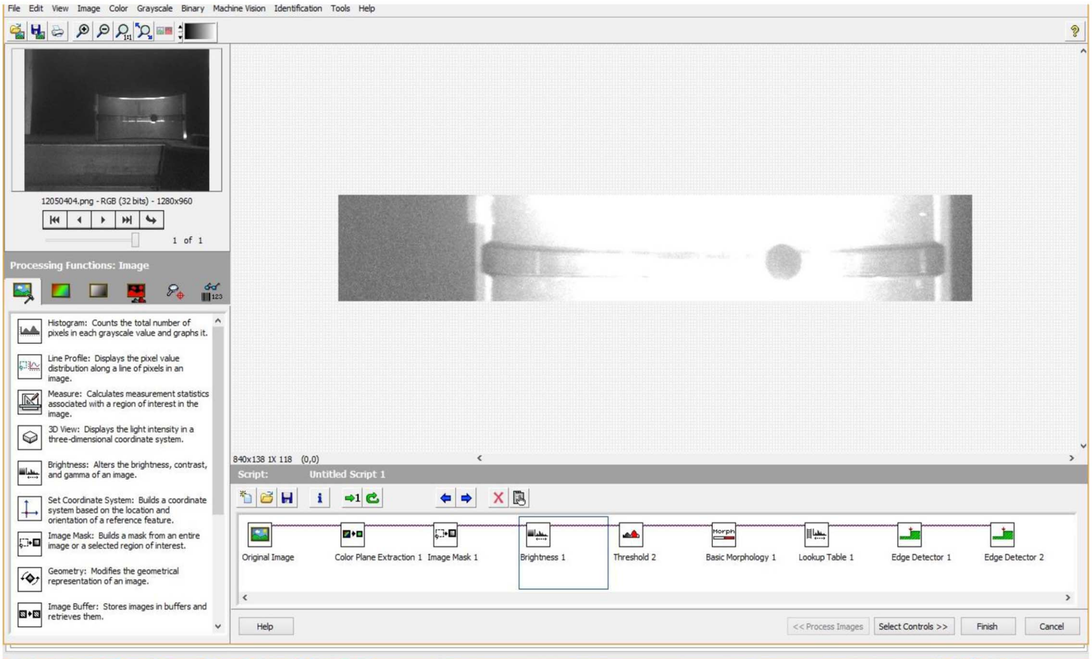
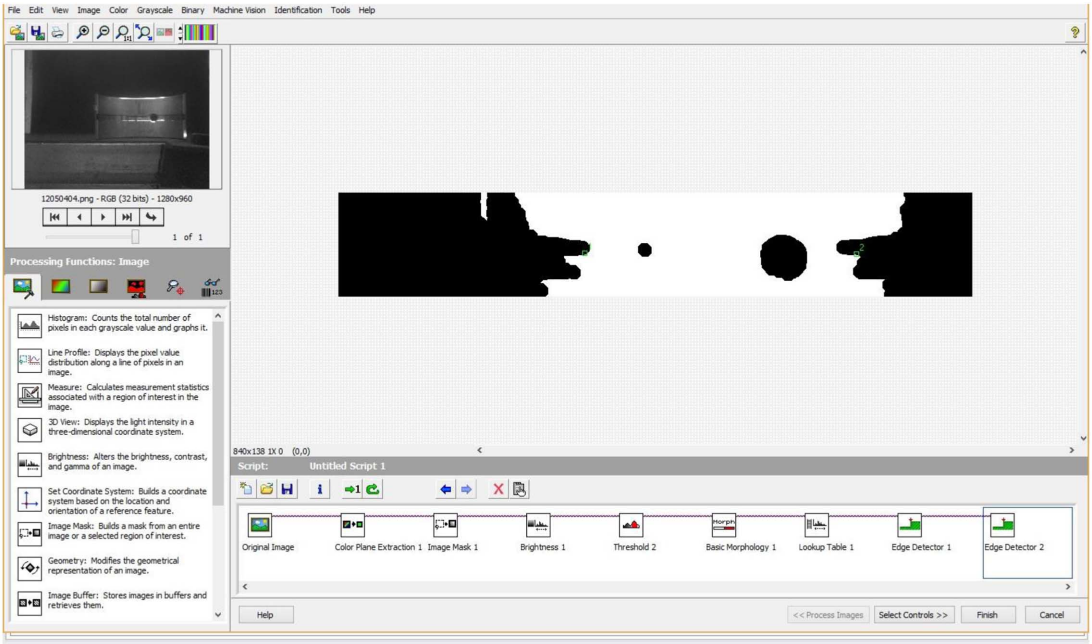


FIG. 14 Edge detection technique to identify the edges of the groove in the bearing.



on the region of interest. Then the image is converted, and the threshold is applied to mark the groove in the bearings. After segregating the groove, edge detection technique is used to identify the groove edges. Figures 13 and 14 depict the operation of the groove

FIG. 15 Masking of the notch from the original image of the bearing.

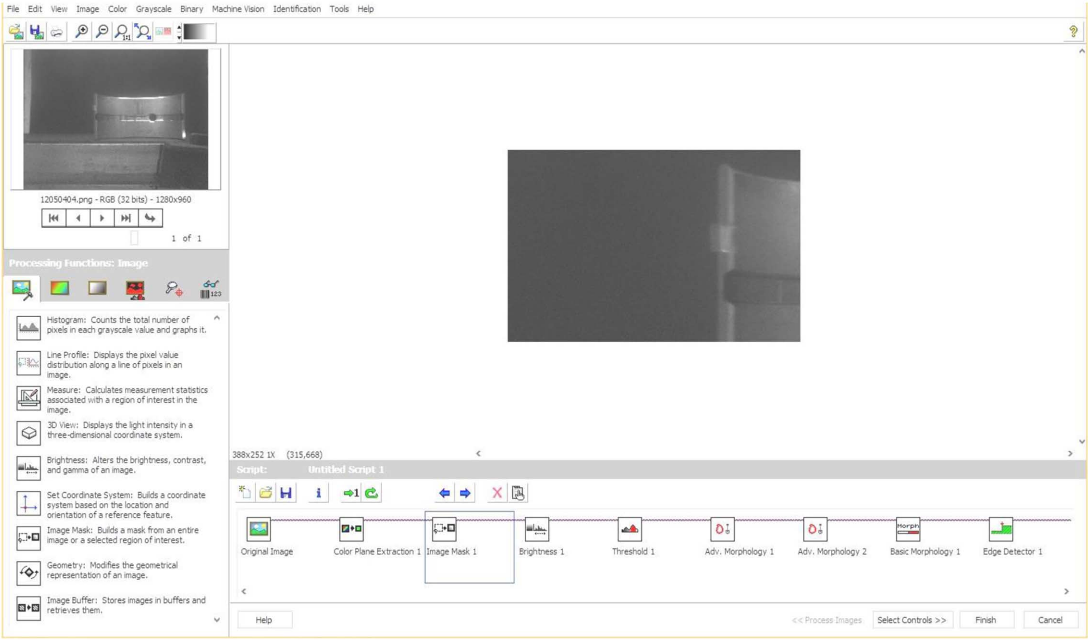
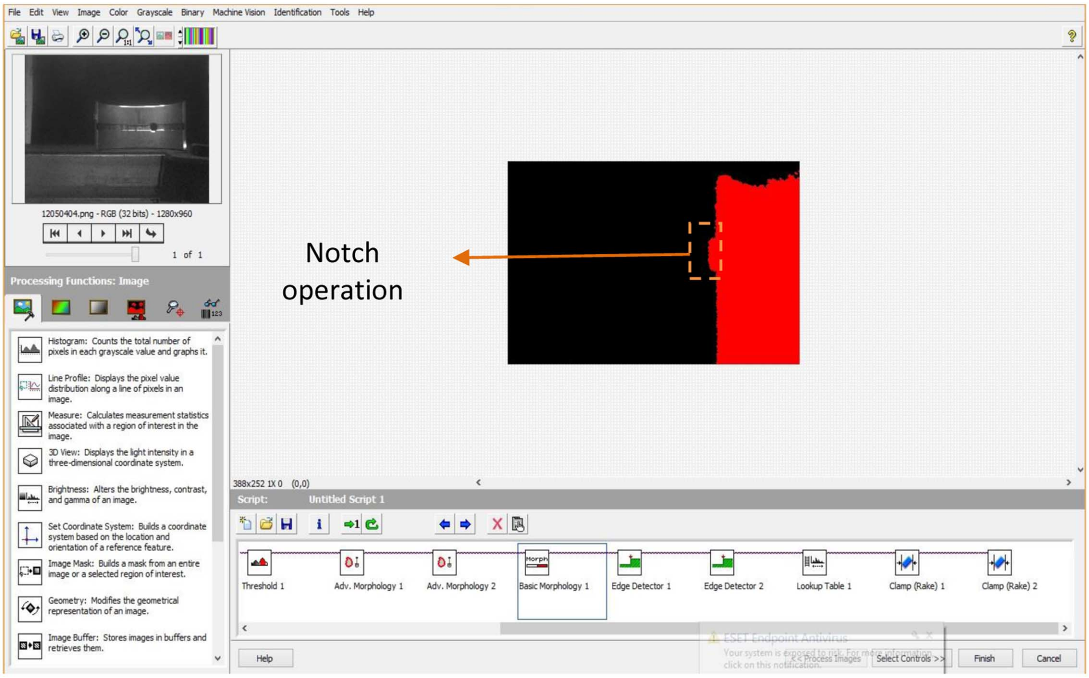


FIG. 16 Notch is separated from the original image using thresholding of the image.



NOTCH OPERATION

The notch is the last operation of the quality inspection of the bearing; the notch is the part in the bearing that is used for the connection with the engine rods. The notch is identified by comparison of the edges of the notch and the edge of the bearing. Figures 15–17 show the detection of the notch from the bearing.

FIG. 17 Detection of the notch by comparing the edge position of the notch with the edge position of the bearing.

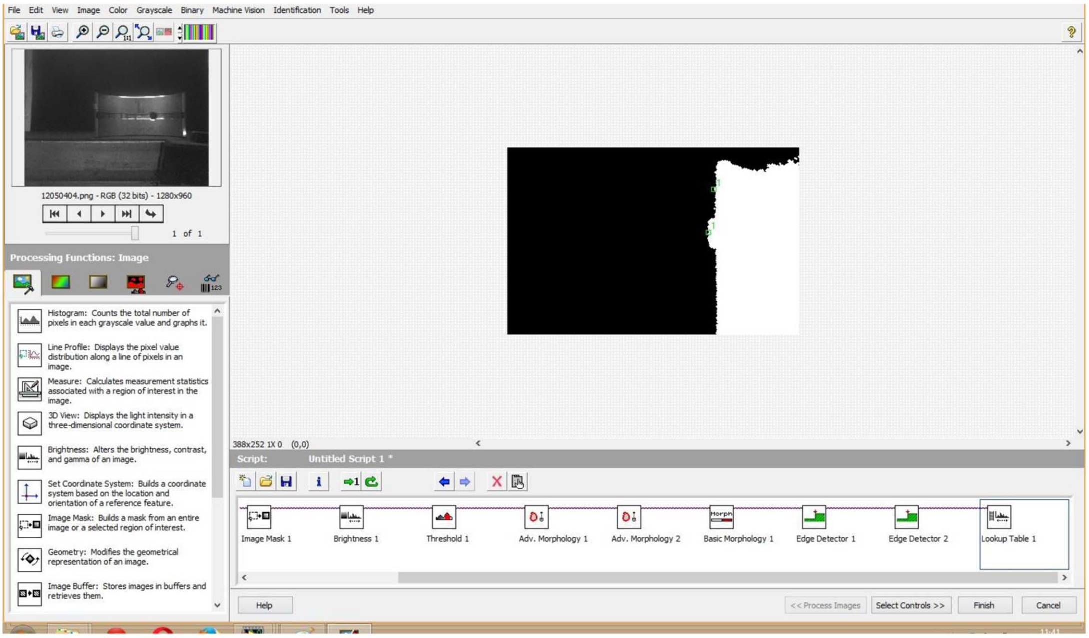


TABLE 1
Inspection time taken and the number of rejections during the inspection in a shift of 8 hours

Description	Time Taken to Inspect the Product per Shift of 8 Hours	Number of Products Inspected in a Shift of 8 Hours	Number of Products Manufactured in a Shift of 8 Hours	% Deficiency in Inspection of the Manufaured Products
Manual process	3.7 seconds	7,783	20,000	61.08
Automated process	1.5 seconds	19,200		4

FIG. 18 Comparison of product inspection per shift in 8 hours.

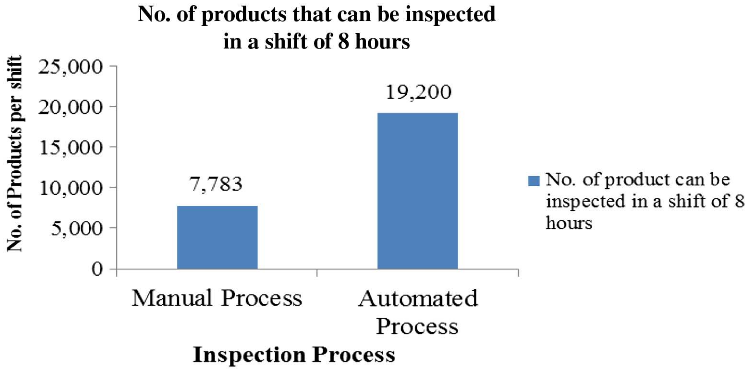
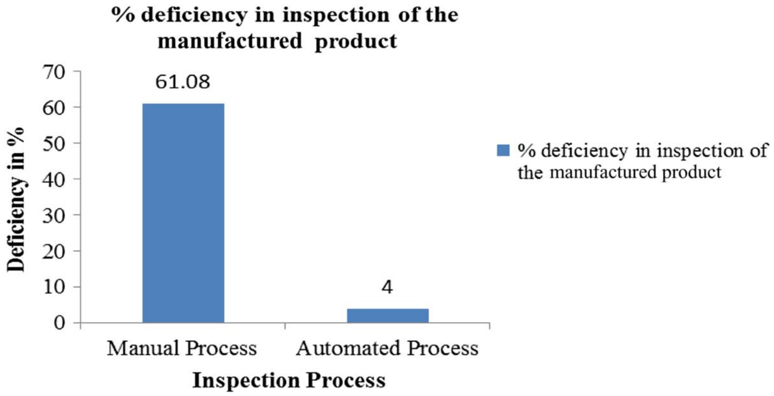


FIG. 19

Deficiency of inspection per shift in 8 hours.



As discussed previously, the four operations of the bearing are tested in the automated inspection system through the camera. The image of the bearing is captured in the production line. The image is then processed by the LabVIEW software to identify the four operations at the same time. As the captured image consists of all four operations, the image is given an "OK" signal, which is passed for the next operation. If any of the bearings is missing an operation such as the hole, notch, groove, or chamfer, the bearing is rejected by the system. **Table 1** depicts the details of the time taken for inspecting one bearing by manual process and automated process and the number of rejections done during the processes. **Figures 18** and **19** depict the comparison of the product inspections and the deficiency in the inspections.

Conclusion

The MVS, which is developed in this work, has shown that the number of products inspected per shift (19,200) is greater compared to the maual inspection (7,783). The number of deficinecies in the inspection process is also less compared to the manual process. Thus, it is proven as the best product with low cost for the quality inspection of the products. The automated system is commisioned and working at the industry to identify the missing operations of the bearings. The previously mentioned results show that the system has better operational outcomes for the bearings.

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