A Novel Robotic Automated Optical Inspection System for on the Fly Production Lines

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Abstract. Automated optical inspection (AOI) is getting popular in quality of control in manufacturing. There is a huge demand to install AOI systems in production lines seamlessly. Usually, a conveyor is used in a product line to carry work-pieces. Thus, it becomes difficult to inspect the quality of products by images when work-pieces are moving. This paper proposed a robotic AOI system which is able to track moving objects in a conveyor to take clear images. This system can be installed into production lines on the fly. To achieve this, the system estimates the pose of the coming work piece using a camera before the work-piece arrives the inspection spot, and adjust the poses of the inspection cameras to align with the work piece. Then, the robot moves along the conveyor at the same speed and the system requires the correct calculation of image Field of View (FOV). By doing this, the robotic AOI system can take clear images of the work piece. We validated the system on a Denso RC8-series industrial robot equipped with eye-in-hand cameras to capture clear images while the work-piece is moving. The results show that the proposed system is able to take clear images when the conveyor speed is up to 10cm/sec.

1. Introduction
For decades, rapid production systems in industry have been continuously growing. Keeping productions in a good quality condition is a key issue for the industry to meet market satisfaction. A challenging problem arising from rapid production systems is to control product quality in a limited amount of time. One of the quality assessment techniques is Automated Optical Inspection (AOI). AOI systems were deployed in order to inspect products using cameras autonomously [1]. They helped the industry to reduce the cost of labour for inspecting the production result. Along with that, there is a huge demand to install AOI systems in production lines seamlessly. Nonetheless, the challenge to AOI systems is that when inspecting moving objects, AOI systems capture blurry images and missed-spots with target object surface [2]. Even though this miss-focus problem is inevitable, AOI systems are still incapable of solving it in on-the-fly production lines. Therefore, developing an ideal AOI system for production lines should be adaptable to the variant working distance from the inspected object.

Some approaches have addressed AOI systems in production lines, such as AOI systems in assembly lines of Printed Circuit Board (PCB) [3], and some patents of inspection methods on moving objects [4][5]. They proposed a path planning method to improve the productivity of AOI machines in the PCB assembly lines. The objective was to find the inspection cluster and sequence of each camera to minimize the working time. There were many papers to improve scanning methods, such as: (1) AOI system for mobile phone panels, (2) AOI PCB defect detection, and (3) AOI system metal part inspection [6][7][8]. These previous works focused on AOI systems in a stationary position. The task...
of a stationary AOI system is to inspect objects in an ideal condition. Hence, it is challenging to us to propose a novel AOI system to inspect moving objects [9]. Here, this paper discusses the proposed AOI system on on-the-fly production lines using an industrial robot and cameras to examine a five-side metallic object. The system is installed on a Denso RC8 Series robot along with six eye-in-hand cameras. The system tracks the pose of moving work-pieces on the conveyor and it takes images to evaluate their appearance quality. Since the working distances from the cameras to the moving work-piece is different, the issues in the paper address how to control the Distance of View (DOV), focus, and exposure from each camera in order to obtain clear images. Thus, our proposed method has to estimate the pose of the coming work-piece using an eagle-eye-view camera and then adjust the robot pose to align with the work-pieces. By doing this, our proposed method offers some promising solutions to tackle uncertainties in AOI systems such as blurry images, and missed-spot location on moving work-pieces.

2. Method
The proposed AOI system is developed using Systems Development Life Cycle (SDLC) method which has several procedures as follow: planning, analysing, designing, implementing, and maintaining process [10]. This method platform is often used by researchers as developing procedure to create a stable performance. The system has two important parts, the first part is detecting pose section and the other part is five-side inspection section. It is necessary to detect the pose of incoming work-pieces because the system should keep the same DOV, focus, and exposure for each camera. Therefore, in order to detect the pose of each incoming work-piece, an eagle-eye-camera is mounted at the starting point of the conveyor. The system calculates the pose of each incoming work-piece and sends it to the robot. Then, the robot changes the pose of the frame mounted with the cameras to align with the work-piece as shown in the Figure 1. After that, the inspection part sequentially takes pictures of the work-piece on the conveyor. We have already set the camera exposure and focus previously based on their working Distance of View (DOV). Here, the cameras are using 5-mm lens and 8-mm lens to capture the images of the work-piece moving on conveyor with the speed of 10 cm/sec. The inspection part is made from a four-side frame as shown in Figure 2.

2.1. The pose detection system
The pose detection system has been built using an eagle-eye view camera equipped with 16-mm lens in the rooftop of the AOI system. It is used to calculate the difference between the neutral and current poses of work-pieces. The size of a work-piece is 420 mm (W) x 440 m (H). The camera starts to detect the work-piece at 100 mm of its initial location as shown in Figure 3. Selecting appropriate camera lens is also important since the Field of View (FOV) of a lens affects pose detection.
In this section, the system detects the contour of the work-piece by representing the continuous point along the boundary which has same color or intensity on binary image [11]. It is linked with two supporting concepts of image processing, i.e., edge detection and boundary detection [12]. The clear distinction between boundary detection and edge detection is that they cannot produce closed contour and divide into different regions. However, contour detection may have some problem on small textures, low contrast object, and high-level noisy images [13]. Therefore, our system is able to tackle the common problem using high DOV cameras and the proposed lightning source system.

2.2. The inspection frame design
The proposed inspection system is built using six cameras which are separated into two groups. The first group consists of four cameras which are mounted on the four-side frame, and two of them have 5-mm lens and the others have 8-mm lens as shown in Figure 4. The second group is two upper cameras with 16 mm lens. They are used to scan the top surface of work-pieces as shown in Figure 5. The whole inspection system has the size around 1140 mm x 720 mm x 130 mm and it is installed on the end-effector of the Denso robot. As shown in Figure 6, we also build the user interface to show inspection images and help users to operate the system easily.

2.3. The lightning source system
The lightning source system is using three kinds of Light Emitting Diode (LED), i.e., red, green, and blue. The lightning system can be adjusted from 0-255 level of intensity to help the user manage different purposes. A bit similar with [14], our lightning system uses a switching-light sequence to detect the defects of work-pieces. Totally, there are eight sequences of switching-light procedures. As a result, the system starts to activate the lightning source based on their corresponding sequence order as shown in Figure 6. The lightning system is controlled by a LOTS device which is capable of
controlling six different channels efficiently. It communicates with a PC using a serial communication protocol. The communication method of lightning source control is shown in Figure 7.

![Communication protocol method](http://www.lotsmv.com/en/product/index-4-83-163.html)

3. Evaluation method
In the evaluation step, the functionality of the system is tested using Black box testing method [10], which is carried out on the detecting pose system, inspection system, and lightning control system. This test is used to find errors that may occur in the system as shown in the Figure 8. We use the term "black box" method because the actual proposed program being executed is not examined.

![Black box method](http://www.lotsmv.com/en/product/index-4-83-163.html)

4. Result and discussion
The proposed AOI system has been successfully developed and the functionality for each section is working well. Here, this section shows some outputs from the system and its evaluation method using black box method.

4.1. The pose detection system
The test was carried out to avoid any errors when the system was executed. The test was done to (1) 2-camera with 16-mm lens, (2) DOV, (3) lightning source, and detecting pose. The testing results validated all parts of the AOI system as shown in Table 1.
Table 1. Evaluation of detection pose system.

| Parameter                  | Note                                      |
|----------------------------|-------------------------------------------|
| 1 2 Cameras with 16-mm lens| Working well                              |
| 2 DOV                      | Working well. It is able to take clear images. It is not blurry. |
| 3 Lightning Source         | Working as proposed sequence              |

The corresponding Table 1 has some performance result that represent how the systems work on the production lines. Here, we represent the performance based on the value differences between reference pose & current pose which has value x, y and theta as shown in Figure 9. Based on Figure 9.

| Average of Picking Workpieces from Conveyor | X dif Average | Y dif Average | Theta |
|--------------------------------------------|---------------|---------------|-------|
|                                            | -2.02         | 11.4577       | -0.692 |

Figure 9. The value of x, y and theta average.

4.2. The inspection system

The inspection system testing was carried out to avoid errors of Field of View (FOV) from each camera while the systems inspected the work-pieces. The test was done using 4 cameras installed on the frame. We used equations (1) and (2) to calculate the FOV from each cameras and Image Circular Diameter (ICD). The ICD parameter has purposed to calculate the image not getting vignette problem while inspected the object. In addition, Equation (1) has purposed to calculate the correct focal length based on the working distance and sensor size. We also evaluated image quality by using equation (3) to represent pixel/cm of inspected object. The CCD sensor in our AOI system was 3.45 um (micro meter), and the camera resolution was 2048 x 1020 pixel. As a result, the defect representation on the picture produce 42 pixel/cm which was good and clear enough for defect detection in object has FOV value (length) around 48 cm, as shown as figure 10.

\[ f = \frac{h.wd}{h fov} \]  
\[ ICD = \sqrt{Hfov^2.Vfov^2} \]  
\[ \frac{Pixel}{cm} = \frac{(H or W)Pix Resolution}{Field of View} \]
4.3. The lightning source sequences

In this step, we evaluated the lightning source system using our sequence procedures as shown in Figure 11. Totally, we had 8 sequences (S1-S8) to capture the images of work-pieces on the moving conveyor. As shown in Figure 10, the defects of work-piece were shown on our interface system. The testing results were confirmed that all parts of the AOI system were running well.

5. Conclusion

In this paper, we have proposed an AOI system to scan clear images of work-pieces on a moving conveyor. The overall system was build using six cameras for appearance inspection and a camera for detecting the pose of incoming work-pieces. The evaluation testing was done using black box method showing that proposed system worked properly as expected. It has delivered good performance by looking the average of the pixel differences of $x, y$ and $\theta$. In addition, the image had 42 pixel/cm which good for defect detection.

6. References

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