Pose Estimation using 1D Fourier Transform and Euclidean Distance Matching of CAD Model and Inspected Model Part

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Abstract. This paper present pose estimation relation of CAD model object and Projection Real Object (PRI). Image sequence of PRI and CAD model rotate on z axis at 10 degree interval in simulation and real scene used in this experiment. All this image is go through preprocessing stage to rescale object size and image size and transform all the image into silhouette. Correlation of CAD and PRI image is going through in this stage. Magnitude spectrum shows a reliable value in range 0.99 to 1.00 and Phase spectrum correlation shows a fluctuate graph in range 0.56 - 0.97. Euclidean distance correlation graph for CAD and PRI shows 2 zone of similar value due to almost symmetrical object shape. Processing stage of retrieval inspected PRI image in CAD database was carried out using range phase spectrum and maximum magnitude spectrum value within $\pm 10\%$ tolerance. Additional processing stage of retrieval inspected PRI image using Euclidean distance within $\pm 5\%$ tolerance also carried out. Euclidean matching shows a reliable result compared to range phase spectrum and maximum magnitude spectrum value by sacrificing more than 5 times processing time.

1. Introduction

Today advanced manufacturing industry, all produce product was design in 3D model using design software such as Solidworks, Catia, AutoCAD and etc. Product design paperwork also included part specification tolerance that is covered in inspection stage. To simplify inspection task in manufacturing industry, new approach in increase effectiveness of product cycle process and time in inspection stage, bridging of CAD model and inspected object parts in machine vision inspection is introduce.

In production line, the produce product such as metal casting part is located randomly before inspection process. Conventional method needed an experience human inspectors to align all the parts for pre inspection process. However, by obtain pose of the parts and direct inspection using machine vision inspection can reduce inspection processing time and eliminate technical error in pre inspection process. This paper is concerned with the problem of pose estimation of metallic surface part before inspection using shape analysis machine vision technique.

Various shape descriptors exist in the literature, mainly categorized into two groups: contour-based shape descriptors and region-based shape descriptors. Fourier representation is propose in many

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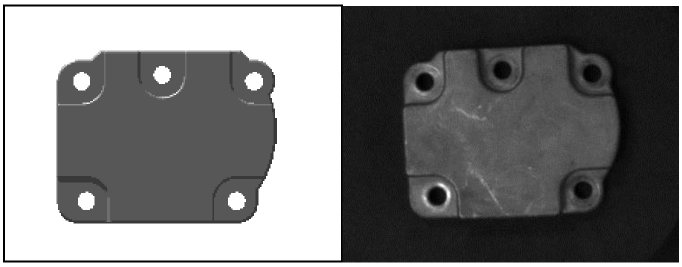
literature of shape analysis and representation as in [1], [2], [3] and [4]. Fourier representation is define as low computation complexity is an important characteristic of a desirable shape descriptor. For a shape descriptor, low computation complexity means minimizing any uncertain factors that are involved in the derivation processes [1]. If a shape descriptor has a hierarchical coarse to fine representation characteristic, it can achieve high level of matching efficiency. Besides that, processing time is also put into consideration in selection of shape representation method. Thus, global contour based shape representation using 1D Fourier Descriptor and Euclidean distance matching method is propose.

2. Methodology

This experiment involves three major stages. Image processing was executed in Matlab 2013a platform. The input image size of 560x420 in bmp file for CAD model, while PRI image size is 1280x960 in tif file.

Stage1: Image Acquisition System, the image of metal casting part is first captured by using CCD camera in office ambient environment in 10 degree interval rotating at z axis. Capture CAD model rotating simulation in 10 degree interval rotating at z axis. Figure 1 a) shows metal casting parts and b) shows CAD model of that part.



(a) (b)

Figure 1. a) input CAD model of casting part and b) input image for real object of casting part

Stage 2: Pre-processing, the interested object part in sequences image of CAD model and PRI is rescale at same scale and size. After that, all images were transform into silhouette image as shown in Figure 2 and Figure 3. Feature extraction using 1D FD and correlation for both condition and kept in database. For the input sequence x and its transformed version X (the discrete-time Fourier transform at equally spaced frequencies around the detected boundary pixels), the two functions implement the relationships shown in equation (1),(2) and (3). In these equations, the series subscripts begin with 1 instead of 0 because of Matlab vector indexing scheme start with 1.

$$X(k+1) = \sum_{n=1}^{N-1} x(n+1) W_N^{kn} \tag{1}$$

$$x(n+1) = \frac{1}{N}\sum_{k=0}^{N-1} X(k+1)W_N^{kn} \tag{2}$$

where

$$W_N = e^{(-2j\mu)/N} \tag{3}$$

is an Nth root of unity

Correlation coefficient between CAD and PRI image were computes in defining pose information relationship for both CAD and PRI image as shown in equation (4). Both CAD and PRI image is in same size.

$$r = \frac{\sum_m \sum_n (A_{mn} - A)(B_{mn} - B)}{\sqrt{(\sum_m \sum_n (A_{mn} - A))^2 (\sum_m \sum_n (B_{mn} - B))^2}} \tag{4}$$

where $\bar{A}$=mean(A) and $\bar{B}$=mean(B)

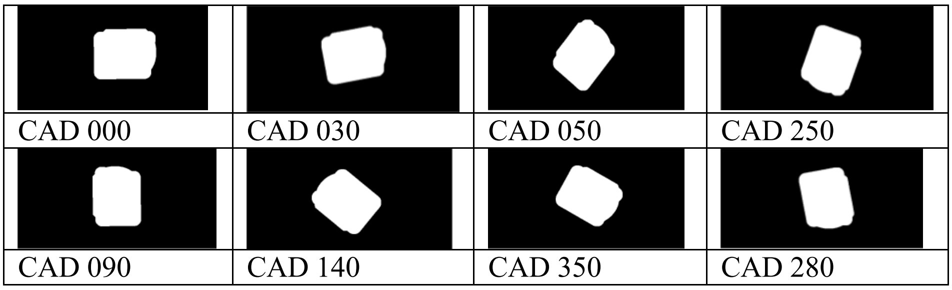


Figure 2. Few pre processing image for CAD model

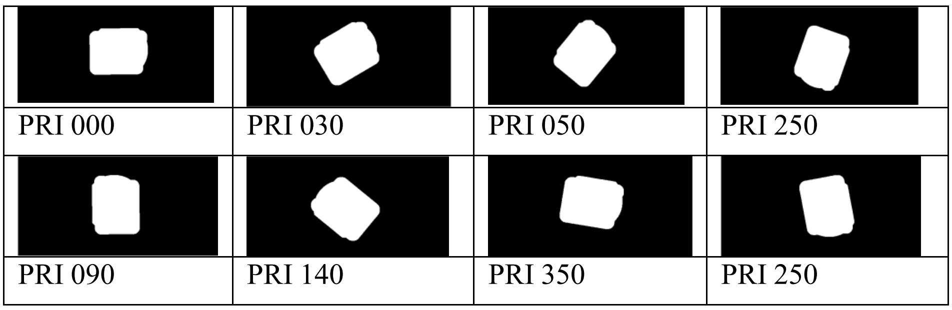


Figure 3. Few pre processing image for PRI model

Figure 4 shows flowchart for CAD and PRI in pose estimation pre-processing stage using Fourier descriptor extraction.

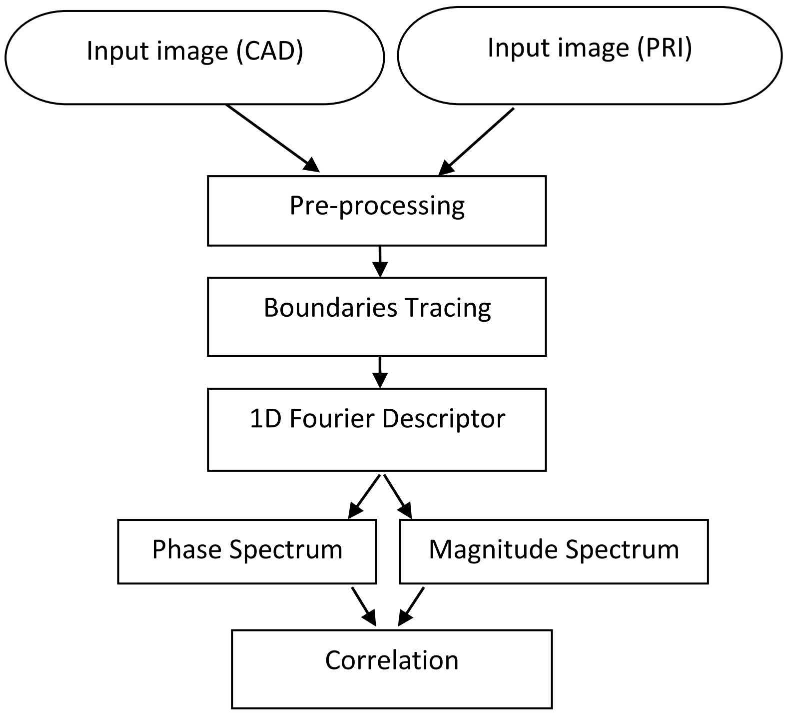


Figure 4. Flowchart for CAD and PRI in pre-processing stage

Stage 3: Processing, inspected PRI image pose was retrieved using maximum magnitude and range phase information from the CAD database within $\pm 10\%$ tolerance as shown in Figure 5.

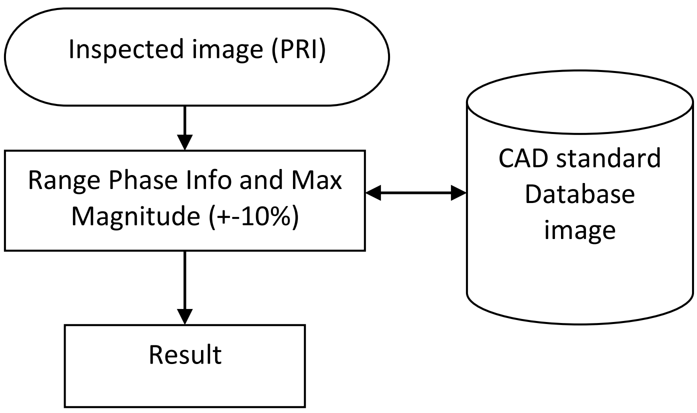


Figure 5. Image processing flowchart for pose estimation relationship of CAD and PRI image range phase info spectrum and max magnitude spectrum

Second method in inspected PRI image retrieval is using Euclidean distance matching is obtained within $\pm 5\%$ tolerance. Euclidean distance equation as shown in (5). Figure 6 shows image processing flowchart for pose estimation matching of CAD and PRI image using Euclidean distance method.

$$\textit{Euclidean Distance} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad (5)$$

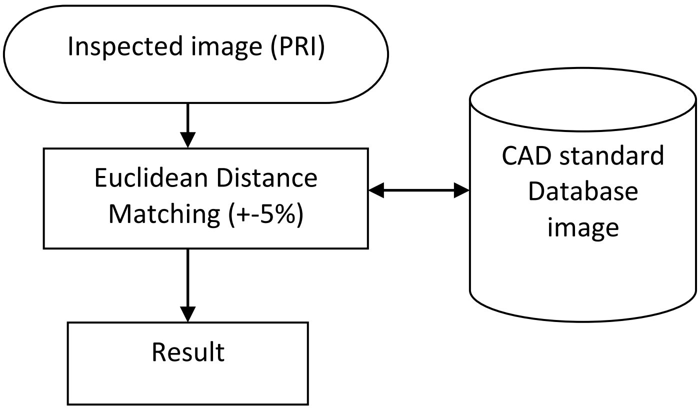
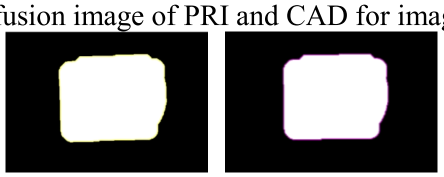


Figure 6. Image processing flowchart for pose estimation relationship of CAD and PRI image using Euclidean distance

3. Result and Discussions

Figure 7 shows diffusion image of PRI and CAD model for scale alignment. Scale alignment of these image is by calculating white area ratio of CAD and PRI. Using this ratio value, CAD image is resize to align white area in PRI image for further image processing. Figure 8 shows boundary tracing for a) PRI image and b) CAD image. Figure 8 a) is 000 PRI image and closer look at the figure, the straight line in this figure is not truly a straight line compare to 000 CAD in Figure 8 b). The inspected part of PRI have fillet connected at the top surface and the side object. The inspected part object is a dull metallic and the illumination during acquisition allow capturing inconsistent pixel alignment in grayscale PRI image compared to CAD model.

Figure 7. Diffusion image of PRI and CAD for image registration



(a) (b)

Figure 8. Boundary tracing for a) PRI and b) CAD image

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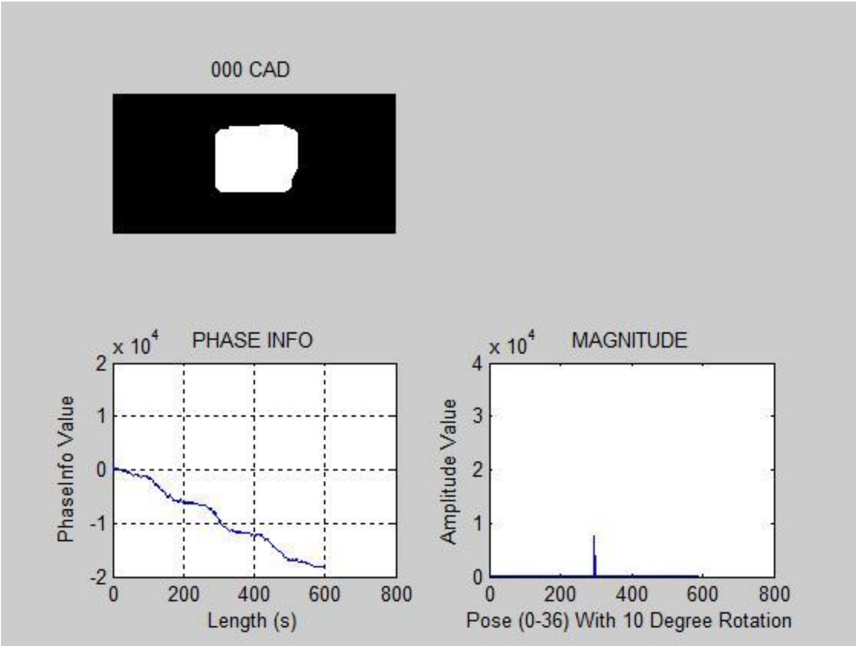
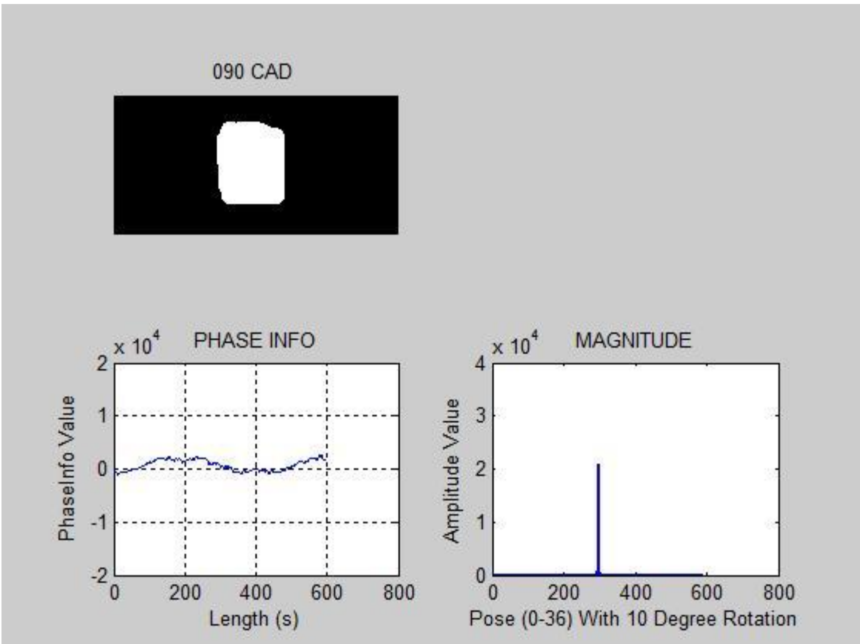
3.1 Fourier Descriptor Processing

Figure 9 shows sets of some samples pose and its Fourier Descriptor phase spectrum and magnitude phase of 000 CAD and 090 CAD. Figure 10 shows sets of some samples pose and its Fourier Descriptor phase spectrum and magnitude phase of 000 PRI and 090 PRI. Phase spectrum shows the unwrap angle of 1D Fourier descriptor boundary signal, while magnitude spectrum shows the absolute value frequency of 1D Fourier Descriptor.

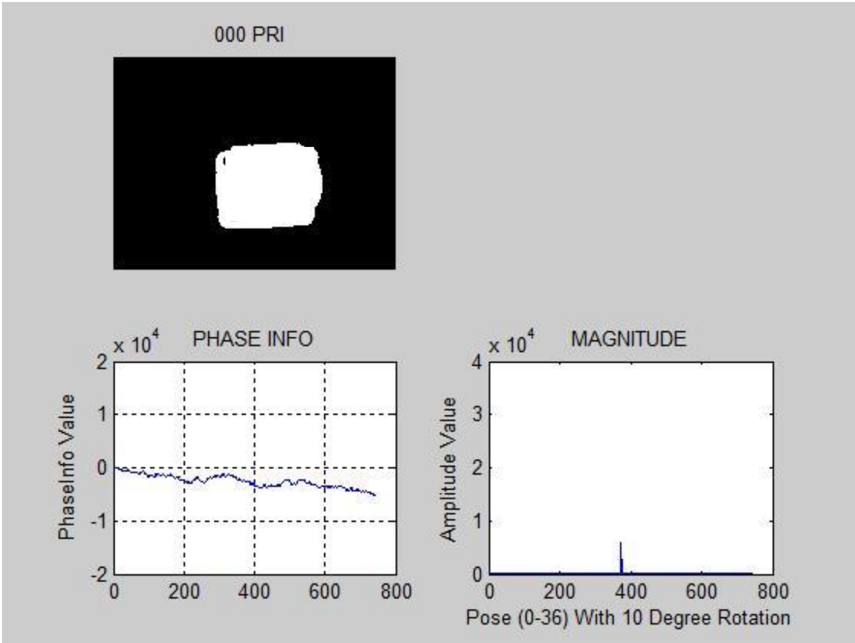


(a)

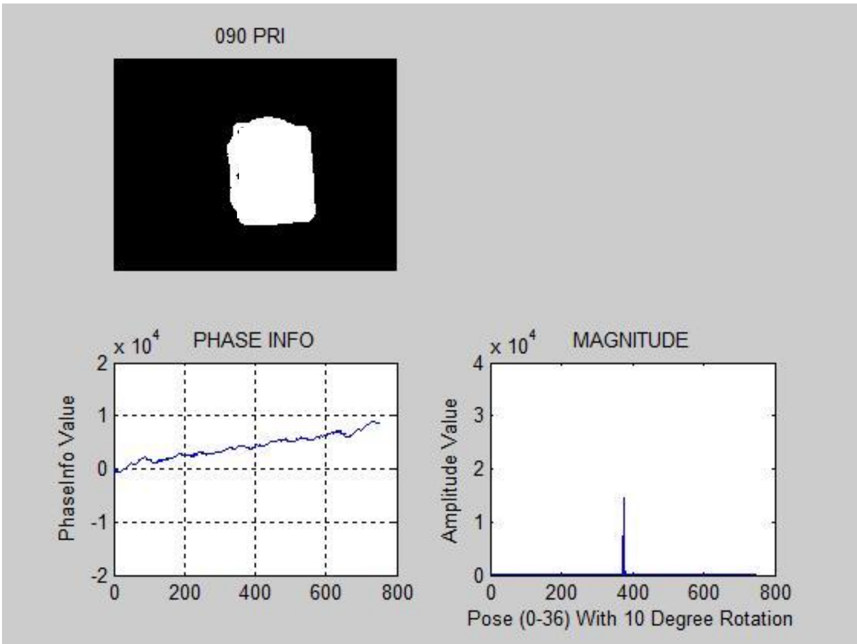


(b)

Figure 9. Some CAD model pose with phase spectrum and magnitude spectrum for (a) 000 CAD-pose 1, (b) 090 CAD-pose 10



(a)



(b)

Figure 10. Some PRI model pose with phase spectrum and magnitude spectrum for (a) 000 PRI-pose 1, (b) 090 PRI-pose 10

Figure 11 shows graph of magnitude spectrum correlation of CAD and PRI. Correlation value for this graph is place in range 0.99 to 1.00. This shows a potential reliability in correlation matching of inspected PRI image and CAD image in database. Table 1 shows certain value of magnitude correlation pose of PRI and CAD. Based on this table, there is certain pose shows the highest correlation value which are, Pose 6 (050 CAD and 050 PRI), Pose 14 (130 CAD and 130 PRI), Pose 24 (230 CAD and 230 PRI) and Pose 33 (320 CAD and 320 PRI).

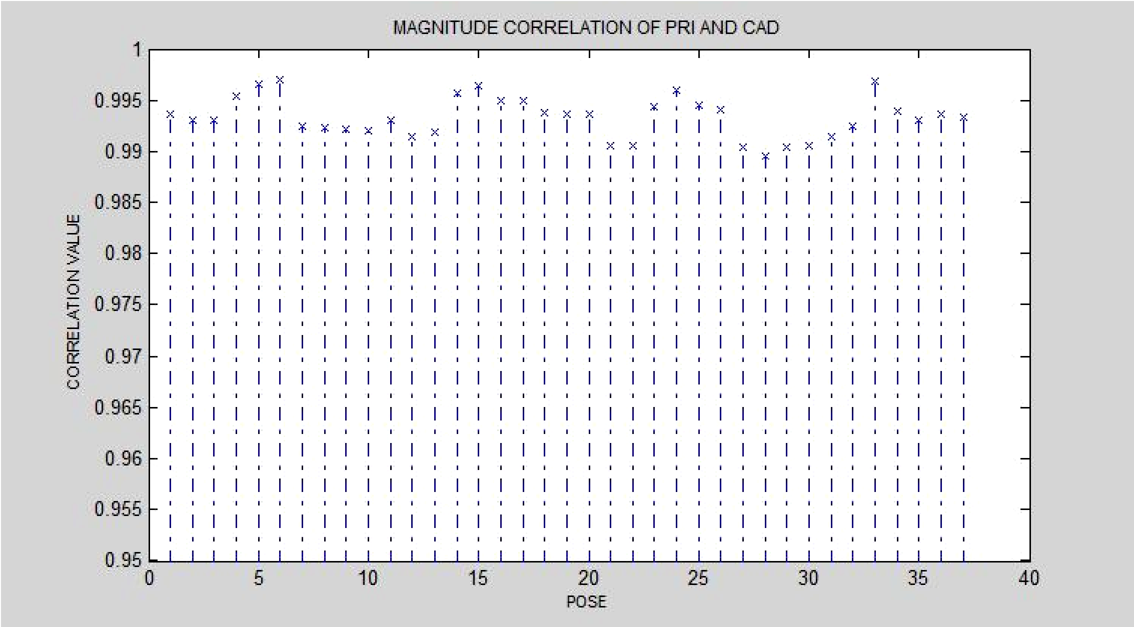


Figure 11. Magnitude correlation value plot for (0-36) pose PRI and CAD

Table 1. Value of certain magnitude correlation pose of PRI and CAD

Pose	Value
1	0.993
8	0.992
15	0.996
21	0.990
22	0.990
26	0.994
29	0.990

Figure 12 shows phase spectrum correlation graph of PRI and CAD image. This correlation value was in range 0.56 - 0.97. This graph shows inconsistent fluctuation of correlation value to its pose as shown in Table 2.

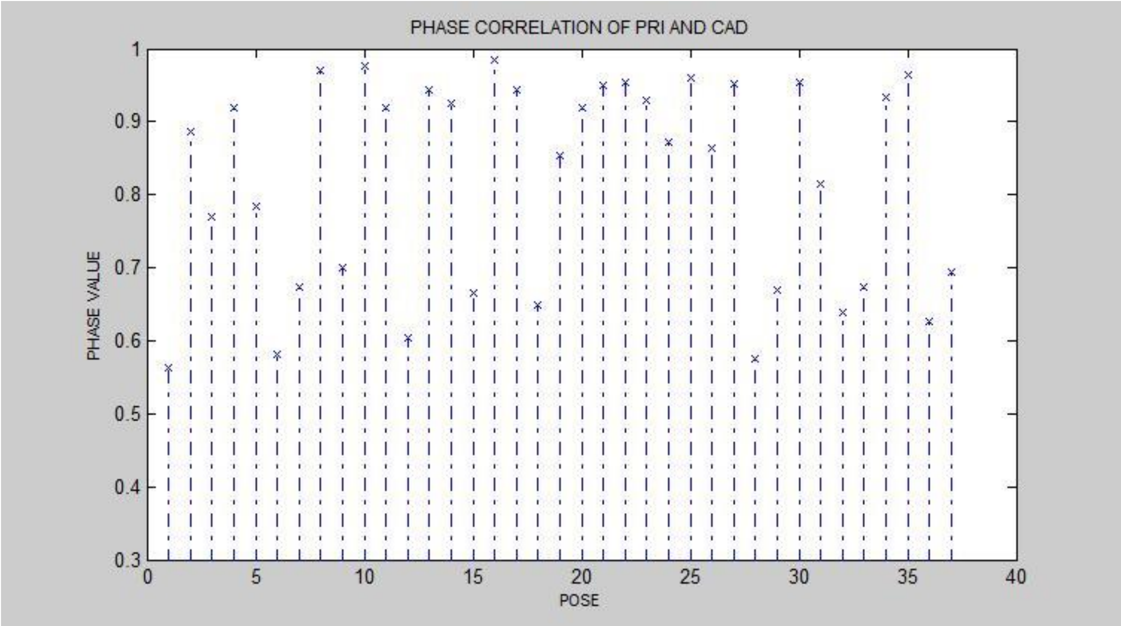


Figure 12. Phase correlation value plot for (0-36) pose PRI and CAD

Table 2. Value of certain phase correlation pose of PRI and CAD

Pose	Value
1	0.563
8	0.970
15	0.665
21	0.950
22	0.954
26	0.864
29	0.668

Figure 13 shows Euclidean distance correlation of CAD and PRI. Based on this graph, the correlation value was in range 0.991 -0.995. There is 2 interested region in this graph as pose 9 until pose 16 and pose 25 until pose 34. This interesting pose is due to shape of inspected part, which is almost symmetrical shape within small difference correlation value 0.0005 per pose as shown in Figure 14. Pose 12 and Pose 30 is almost same value as 0.99476 and 0.99428.

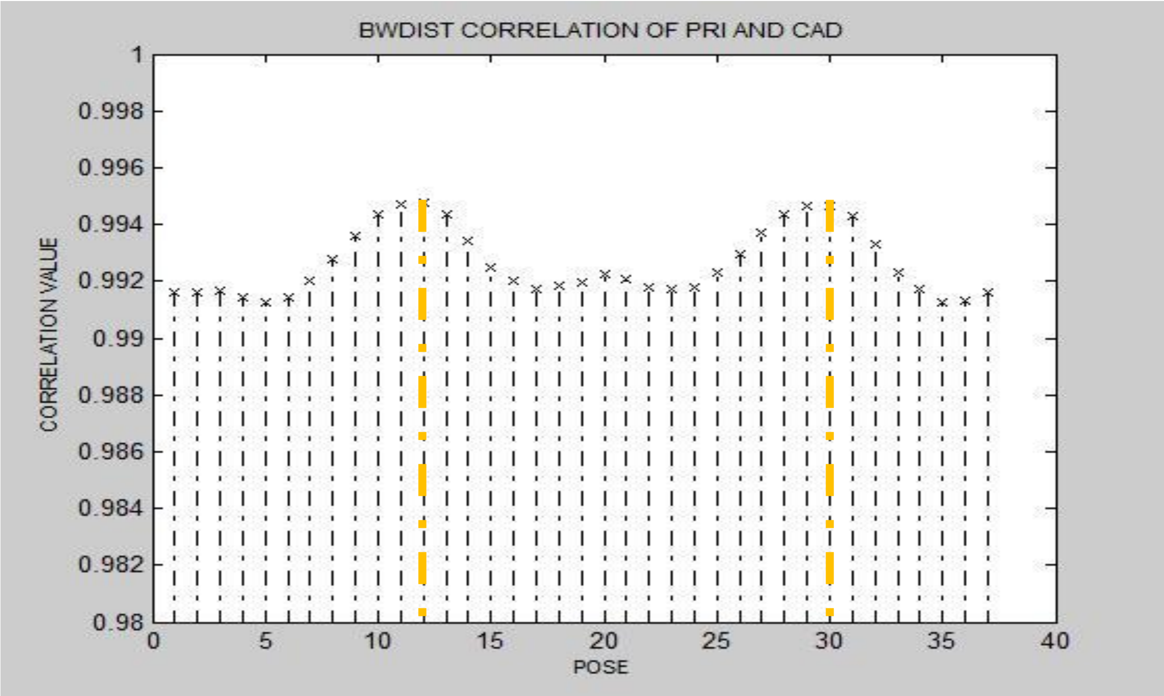


Figure 13. correlation of Euclidean distance of PRI to CAD image

Table 3. value of certain Euclidean distance correlation pose of PRI and CAD

Pose	Euclidean Correlation
12	0.99476
30	0.99428

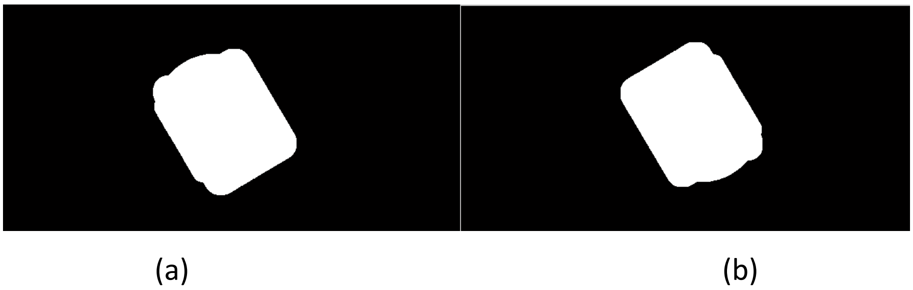


Figure 14. Almost symmetrical shape of tested part a) Pose 12 and b) Pose 30

3.2 Processing (Image Retrieval)

Figure 15 shows interface of inspected image retrieval to CAD database using max magnitude and range phase spectrum within ±10% tolerance. Using this method, image retrieval show a non-reliable image retrieval of inspected image in CAD database. Some pose is recognize correctly, and some pose wrongly recognize. However, this method consume less processing time which is 17.8 seconds depends on inspected object pose sequence to CAD model pose in database.

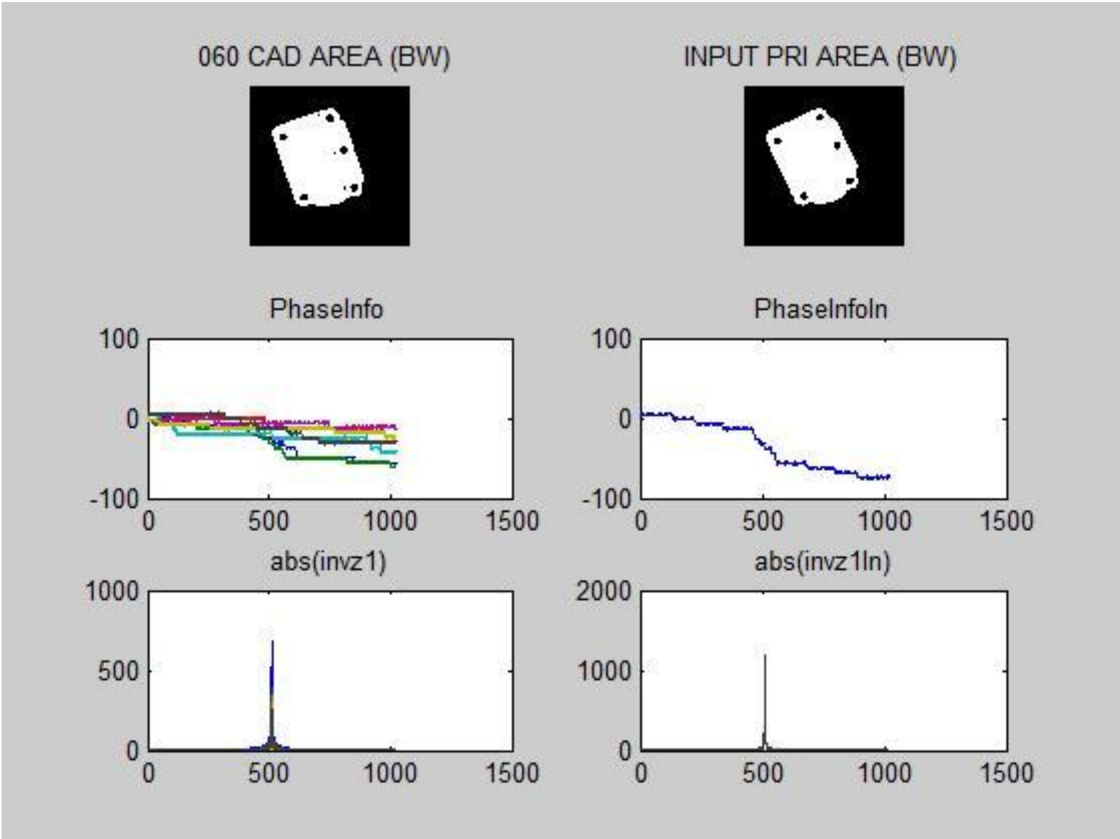


Figure 15. Inspected image retrieval to CAD database using max magnitude and range phase spectrum within ±10% tolerance (17.8 seconds)

Figure 16 shows interface of inspected image retrieval to CAD database using Euclidean Distance matching within ±5% tolerance. Using this method, image retrieval show a reliable image retrieval of inspected image in CAD database. Which is correctly recognize pose in CAD database for all tested pose. However, this method consume extra processing time till 93.2 seconds depends on inspected object pose sequence to CAD model pose in database.

Figure 16. Inspected image retrieval to CAD database using Euclidean distance matching within ±5% tolerance (93.2 seconds)

4. Conclusion

This paper has brings out a few steps in bridging pose estimation of PRI and CAD model has been carried out. The steps include Image Acquisition System of PRI image and CAD model image, transform and rescale the all image in pre-processing step and processing step in matching inspected PRI to CAD model database. The results shows pose estimation using Fourier descriptor needs much improvement in matching PRI pose to CAD model pose. While, Euclidean distance matching of the pose shows a reliable method in retrieve PRI pose in CAD model database by sacrificing extra processing more than 5 times in this case of same 150 degree pose retrieval depends on pose sequences in CAD model database.

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