

REAL TIME TWO-STEP INSPECTION SYSTEM FOR ASSEMBLED VALVE KEYS IN AUTOMOBILE CYLINDER HEADS

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Abstract

This paper presents a two-step vision-based approach for real time inspection of the assembled valve keys in automobile cylinder heads. In the first step a combination of Sobel edge detector with gradient pair vector method is used for the detection of circular shaped valve keys. This method is very fast but also highly sensitive to noise, resulting in a relatively high percentage of false negatives. The second inspection step employs Canny edge detector with circular Hough transform. The images of the valve keys rejected in the first step pass through the second inspection step. This procedure differentiates between the false negatives and the true negatives. The cylinder heads rejected in the second step are separated afterwards from the main stream of the transportation line. In the statistics obtained, the first inspection step successfully rejected all of the wrongly assembled valve keys. The false rejection rate was around 4.6% of the total number of the valve keys rejected. The second inspection step successfully differentiated between true negatives and false negatives, reducing false negatives to 0%.

Keywords: *Assembled Valve key inspection; Machine Vision; Circle Detection; Two-step Inspection; Real Time Inspection; Vision Based Inspection.*

1. INTRODUCTION

The valve key inspection is a very important part in determining the correct assembly of an automobile

cylinder head. A laser check station is employed for this purpose in automobile assembly plants.

Laser beams are used to scan valve keys and changes in the reflected and transmitted beam are used to identify defects in the valve key assembly. The acquisition and processing of 3-D data allows improved methods of valve key identification, localization, and inspection [1]. The laser inspection station consists of a laser source in combination with a CCD-imaging device to provide accurate three-dimensional measurements [2].

Implementation of the vision solution for the identification of the assembled valve keys is the step towards the replacement of the slow and expensive laser check solution.

Our task is to detect circular-shaped valve keys in the images. The Circular Hough transform (CHT) [3] is one of the best-known algorithms and aims to find circular shapes within an image. The large amount of storage and computing power required by the CHT are the major disadvantages of using it in real time applications.

The need for using a two-step approach emerges from the constrained industrial environment, where usually cameras with built-in processors and memory units are used for inspection. The real time inspection require methods to be fast, whereas the higher demand for improved quality control needs more reliable and robust inspection methodology. To meet the seemingly complementary goals simultaneously, we use a two-step inspection system. The first step uses Sobel edge detection with vector gradient method [4] for valve key inspection. This method is fast but not so robust against noise. We use high threshold values at this stage to ensure that there are no false positives. In the second step

we use Canny edge detection with circular Hough transform to inspect the rejected valve key's images. Since the rejection rates at the first step are quite low (about 2.54 %), the computation for the second step can be done at a remote station.

The operation of the two steps is explained along with the camera calibration procedure in section 2. Section 3 presents some results obtained by testing our system. Section 4 concludes the paper by giving an overview of the methodology used and the results achieved.

2. METHOD

2.1 Camera Calibration

When optical systems are used for measurement, modeling the entire process of image formation is decisive in obtaining accuracy. A camera in an optical system can be considered as a device that performs a linear projective transformation from the projective space \mathbf{P}^3 into the projective plane \mathbf{P}^2 . We use the pinhole camera model since it can accurately represent the geometry and optics of most of the modern Vidicon, CCD, and CID cameras [5].

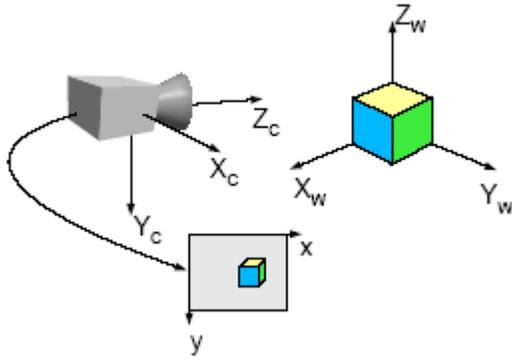


Figure 1: Coordinate systems used for camera calibration

Modeling the projection process consists of transforming point coordinates from world coordinates $\mathbf{p}_E^w = (x_w, y_w, z_w)^T$ to camera coordinates $\mathbf{p}_E^c = (x_c, y_c, z_c)^T$, and then from camera coordinates to image coordinates $\mathbf{p} = (x, y)^T$ as shown in Fig. 1. Using the homogeneous coordinates, the transformation from the world coordinate system to the camera coordinate system can be written as a projection matrix \mathbf{T} as

$$\begin{bmatrix} \mathbf{p}_E^c \\ 1 \end{bmatrix} = \mathbf{T} \begin{bmatrix} \mathbf{p}_E^w \\ 1 \end{bmatrix}$$

The 4x4 matrix \mathbf{T} contains the extrinsic parameters of the camera:

$$\mathbf{T} = \begin{bmatrix} \mathbf{R} & \mathbf{t} \\ \mathbf{O} & 1 \end{bmatrix}$$

The vector \mathbf{t} and matrix \mathbf{R} describe the position and orientation of the camera respectively with respect to the world coordinate system. Since we are inspecting a planar surface parallel to the camera retinal plane, we choose our world coordinate system such that the object under inspection lies in the xy -plane of the world coordinate system. So the camera coordinate system is calculated from the world coordinate system using only a translation t_z in the z -direction, i.e. $\mathbf{t} = (0, 0, t_z)^T$. Hence the matrix \mathbf{T} can be written as

$$\mathbf{T} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & t_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

We have used $t_z = 495$ mm for our inspection setup. The focal length f of the camera was 50 mm. Since the diameter of the valve key under inspection is known, we can use this information to calculate intrinsic camera parameters. Two sample points are taken on the object and their distance in pixels is measured in the image. This gives us the mm-to-pixel ratio of 0.067 mm/pixel. The relationship between image coordinates and intrinsic camera parameters is given as

$$x = -c_x x_c + x_0$$

$$y = -c_y y_c + y_0$$

Where

$$c_x = \frac{d_i k_x}{t_z}, \quad c_y = \frac{d_i k_y}{t_z}$$

Where k_x and k_y are the horizontal and vertical scale factors respectively, with units of pixels/mm, (x_0, y_0) is the center point of the image, and d_i is the image distance from the lens center ($d_i \approx f$, for $d_o \gg d_i$). Using $x_0 = 320$ pixels, and $y_0 = 240$ pixels, we get $k_x = k_y = 142$

pixels/mm. Once the intrinsic camera parameters are known, we can use it for measuring planar objects. Secondly, we also obtain a fixed radius to be searched in Hough-space as explained in section 2.2.3.

2.2 Valve Key Inspection

The first task after obtaining the images from the camera is to inspect the valve key in each image. An image of the engine cylinder head containing the valve key is shown in Fig. 2(a). The first inspection step consists of Sobel edge detection followed by gradient pair vector method for circle detection. This method behaves poorly in the presence of noise resulting in a higher number of false detections. Therefore we have employed second step to separate true negatives from false negatives. This task can be subdivided into following procedure.

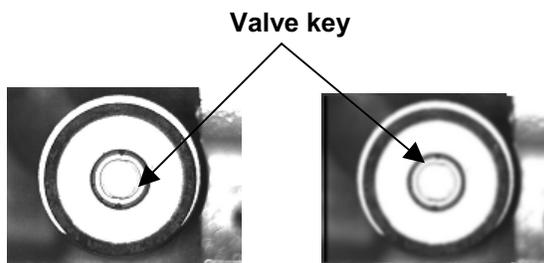


Figure 2: An image of the valve from top (a) The original image (b) Gaussian smoothed image

2.2.1 Gaussian Filtering: Smoothing the image is accomplished by using a 2-dimensional isotropic (*i.e.* circularly symmetric) Gaussian smoothing filter of the form

$$G(x, y) = g(x)g(y)$$

where,

$$g(\varepsilon) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{\varepsilon^2}{2\sigma^2}} ; \varepsilon \in (x, y)$$

We have used Gaussian filtering since it provides gentler smoothing and preserves edges better than a similarly sized mean filter. A discrete approximation to Gaussian was used with $\sigma = 1.0$ using a 5x5 convolution mask.

The result of applying the Gaussian smoothing to the valve key image is shown in Fig. 2(b).

2.2.2 Edge Detection: We use Canny edge detector due to its high robustness against noise in the image. The result of applying Canny edge detector to the Gaussian smoothed valve key image is shown in Fig. 3(a).

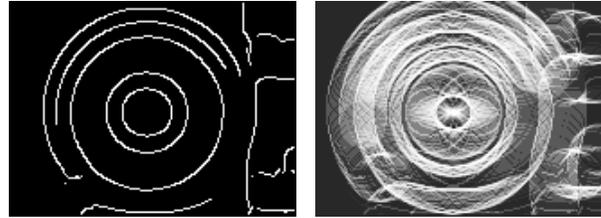


Figure 3: (a) Edges detected by Canny edge detector (b) Transformed image in the Hough-space

2.2.3 Circular Hough Transform: The edge-enhanced image obtained from the Canny edge detector is used to calculate the circular Hough transform. Since we know the radius of valve shaft in pixels, we can restrict our parameter domain from 3 dimensional (x,y,r) to 2 dimensional (x,y) . The transformed image in the Hough-Domain is shown in Fig. 3(b). Histogram equalization is used to enhance the image contrast. Finally we do peak detection to find the best candidate for the center point of the circle. The decision for the acceptance or rejection of the valve key assembly under inspection is based on the number of votes received by the best candidate.

3. EXPERIMENTAL RESULTS

3.1 Results Evaluation from the First Inspection Step

Our two-step vision inspection system was implemented at an automobile cylinder head assembly line under production conditions. The statistical results obtained after using our first step visual inspection are given in table 1.

Table 1: Result comparison between first step of vision based inspection and laser check

Camera Number	Total valve keys Inspected	Positive detections		Negative detections	
		Laser	Vision	Laser	Vision
1	13,935	13,597	13,580	338	355
2	13,935	13,598	13,582	337	353

A total of 27,870 valve keys were investigated on 4645 cylinder heads during testing. High values of thresholds used at the first stage successfully rejected all of the wrongly assembled valve keys. Hence the false acceptance rate was reduced to 0%. There were a total of

33 false negative investigations done by the first step of vision check as compared to the laser check. The main reasons behind false negative investigations include excessive oil on valve key surface, irregularities in tappet surface smoothness, and presence of external objects.

3.2 Results Evaluation from Second Step Inspection

All true negative detections are categorized into three types; no valve assembly present, one valve key present, and others. One example from each category is shown in Fig. 4. These pictures along with false negative detections are then investigated with our second step of vision inspection comprising Canny edge detector and Hough transform.

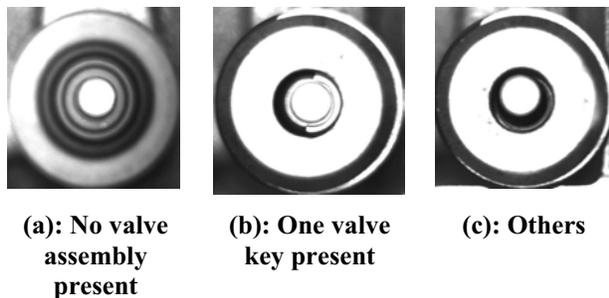


Figure 4: Different causes for first-step rejections

We used a high threshold value for Canny edge detector. In cases where no valve key assembly was present, the image gradients in the region of interest were not strong enough to produce an edge. Therefore the largest source contributing to about 88% of the total rejections was successfully identified. Circular Hough transform, based on the number of votes obtained identified the other two cases. The statistics obtained on the number of votes received by the best candidate in each image are as shown in table 2.

The thresholding on the number of votes successfully reduced the false negative detection to 0% while keeping true negative detections at their current level.

4. CONCLUSION

In this paper we have presented a vision-based two-step approach for the inspection of the assembled valve keys. State of the art laser based inspection systems are very expensive and slow in response. Our approach aims at replacing the current laser based inspection with vision-based inspection.

In the first inspection step, all the wrongly assembled valve keys were correctly detected. The false rejection rate, however, was 4.6% of the total number of rejected

Table 2: Statistical analysis of number of votes obtained from the Second Step Inspection

	True Negatives Detection			False Negative Detections
	No Valve Assembly	One Valve Key missing	Other reasons	
No. Of Images	623	3	50	33
Mean (Votes)	20.3	66.7	59.74	138.15
Median (Votes)	22	71	58	133
STD (Votes)	14.04	9.88	7.69	29.64

valve keys. The main reasons for false rejections by the first inspection step are production environment (oil, dirt etc. on valve key surface), tappet surface condition, and camera trigger timing. Using a high threshold for Canny edge detector in combination with circular Hough transform, the second inspection step successfully differentiated between true negatives and false negatives, reducing false negatives to 0%.

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