An Automated Panorama Image Construction
for Dimension Inspection

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Abstract

In hard disk drive industrials, one of the processes in quality control section is to measure the dimensions of the hard disk drive components. To measure the dimension using high resolution visualization, we utilize a microscope to acquire images of hard disk drive components. The component that we are focusing on is a bore hole of pivot arm. Since dimension measurement is needed to be very accurate and the field of view of the microscope is not wide enough to capture the whole part of the bore hole, we capture several parts of the bore hole and reconstruct the whole part using a panorama image construction system. In particular, in this paper, we propose to use a block matching and texture operator with majority voting filter for the translation image stitching. The result of the panorama image construction system shows that an average root mean square error is 1.374 pixels to reconstruct the whole parts from an image sequence containing 40 images. The reconstructed bore hole image is visually correct as well.

Introduction

Nowadays, the hard disk drive (HDD) industrial is one of the prolific industrials of Thailand. The dimension measurement of an HDD component is an important process in the HDD industrials. In this research, we focus on a dimension measurement of a bore hole which is the hole at the center of a pivot arm. Generally, the dimension measurement of a bore hole can be performed using several measuring equipments such as an air gauge, pin gauge, and smart scope. However, these human-operated equipments can be used to measure only a few pivot arms among a large amount of them manufactured each day. Moreover, errors from the measurement may occur from human fatigue.

The automated dimension measurement using high resolution visualization is one of the measurement methods used to solve this problem. A microscope is used to acquire a bore hole image. Because the accuracy of dimension measurement is needed in our application, but the field of view of the microscope cannot cover the whole part of the bore hole, we propose a method to solve this problem by constructing a panorama image from

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several parts of the bore hole image sequences. The panorama construction or image mosaicking has two major procedures. The first procedure is called the direct method that uses all intensity information to align images by an iterative method (Pires and Aguiar, 2005; Zomet et al., 2006). The second procedure is the feature-based method that extracts features from interesting points, such as corners and edges, in an image and information around them (Garcia et al., 2001). The scale invariant feature transform (SIFT) and the multi-scale oriented patches (MOP) were applied to construct panorama images based on gradient techniques (Brown and Lowe, 2003; Brown et al., 2005). However, the MOP needs a contrast image for the best operation. Unfortunately, the problem in our research needs a method that can be operated on low-contrast images and robust to the noise. We therefore propose a new feature-based panorama construction method. The interesting point selection is performed using Harris corner (Cheng et al., 2005). The correspondence is evaluated using the block-matching and texture operator (Garcia et al., 2001; Christodoulouet al., 2003; Garcia et al., 2001). We also choose some filters, i.e., the statistical filter (Leone et al., 2006), median filter, and majority voting filter, to improve the panorama image construction.

The rest of this paper is organized as follows. We describe the proposed system in section II. The experimental setup and the results are shown in section III. Finally, section IV concludes the paper.

## The Proposed Panorama Construction System

The proposed panorama construction system has four processes to construct a panorama image from a bore hole image sequences, i.e., 1) enhancing and finding interesting points, 2) correspondences evaluation, 3) outlier removal, and 4) constructing panorama image.

A. Enhancing and Finding Interesting Points

The interesting points in a bore hole image are difficult to find because each part of the bore hole image does not have a notable feature. To remedy this problem, we add a background to a bore hole. This can be done by putting a round piece of paper with the background into the bore hole during the measurement process. We see that it gives more notable features inside the bore hole as shown in figure 1. The image acquisition system used in this research produces image borders as shown in figure 1. Therefore, we eliminate the borders before proceeding to the next steps.

In this research, the interesting points are selected using the multi-scale Harris corners (Brown et a., 2005). The input image is preprocessed by convolving with a Gaussian image pyramid. We choose the pyramid smoothing width $\sigma_p = 1.0$ and the sampling rate s = 2. The Harris corners are then computed from the Harris matrix:
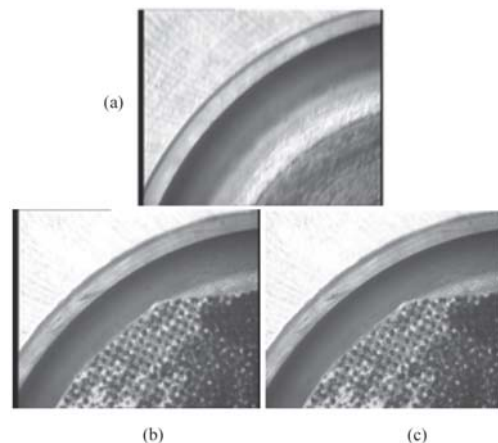
Figure 1. Images of a bore hole (a) original image, (b) with background in the bore hole, (c) after border elimination.

$$H_r = \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix}, \qquad (1)$$

where I_x^2, $I_x I_y$, and I_y^2 are calculated form the gradient operator. We can calculate the corner strength function from the equation of harmonic mean of eigenvalues (λ_1, λ_2) as

$$f_{HM} = \frac{|H_r|}{\text{trace}\{H_r\}} = \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2}. \qquad (2)$$

An interesting point is selected when it has the corner strength f_{HM} more than its 8 neighbors and above the threshold value of 500.

In order to make the feature point matching procedure easier, the interesting points should be nicely distributed throughout the images. The disadvantage of using only a corner strength value is that the selected points are not distributed thoroughly. We use the adaptive non-maximal suppression (ANMS) (Brown et a., 2005) to ease this advantage. This method distributes interesting points in all areas of the images. Figure 2 shows a comparison between the interesting point selection using the corner strength with and without the ANMS. The white dots represent the interesting points. We can see that the interesting points are more uniformly distributed when using the corner strength with the ANMS as shown in figure 2(b).

B. Evaluation of Correspondences

In this research we use the region matching method called the block-matching to perform the coarse matching (Garcia et al.,2001;Garcia et al., 2001). Let I_m be the present image and I'_m be the next image to construct a panorama image.

The block-matching uses an $n \times n$ window centered at each interesting point in the present image $p(x,y)$ to compare with an $n \times n$ window centered at a interesting point in the next image $p'(x,y)$. Let I be an $n \times n$ window in the present image and I' be an $n \times n$ window in the next image, we can compute the correspondence between these 2 windows by

$$corr(p, p') =$$
$$\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left[I(x+i,y+j)-\overline{I(x,y)}\right]\left[I'(x'+i,y'+j)-\overline{I'(x',y')}\right]}{n^2\sqrt{\sigma^2(I)\cdot\sigma^2(I')}}, \quad (3)$$

where $\overline{I(x,y)}$ is an average value of the intensity in the $n \times n$ window in the present image and $\overline{I'(x',y')}$ is an average value of the intensity in the $n \times n$ window in the next image. $\sigma^2(I)$ is the variance of the image I_m in the $n \times n$ window, i.e.,

$$\sigma^2(I) = \sqrt{\frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left[I(x,y)\right]^2}{n^2} - \overline{I(x,y)}^2}. \qquad (4)$$

After 10 candidate points are selected based on Eq.(3), a set of texture operators is used to determine the most similarity of the 10 candidate points. Each interesting point in the image I_m is processed using 9 texture operators, i.e., contrast 3×3, contrast 5×5, contrast 7×7, L3L3 standard deviation, E3E3 positive average, E3E3 negative average, L5S5 positive average, E5L5 standard deviation, E5S5 negative average (Garcia et al., 2001; Garcia et al., 2001; Leoneet et al., 2006). The output of the 9 texture operators are computed from each interesting point in the image I_m and their

candidate points. The similarity can be measured by using the Euclidean distance between the texture vector of each interesting point in the image I_m (the vector contains the texture values computed by the 9 texture operators) and the texture vectors of the 10 candidate points. The pair with the minimum Euclidean distance is the best match.
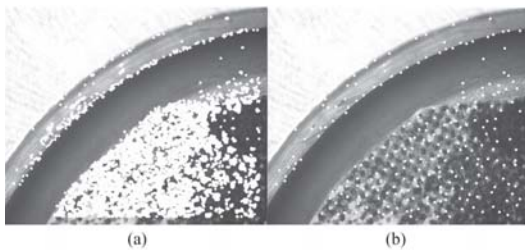
Figure 2. Interesting points (white dots) selected by corner strength (a) without ANMS (b) with ANMS.

C. Outlier Removal

After the correspondence pairs are selected, the false matching may still occur. The outlier removal step helps eliminating the false matching for better panorama image construction. In this research, the panorama image construction is only translation stitching. We apply three methods of outlier removal. Firstly, the statistical filtering is applied by calculating the Euclidean distances between the correspondence pairs in the present image and the next image. The average and standard deviation of these distances are then calculated. If the Euclidean distance is different from the average by more than twice of the standard deviation, then the corresponding point will be removed from the list. The second method calculates the median of the Euclidian distances between the corresponding points in two images. This method will remove the

corresponding points whose Euclidian distances are more than the median value. The last method is the majority voting filter that selects the city block distance along x-axis and y-axis. This method chooses a group of the corresponding pairs that is most similar in the city block distance sense and gets rid of other pairs.

Figure 3 shows examples of the outputs from the 3 outlier removal methods. The white dots represent the interesting points in the current image whereas the black dots represent that in the next image. Therefore, the white lines represent the remained corresponding pairs after the outlier removal. Because we have prior knowledge that the consecutive images are related by the translation only, we expect to have a group of white lines that have the same length and direction in the good matching.

From figure 3, we see that the statistical filter does not only remove some outliers but also remove some well-matched pairs. The median filter method can remove outliers and retain the well-matched pairs. However, thismethod cannot remove some outliers, for example, when a large group of the outliers have similar Euclidean distances. Finally, the majority voting filter can solve the problem in the median filter and can remove the outliers better than other methods as shown in figure 3(c).

D. Constructing Panorama Image

In this step, the distances along the x-axis and y-axis from the majority voting filter are used for the panorama image construction by translation only. We choose the majority voting filter in this research because it yields the best outlier removal as shown earlier.
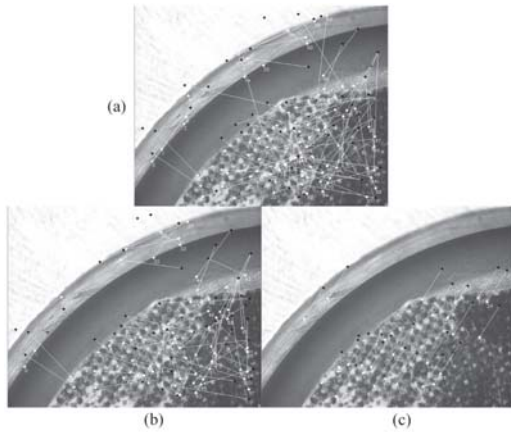
Figure 3. Outlier removal by (a) statistical filter, (b) median filter, (c) majority voting filter.

Experiments and Results

In the experiments, we test the panorama image construction system with an image sequence containing 40 images of a bore hole with added background. The size of each image in the sequence is 720×576. We show 6 out of 40 of them in figure 4. The constructed panorama image of the bore hole is shown in Fig 5. We can see that the 40 images are nicely stitched together to form the panorama image. In addition to the visual inspection, we numerically evaluate the construction performance by computing the root mean square error (RMSE) of the consecutive images during the construction process. As mentioned earlier, we have prior knowledge that the consecutive images are related by the translation only. If the matching is good, then we should have a group of white lines that have the same length and direction. In this research, we consider RMSE of the length only. The RMSE between the current image I and the next image I' can be defined as

$$RMSE(I, I') = \sqrt{\frac{\sum_{i=1}^{n} (l_i - l^*)^2}{n}} \quad , \qquad (5)$$

where l_i is the distance between the ith interesting points in the images I and I', and n is the number of pairs of interesting points. l^* is the actual translation distance between the two images that we manually determine. Therefore, we manually determine the translation distances of 39 pairs of images.
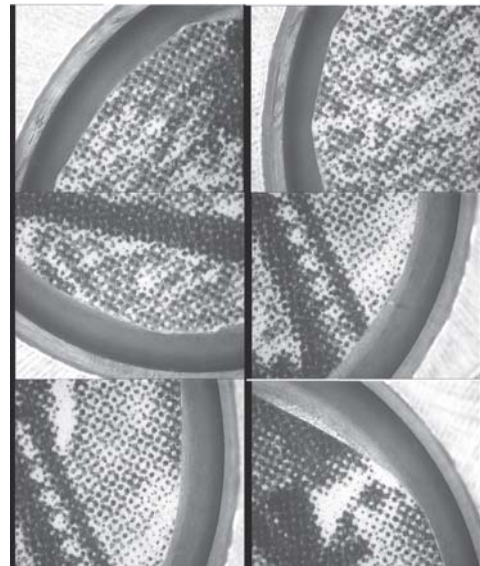
Figure 4. Six sample images from image sequence.
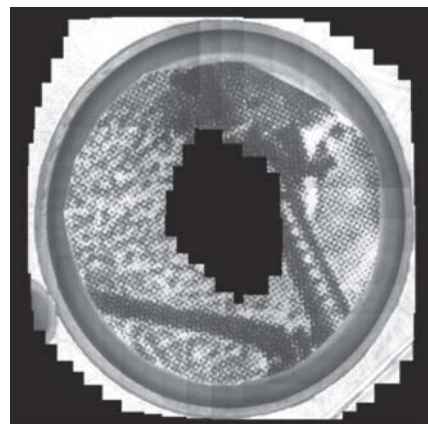
Figure 5. A sample panorama image constructed from 40 frames of bore hole image sequence.

We calculate the RMSE between each pair of images starting from 1 and 2, and ending up with 39 and 40. That implies to 39 values of RMSE. These values are plotted in figure 6. We see that the RMSE of the best match is 1.281 pixels and that of the worst match is 1.683 pixels. The average of the RMSE of the panorama image construction system is 1.374 pixels. The experiments show that the proposed panorama image construction system can perform with the translated image sequences.

Conclusion

In this research, we utilize a block-matching and texture operators along with the majority voting filter in the panorama image construction. The results show that the proposed system can perform very well. Each pair of consecutive images is well stitched together with the average root mean square error of 1.37 pixels compared to the actual translation distances. Our work can be applied to the visual analysis application for the pivot arm component especially a bore hole. In such a case, a large field of view to cover the whole bore hole will cause the low resolution. After the panorama image construction, we can have a large field of view while maintain a good resolution. In the future, we will apply the system to the rotation image stitching and to a real-time application.
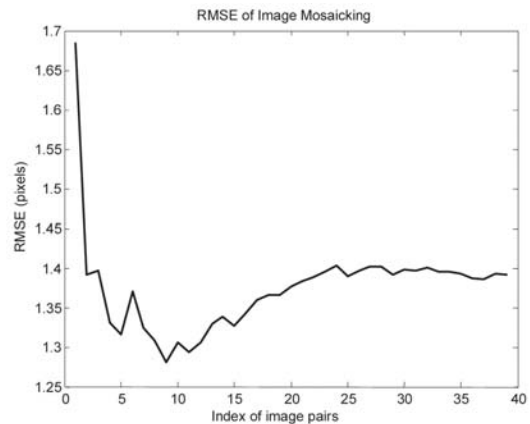
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Figure 6. RMSE of image mosaicking on 39 pairs of images.

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