Image Mosaicing Based Condition Monitoring Approach for Multi Robots at Production Lines in Industrial Autonomy Systems

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***Abstract*— In today industry, manufacturing become big and serial as it never been before thanks to the autonomy robots. Hitches on such autonomy systems used in industrial production may cause production delaying. In this study, it is aimed to obtain alive bird's eye view map of full system in order to monitor manufacturing robots at production facilities that are big and impossible to be monitored with only one camera. Finding the similar scenes of input images, estimation of homography, warping and blending operations are applied respectively in order to mosaic the images by twos. Thus the robots in the facility can be observed in one screen. With observation of the obtained images, faults on cyber-physical systems that may cause damage in machines which are not cheap can be handled beforetime.**

***Keywords*— Condition monitoring, Multi robots, Production lines, Image processing, Image mosaicing**

I. Introduction

Accuracy and security of cyber-physical systems become crucial with growing up cyber-physical systems in industry. In today industry, manufacturing become big and serial as it never been before thanks to the autonomy robots whose cyber and physical layers are diverse. Monitoring physical layer from cyber layer is necessary for link the layers and integrate them more tightly. Furthermore, it will ease the control of big facilities. Hitches on cyber-physical systems used in industrial production may cause production delaying. Furthermore, these hitches may cause damage in hardware which are not cheap. So observation of the system and determination of possible accident are required for deduction the cost of delay in production and repair. With processing the obtained image by algorithms in cyber layer, the cyber-physical system would be more integrated and secure.

In this study, it is aimed to obtain alive bird's eye view map of full system in order to monitor manufacturing robots at production facilities that are big and impossible to be monitored with only one camera. With the created alive map, it will be possible to monitor positions of all robots instant and extract more detailed information about the facility. It is need that locate cameras each of whose angel of vision contain the small piece of neighbour one's. Finding the similar scenes of input images, estimation of homography, warping and blending operations will be applied respectively in order to mosaic the images by twos. After all steps done, only one stitched image will be obtained from all these images taken by cameras at the same time. Thus the robots in the facility can be observed in one screen and machines which could lead to accidents can be noticed early. The stitched image can also be used for image processing in cyber layer.

There are studies about image mosaicing in literature [1-5]. One of the studies, Divya et al. **[1]**, implemented weighted average method in addition to the methods used in image mosaicing such as feature extraction, cluster analysing, dynamic programming to obtain wide angle panorama. Although the study is effective for illuminated images, it is not useful for dark images. Another study about this subject is Lin's study [2]. Lin et al. use image mosaicing in order to obtain cylindrical panoramic image. *Scale Invariant Feature Transform* (SIFT) and *Random Sample Consensus* (RANSAC) are used in this study. Patel et al. [3] employ *Speeded-Up Robust Features* (SURF) for feature extraction and *Sum of Squared Differences* (SSD) for feature matching. They also used RANSAC to eliminate incorrect matchings. At the end of their study, they compare Harris and SURF and decide that SURF is more effective for multi-imaged image mosaicing problems. Huang et al. effort to mosaic frames in videos [4]. Instead of using all frames in a video, they used the frames that contain small piece of other frame to enhance video mosaicing performance. In their study, Lee et al. [5] employ SURF for feature extraction and *Histogram of Gradient* (HoG) for matching. They also utilize from *Approximate Nearest Neighbour* (ANN), RANSAC algorithms.

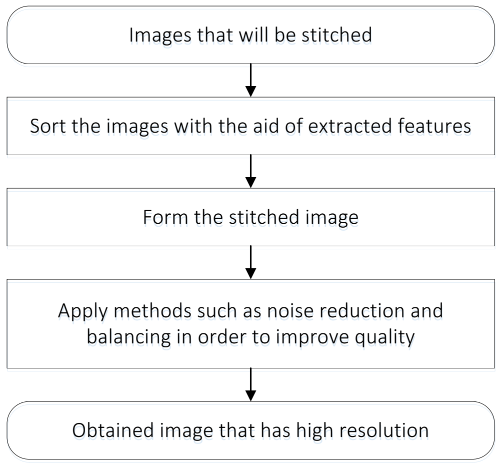


Figure 1. General Image Mosaicing Steps in Literature [6]

Qui et al. aimed to stitch images and eliminate ghosts occurred while stitching images [7]. In this manner they used SIFT and RANSAC methods. In order to obtain optimal stitching line dynamic programming methods are employed. Laraqui et al. [8] also employ SIFT for feature extraction. Difference of their study is that they use voronoi diagram to eliminate incorrect matches.

The paper continues with information about image mosaicing that is given in section 2. In section 3 simulation results are given. Conclusion is handled in section 4 and references are listed following conclusion.

II. Image Mosaicing

Image mosaicing is the process of obtaining single image from more than one images that contain common view with corresponding of the matching points. It helps to obtain qualified images with not expensive cameras [9], take the image of scenes that can not be viewed with one camera, obtain panoramic images, delete moving objects in a video. It has a wide application area from smart systems to military systems.

Regardless the count of images that will be stitched, the images are stitched by twos as seen in figure 2. There are stitching methods in space and frequency domains. The methods in space domain can be grouped as area-based methods and feature-based methods [10]. In this paper, feature-based techniques are applied because area-based techniques are sensible for changes in size, angle and illumination. In feature-based image mosaicing methods, interest points that are characteristic points in image and their features are found first. With the help of extracted features, matching operation is applied. Mismatches that may be occurred are eliminated and homography is estimated. With the found homography matrices warping operation is actualized and blending is applied to make the stitching seamless [11]. General steps of feature-based image mosaicing process are given by Fig. 3.

A. *Feature Extraction*

In order to stitch images, it is required to determine common areas / objects first. Feature based methods use characteristic points called interest point instead of all pixels in an image in order to make algorithm more efficient. Interest points can be edges, corners or blobs. There are several edge and corner detection methods to identify the interest points [13,14]. In this paper, interest points are extracted by Difference of Gaussian (DoG) method which is a blob detection method.

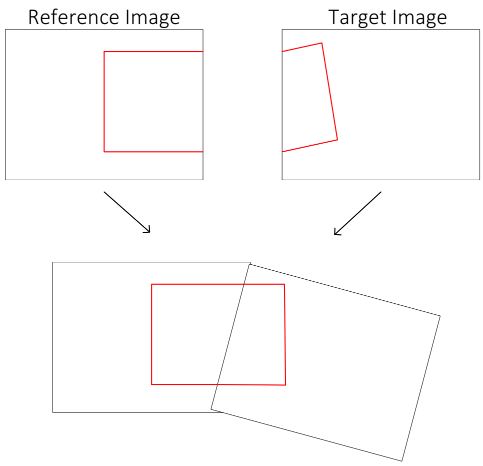


Figure 2. Stitching images after warping [12]

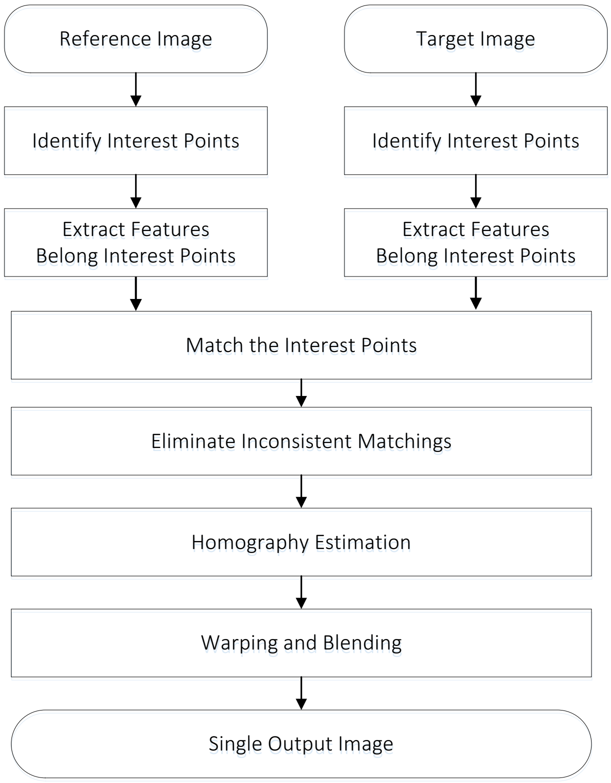


Figure 3. General steps of feature-based image mosaicing [11]

In order to link between images, interest points are used. Some features must be extracted for calculating the similarity of interest points. There are various feature extraction methods in literature [15]. In this study, we used Scale Invariant Feature Transform method [16].

B. *Matching*

After extracted SIFT features, it is searched corresponding interest points from second image to interest points from first image according to similarity [17]. In this stage second nearest neighbour distance rate is used to prevent mismatches [18]. According to this method the distance between interest points from reference and target image are calculated. The nearest 2 corresponding interest points are selected for each interest point from reference image. If the first distance is smaller than the multiply of distance ratio and second distance, it means there is no confusion probably and the first one selected as matched point. Otherwise it means there is confusion and no matching is realized.

$$matching = \begin{cases} 1, & A < B * \alpha \\ 0, & otherwise \end{cases}$$

where A is distance of first nearest point, B is distance of second nearest point and α is tolerance of distance difference.

C. Elimination of Mismatches

Although the second nearest neighbour distance method reduce the count of mismatches, it can not completely eliminate them. When we try to superpose the matched interest points, the mismatches make a fuss. So, the count of mismatches must be minimized before homography estimation. In this study RANSAC is used to eliminate the mismatches.

According to RANSAC method [19], some of the data are selected randomly and a model is tried to fit the samples. After all data are tested by the model respectively. If the model gives the correct result within the tolerance defined before, the datum is marked as in-liner. If in-liner data is sufficient to verify the model, the model is added to solution set. This operation is actualized pre-determined iteration times. At the end of the iterations best model that fits the majority of data with minimum error is selected as solution. The diagram belongs to RANSAC algorithm is given by Fig. 4.

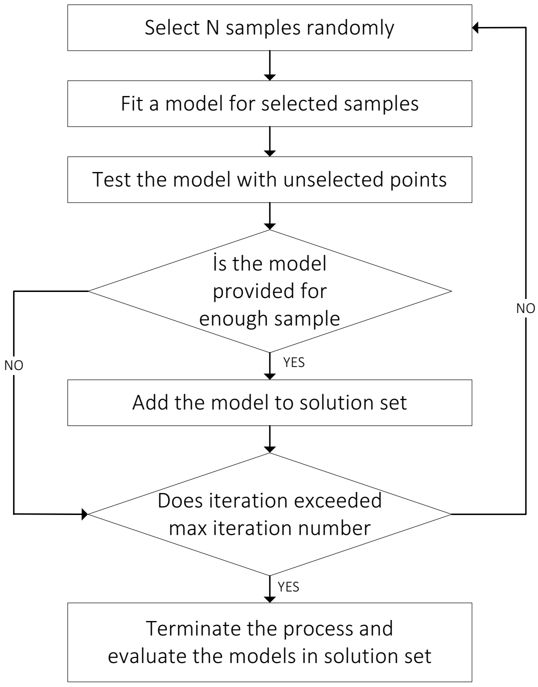


Figure 4. Block Diagram of RANSAC Algorithm [22]

D. Homography, Warping and Blending

We aimed to fit a model whose input is the pixel coordinate of target interest points and output is the pixel coordinate of corresponding reference interest point. The model that help us to calculate the new position of target image pixels' in order to superpose these images is called homography matrices. Homography matrices is 3x3 sized matrices and it is used to move the points in homogeneous coordinate system. The equation for calculating new position of point and and its extended version are given by respectively (1) and (2).

$$H.P = P' \quad (1)$$

$$\begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \end{bmatrix} \begin{bmatrix} X_o \\ Y_o \\ Z_o \end{bmatrix} = \begin{bmatrix} X_n \\ Y_n \\ Z_n \end{bmatrix} \quad (2)$$

where H is homography matrices, P and P' are former and new coordinates of pixel in homogenous coordinate system respectively. To transform 2 sized vector to homogenous coordinate system, Z_o is selected as 1; to transform homogenous coordinate system to X and Y values (3) is used.

$$X' = \frac{X_n}{Z_n} \quad , \quad Y' = \frac{Y_n}{Z_n} \quad (3)$$

where X' is new value of X and Y' is new value of Y. After found of new coordinates of target image, target image is transformed and coordinates of corresponding points be the same. With the displaying transformed image and reference image in one frame, image stitching process is done.

Stitched image may have visible colour transition because of the cameras whose angel of vision is not illuminated as same as the other one's. At last, to extinguish the difference blending operations are used [20]. In order to remove blur that may be derived from stitching operation or derived due to the high speed of robots at production line, some blur removal methods in literature can be used [21].

III. Experimental Results

In this paper, the image stitching operation is implemented on images that belongs to robots at production line. The diagram of desired system given by Fig. 5. Although the sample system shown by Fig. 5 includes 4 cameras with the same characteristics, the count of cameras can be increased. A computer with intel i7 6020M CPU, 6 GB ram, and Windows 7 64bit home premium is used to perform the proposed approach on the sample images belong to production environment.

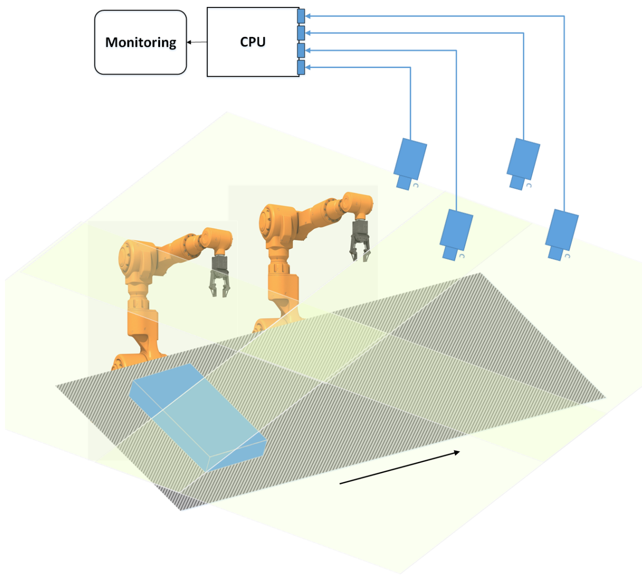
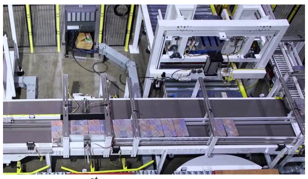
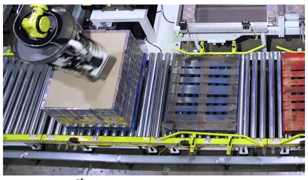


Figure 5. Desired system for grabbing images.

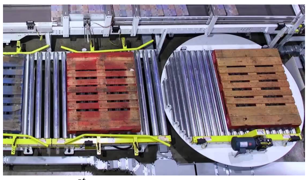
(*a*) 1st camera of first row



(*b*) 2st camera of first row



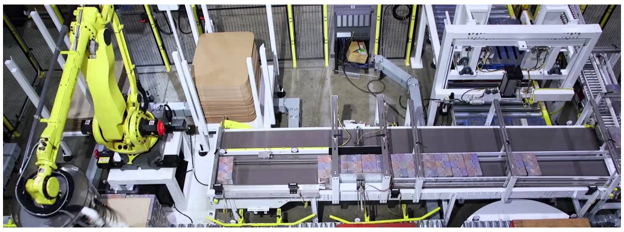
(*c*) 1st camera of second row



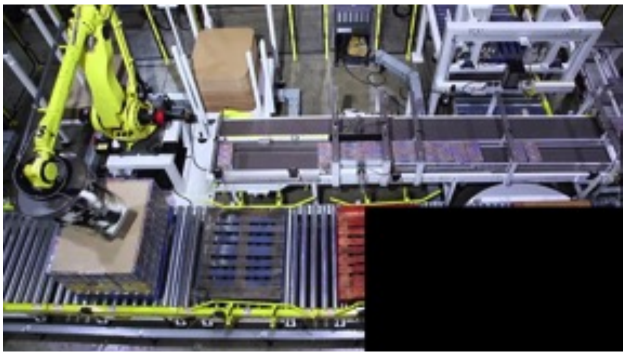
(*d*) 2st camera of second row

Fig. 6. Images that are stitched

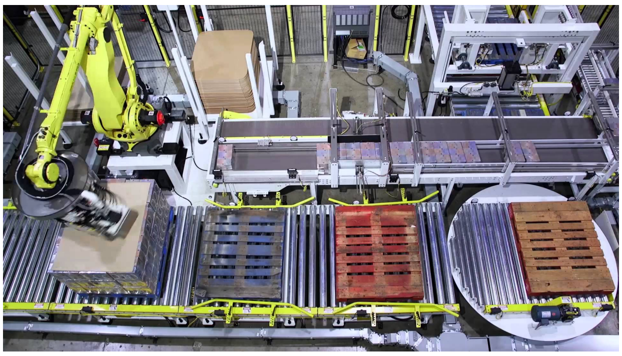
In order to test the effect of the images order, the four image given by Fig. 6 are stitched respectively first. The result of this process is given by Fig. 7. Then the same images are subjected to the process of stitching by twos. In Fig. 8, *e* is obtained by stitching of *a* and *b*, *f* is obtained by stitching of *c* and *d*, and finally *g* is obtained by stitching of *e* and *f*.



(*e*) Stitching of (*a*) and (*b*)

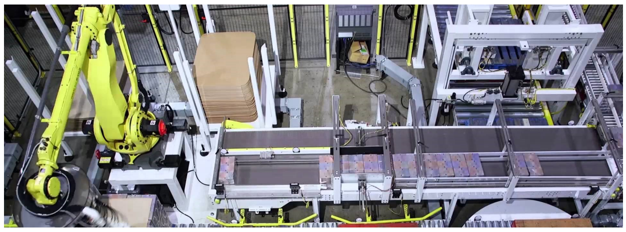


(*f*) Stitching of (*e*) and (*c*)

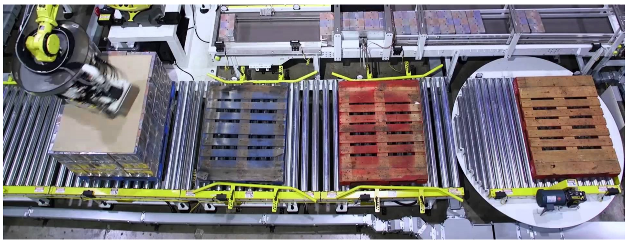


(*g*) Stitching of (*f*) and (*d*)

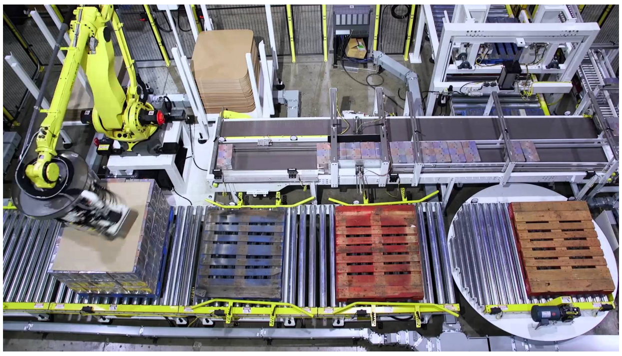
Fig.7. An example of stitching by order.



(*h*) Stitching of (*a*) and (*b*)



(*i*) Stitching of (*c*) and (*d*)



(*j*) Stitching of (*h*) and (*i*)

Fig. 8. An example of stitching by twos.

Although there is not much difference in point of the quality between final stitched images that are obtained in Fig. 7 and Fig. 8, we can see that the process given in Fig. 8 works faster than the process given in Fig. 7 when we look elapsed time given in table 2 and table 3.

Although cameras are stable and the distance between them is nearly constant, possible changes on camera angle or shakes make it necessary to find optimal points that are used in process of image superposing. We suppose that cameras are positioned as one's visual angle contains 1/3 of the neighbor one's visual angle maximum, include deflection. So instead of searching interest points whole image, we did it only in interested area. The results with 1/5 of interest area are given by table 3. The elapsed times in table 3 can be reduced by parallelization. The results given by table 1 shows that there is no much difference between matched interest points that are searched in full image and 1/3 of the image. But when we look the elapsed time to find interest points, the second one works faster than first.

TABLE I. ELAPSED TIME FOR INTEREST POINT EXTRACTION

Searching Area	Search Size	Found IP	Matched IP	Time (ms)
Full of a	336 x 189	681	84*	29
1/3 of a	111 x 189	205	87	13
1/5 of a	66 x 189	123	47	7

TABLE II. THE PERFORMANCES OF STITCHING BY ORDER WITH FULL SEARCH AREA

Process in Fig. 7.	Size	Time (ms)
e	560 x 189	65
f	560 x 310	92
g	560 x 310	123
Total	560 x 310	280

TABLE III. THE PERFORMANCES OF STITCHING BY TWOS WITH LIMITED SEARCH AREA

Process in Fig. 8.	Size	Time (ms)
h	560 x 189	15
i	560 x 189	16
j	560 x 310	28
Total	560 x 310	59

IV. CONCLUSION

It is very crucial to monitor physical elements especially for cyber-physical systems that is trend of the industry of today, which is called industry 4.0. In this paper, it is proposed that use image mosaicing to monitor conditions of multi robots at production lines and the proposed method is tested by experimental. In order to test the method 4 images that belongs the same science are used, and no one of them contains more than 1/3 of another one in spite of the possible deflections. With the knowledge of this, only a part of image is used to search interest points instead of full image. Finding interest points, feature point extraction, matching, warping and blending operations are used respectively to stitch images. Since the order of images that are stitched are certain, sorting of images is not required for such camera array applications. The images are stitched by order and by twos respectively. The effect of image order is demonstrated by results given by table 2 and table 3. The results show that stitching by twos outperforms stitching by order for the camera arrays which occurred from *NxN* camera, N is even number. Furthermore, if N is not even or the size of camera array is not *NxN*, a sub array that provides the constraints and the operation is applied for sub array. After the remains may be stitched by orders. Little time consumption of this approach make it possible to be used in camera array problems. The feature-based method makes the solution more reliable in case of changing in position, angle or illumination.

Consequently, it is possible to get high quality reliable image using low quality cameras thanks to the method. Monitoring the condition of robots at production line, which is a requirement for today's industry facilities, in a screen is achieved by the study.

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