Defects Detection of Cylindrical Object's Surface using Vision System

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Abstract: — This research is aimed to accomplish an automatic visual inspection for the lateral surface of cylindrical objects using cameras and image processing technique. In this paper, the main concern is on the hardware tools that are needed to test the defects of the cylindrical objects and to make comparison between the lines scan and matrix camera. The proposed inspection is carried out with the line scans camera system, matrix camera with conical mirror and multi flat mirrors systems. Previous systems require a suitable hardware setting for inspected object to perform experiments and acquiring images. In this study, the images of the inspected objects will be taken from each system and by processing the images in MATLAB, these images are compared with each other in a specific way, thereby ensuring only the best images will be chosen for the inspection task. The characteristics of each system are considered depending on the final results of the MATLAB graphics produced.

Keywords:- Line Scan Camera, Matrix Camera, Conical Mirror, Multiple Flat Mirrors, Image Processing In MATLAB.

1. Introduction

The finishing surface of industrial parts such as: shafts, bearings, pistons, rings and pins should be smooth within the permissible limits before installation process, as the defects in these parts may damage or reduce the life of machine.

There are several inspections methods that can be divided into two groups: Destructive inspection methods (DT), Nondestructive testing (NDT), depending on the required degree of surface smoothness and the presence of defects in crystalline structure of these parts.

Visual test is one of the famous methods of non-destructive tests. It gives the possibility to detect the defects like: shape defects, corrosions, fatigue cracks and leaks at different stages during the production process, which eventually results in time-savings and lower financial costs. This test can be carried out either by naked eye inspections (not applicable and inaccurate), or by inspections with the use of endoscope, magnifying glass and cameras.

Several researches have been done in the area of automatic visual inspection for testing the surface objects which can be from simple surface like sheets to complex like cylindrical, multi-shape objects. Zhang et al. presented an automatic vision system to detect and classify surface defects due to the processes of grinding and polishing [1]. Omar et al. has provided a system capable of self- adjustment painting booth operation for an automotive fuel tank production, based on the defects detected by automatic inspection system [2]. Jia et al. proposed a real-time visual inspection system that uses vector machine to automatically learn complex defect patterns [3]. Norifumi et al. innovated a new method based on an optics model for highly reliable surface inspection of industrial parts [4]. Sun et al. proposed a real-time imaging and detection system for weld defects in steel tubes [5]. Rosati et al. presented an automatic defects detection for coated plastic component in automotive industry [6].

In this research, line scan and matrix camera system were used to visually inspect the lateral surface of cylindrical object against surface defects.

Line scans camera system, gives the opportunity to perform image acquisition of cylindrical object's surface line by line, while Matrix camera system is suited for text recognition and image processing in one-frame unit. Two systems are designed to inspect the cylindrical objects using matrix camera:
- Camera with conical mirror.
- Camera with multiple flat mirrors.

The images from cameras should be manipulated by image processing programs in order to either improve its pictorial information for human interpretation or for autonomous machine perception [7]. The processing of images in this project has been done using special codes in MATLAB, which stores images as matrices, in order to make these images suitable for utilizing in comparison step between the three systems with a condition that ensure good extracting of features.

2. Line Scan Camera System

A line scan camera is an image capturing device having a CCD sensor which is formed by a single line of photosensitive elements (pixels). The line scan camera should be used in applications where high resolution images are required, and for inspecting the objects which moves like sheet (continuous processing).

The hardware of this system consists of the following parts as illustrated in Fig. 1:

1- Line scan camera with lens: DALSA S2-11-05H40, base camera link with 8 bit with CCD 512 pixels, C-Mount.
2- Holder of camera: maintain the camera in the correct position of object.
3- Holder of object: with capability of rotation using stepper motor.
4- Holder of light: to produce homogeneous light.

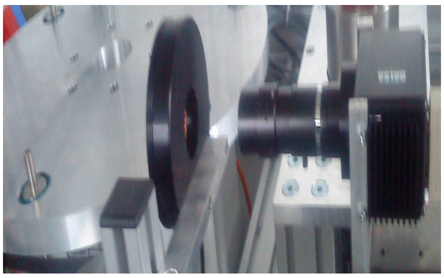
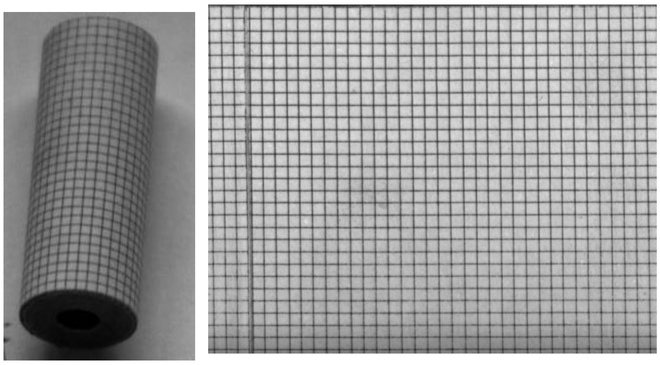


Fig. 1. Line scan camera system

A lot of experiments have been done with different cylindrical objects in height and diameters. The setting of experiment for line scan camera was as follow: The distance between lens and inspected object is 200 mm and the distance between light and inspected object is 150 mm. The lens used is TAMRON 1:3.9 Ø=25.5 mm, focal length=75mm. The image for the object is shown in Fig. 2a. Fig. 2b shows the image by using the line scan camera system.



(a) (b)

Fig. 2. (a) Horizontal and vertical lines pattern on cylindrical object (D=11 mm, H=30 mm). (b) Image acquired of this object by line scan camera.

3. Matrix Camera System

Matrix camera is an array image sensor, which uses a rectangular mosaic of pixels to capture an image. This camera works well to capture the large objects smaller than the field-of-view of a camera. Two experimental setups for performing this inspection system are:

3. 1 Matrix Camera System With Conical Mirror System

The hardware components of this system include the following parts, as in Fig. 3a:-

1- Matrix camera: the camera used for this purpose is JAI CV-M1 with 1300×1030 CCD sensor, C-Mount.
2- Conical mirror: the angle of this cone is 45°, diameter of bottom base is 11mm.
3- Base body.
4- Holder of mirror.
5- Holders of camera.
6- Holders of object.
7- Holders of light

(a) (b)

Fig. 3. (a) Matrix camera with conical mirror system. (b) Close view of conical mirror.

The image of the object in Fig. 2a is shown in Fig. 4 through matrix camera with conical mirror.

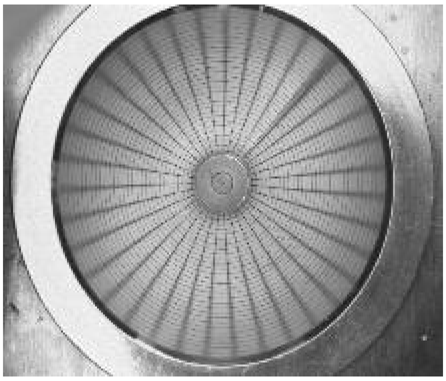


Fig. 4. Image of cylindrical object in matrix camera with conical mirror system.

3. 2 Matrix Camera System With Multiple Flat Mirrors System

The multiple flat mirrors system consists of the following parts as in Fig. 5a:-

1- Matrix camera: the camera is JAI CV-M1 with 1300×1030 CCD sensor, C-Mount.

2- Multiple flat mirrors: five mirrors (50×20×3 mm) supported by holders on the ring using taped glue as in Fig. 5b.

3- Ring with 16 division angle: A range with outer radius=167mm and inner radius=120mm with thickness 15mm) gives us a possibility to divide the range into sixteen sectors (each one can hold mirror).

4- Connection beams: five beams (80×20×8) mm connects the holder of mirrors to ring.

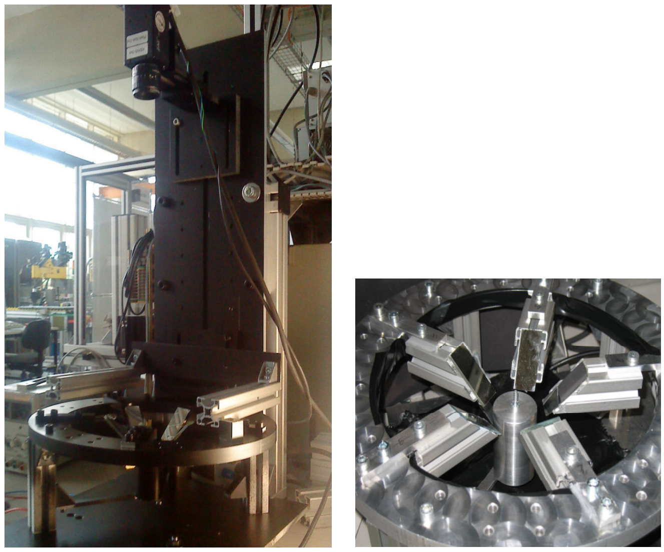
5-Mirror holders it has incidence of 45°.

6- Object holder: cylindrical part with 50 mm in diameter and with 200mm in height is supported in the exact middle of range.

7- Base body.

8- Holders of cameras.

9- Holders of light.



(a) (b)

Fig. 5. Matrix camera with multiple flat mirrors system.(b) Close view of multi flat mirrors.

The resulted image of Fig. 2a is shown in Fig. 6.

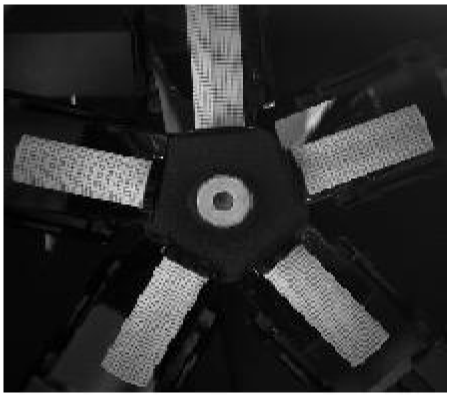


Fig. 6. Image of cylindrical object in matrix camera with multiple flat mirrors system.

4. Comparison of Inspection Systems

It is important to compare the previous inspection systems so as to decide which one is suitable for this project. But it is a difficult procedure due to different view of images taken from these systems, as illustrated in Figs. 2b, 4 and 6. Therefore there is a need to make a graphic model with development view of the three systems, which produce the development in view of producing enormous information for the defects of the objects as shown in Fig. 2b.

4.1 Development View of Matrix Camera's Images in MATLAB

The images from matrix camera with conical and flat mirrors systems have to be manipulated by MATLAB source codes in order to extract the development rectangular view.

4.1.1 MATLAB Algorithm for Image of Matrix Camera with Conical Mirror

MATLAB Algorithm consists of the following three steps:

1. Reading and cropping image by crop image with dimensions x=2*(big radius) and y =2*(big radius). Where, (big radius) is the largest circular line, as in Fig. 4.

2. Transferring of symmetrical rotating lines to normal straight lines: The lateral surface of inspected cylindrical object is shown in Fig. 4 as circular lines. The equation of every circle line is: $x^2+ y^2=r^2$ But this equation generates positive and negative values, and unfortunately, MATLAB image processing can deal only with positive values. Therefore, the circle is divided into four sections as follows:

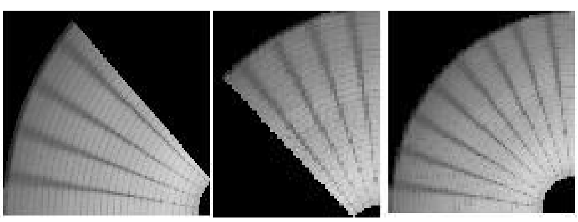
First quarter: $(Sx- x)^2+ (Sy- y)^2= r^2$ (1)

Second quarter: $(x-Sx)^2+ (Sy- y)^2= r^2$ (2)

Third quarter: $(x-Sx)^2+ (y -Sy)^2= r^2$ (3)

Fourth quarter: $(Sx-x)^2+ (y -Sy)^2= r^2$ (4)

Where, (Sx, Sy) is the center of the circle (known). From the above equations, in order to find the value of third variable, the value of two variables should be known. In order to increase the accuracy and avoid squared highest values, every quarter is divided into two sections, as in Fig. 7.

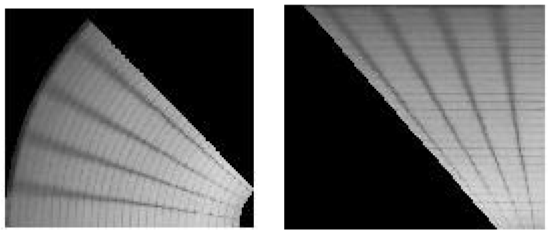


(a) (b) (c)

Fig. 7. Combining the left half (a) and right half (b) to get the first quarter (c).

cylindrical object in a rectangular shape.

Then, every circular line has to be transferred to normal line by using special assignment code in MATLAB.



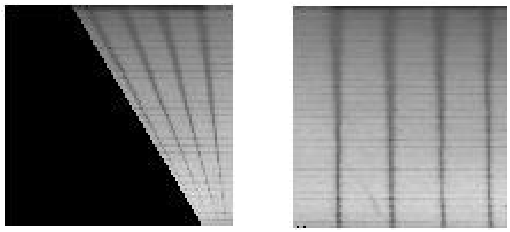
(a) (b)

Fig. 8. Transferring step of circular lines into straight lines.

In the previous step, the outcome straight lines as in Fig. 8b have no similar length. So measuring scale algorithm is used. If the length of lines from the biggest radius is *br* and from smallest radius *sr*, the measuring scale is:

$$ms=br/(br-ir+1) \quad (5)$$

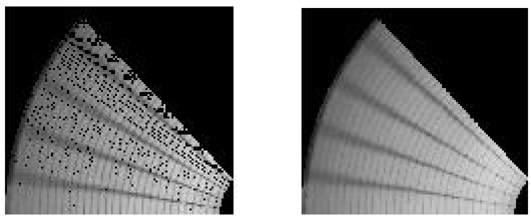
The result is illustrated in Fig. 9.



(a) (b)

Fig. 9. Stretch of lines from (a) to (b) done by MATLAB program

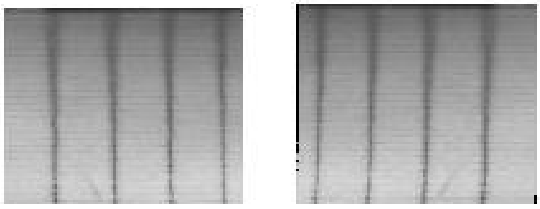
3. Filtration: As the values of pixel's coordinate system must be always integer in MATLAB, approximating values should be gotten for the equations 1-5. Two dimensional order statistic filters were used for this purpose as shown in Fig. 10.



(a) (b)

Fig. 10. The effects of Two Dimensional Order filter (a) Image before filter (b) Image after filter.

Two sections of these quarters must be reflected, as in Fig. 11.



(a) (b)

Fig. 11. (a) Half section of quarter need to reflect (b) Reflecting of this section.

The collections of quarters in one frame are the developed view of matrix camera with conical mirror as in Fig. 12.

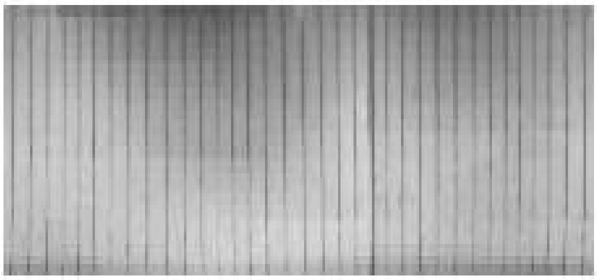


Fig. 12. Development view of object in matrix camera with conical mirror.

4.1.2 MATLAB Algorithm for Image of Matrix Camera with Multiple Flat Mirrors

In order to get image from five partial mirrors system as shown in Fig. 5, initially it should be marked on the base , the global coordinate system (xrf, yrf, zrf) and a partial mirror coordinate system of all mirrors (xi, yi, zi). The camera axes should be focused in the center of object.

The following algorithm is used for manipulating the image in this system:

- Reading, cropping and rotating image for the partial mirrors.
- Capturing the image of object in each mirrors: The axes of partial mirrors should meet each other at the center of object. Due to some deformation in hardware system, some correction in angles of mirrors has been done. The equations used to capture every mirrors image are:

$$x_i = y_i \tan \varphi_i \pm \frac{d}{2} \qquad (6)$$

Where, $\varphi_i = \psi_i + \omega_i$, ψ is constant angle for each mirror and depending on pentagon properties $\psi_{i+1} = \psi_i + 72°$. *xi* and *yi* are the coordinate system of each mirror. ω is the rotational angle of the whole system around the reference image coordinate system, d is diameter of object. Due to the previous captured image from every mirror is in a certain angle, the program makes rotation for this image till vertical direction and then cut the interested captured image, as in Fig. 13.

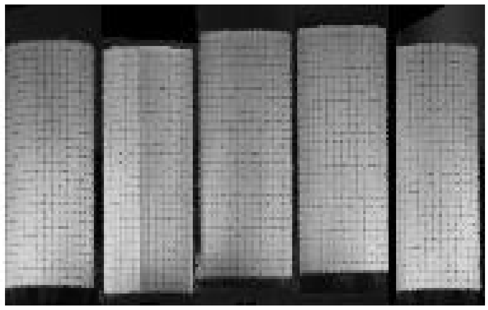


Fig. 13. The five captured partial images of object.

- Registration: Special registration has been done for the partial view of mirrors, regarding to the calculation of equal sides of pentagon with conditions that the center of tested part meets the center of mirrors axes. The capturing width of object in all mirrors is equal to the diameter of the tested part inserted by user and the software program calculates the angles from the first mirror axes, which increased by (360/5= 72°) for second 144° and so on. As the mirrors are supported in ring with 72° between them respectively, the difference between hardware and software measurement is small. The actual width for each mirror is calculated depending on the property of pentagon (with equal sides). The final registration of this tested object is illustrated in Fig. 14.

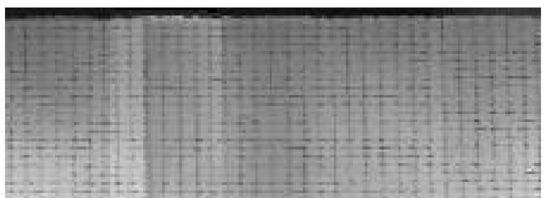
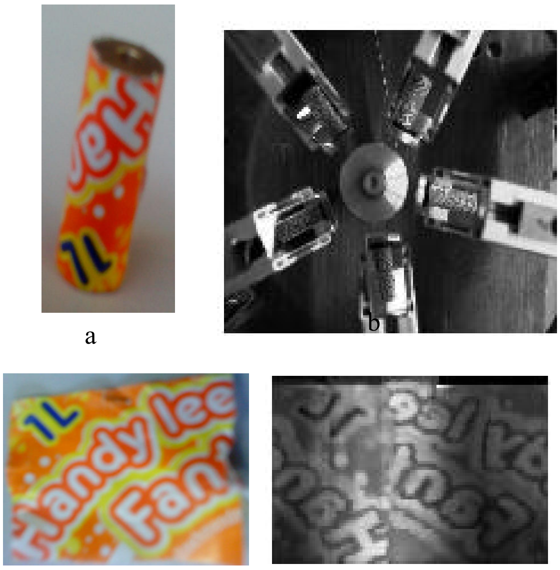


Fig. 14. Development view of registration the partial views of mirrors using program in MATLAB.

The accuracy of the registration between five partial mirrors is shown in Fig. 15.



a b

c d

Fig. 15. (a) Pattern of letters covered cylindrical object. (b) Image from matrix camera with multiple flat mirrors. (c) Cover of the object before supporting on object. (d) Collecting of partial views after image processing.

4.2 Image's Resolution and Accuracy of Systems

A number of experiments have been done for inspecting the objects in these systems. The horizontal and vertical lines pattern object of Fig. 2a is illustrated in line scan camera in Fig. 2b. Similarly, the developed view of matrix camera with conical mirror and five flat mirrors are as shown in Fig. 12 and Fig. 16, respectively. The image resolution of these objects in the line scan camera system seems to be the best in comparison with matrix camera system. The accuracy of image with the effect of non-homogeneous lighting, that acquired by five mirrors is bad and is improved by conical mirrors, but the line scan camera system has the best accuracy. The line scan camera system should be used to inspect cylindrical object with multi-diameters objects, high resolutions in images for inspected object and accurate images without distortions for some applications. The matrix camera should be used in comparison with line scan camera to spare time required for accumulating light and adjusting camera field view, also save power which is necessary to rotate the object in line scan camera. The matrix camera with conical mirror has some advantages over multi flats mirrors system, which is conical mirror system produces full field view of object comparing with multi flat mirrors. On the other side the matrix camera with multi flat mirror system should be used in comparison with conical mirror system to inspect the objects which have different diameters.

5. Conclusion

The comparison between these systems in terms of resolution and accuracy is always significant, depending on the results of the experiments, for the same tested objects. The image of line scan camera image has the best accuracy and best resolution, whereas the developed view of conical mirror has good resolution and accuracy, instead of five flat mirrors, that has good resolution but bad accuracy.

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