Image detection of inner wall surface of holes in metal sheets through polarization using a 3D TV monitor

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ABSTRACT

We propose an effective technique for optically detecting images of the inner hole-surface of a hole (hereafter, referred to as the hole-surface) using the polarization property of a 3D television (TV) monitor. The polarized light emitted by the TV monitor illuminates the hole-surfaces present in the test target placed on the screen of the monitor. When the polarizer placed in front of a camera lens is adjusted such that the camera captures a dark image for the transmitted light, only the highlighted hole-surfaces are visible in the captured image.

Keywords: polarization, 3D television, sheet metal, inner wall surface of a hole

1. INTRODUCTION

Sheet-metal working is one of the most important processes in industrial manufacturing because many commercial products require a metal chassis. However, a majority of inspections for sheet-metal products are conducted manually even now as shown in Fig. 1. Because this kind of inspection takes a long time, it is an obstacle to quick delivery and cost reduction. Moreover, since the inspection is implemented once before mass production begins, numerous defective products will be produced if some accidents such as misfeed or breakage of the mold occur during the manufacturing process. An automated inspection system needs to be introduced for sheet-metal working in order to reduce the production cost.

For this purpose, we plan to configure a suitable system that uses optical and computerized image processing techniques. The proposed sheet-metal production cycle shown in Fig. 2 applies computerized image processing techniques to the inspection. This enables automatic inspection, quick delivery, and cost reduction. Inspecting samples during mass production is easy, and it prevents massive product failures. The test data or related web contents can be shared between companies in the same trade so as to increase production efficiency.

Although a digital camera is a suitable imaging device for this purpose, it captures unnecessary images of the inner wall surface of a hole (hereafter, referred to as the hole surface) in a thick test target. At times, it is difficult to distinguish between the surface of the target and the hole surface. Hence, the unnecessary hole surface images only serve to further complicate the image processing that requires to be performed for edge detection.

We have previously proposed an effective technique for optically detecting the hole surface image using the polarization. It is, however, complicated work because we have to rotate crossed polarizers without moving the test target. In our new technique, the complicated work is reduced by use of the property of a 3D television (TV) monitor. The polarized light emitted by the TV monitor illuminates the hole surfaces present in the test target placed on the screen of the monitor. When a retardation film and polarizer placed in front of a camera lens is adjusted such that the camera captures a dark image for the transmitted light, only the highlighted hole surfaces are visible in the captured image because the light scattered at the hole surfaces is depolarized. This reduces the complexity of performing image processing for edge detection. We confirmed the proposed technique by verifying the hole images observed with various combinations of polarizing conditions.

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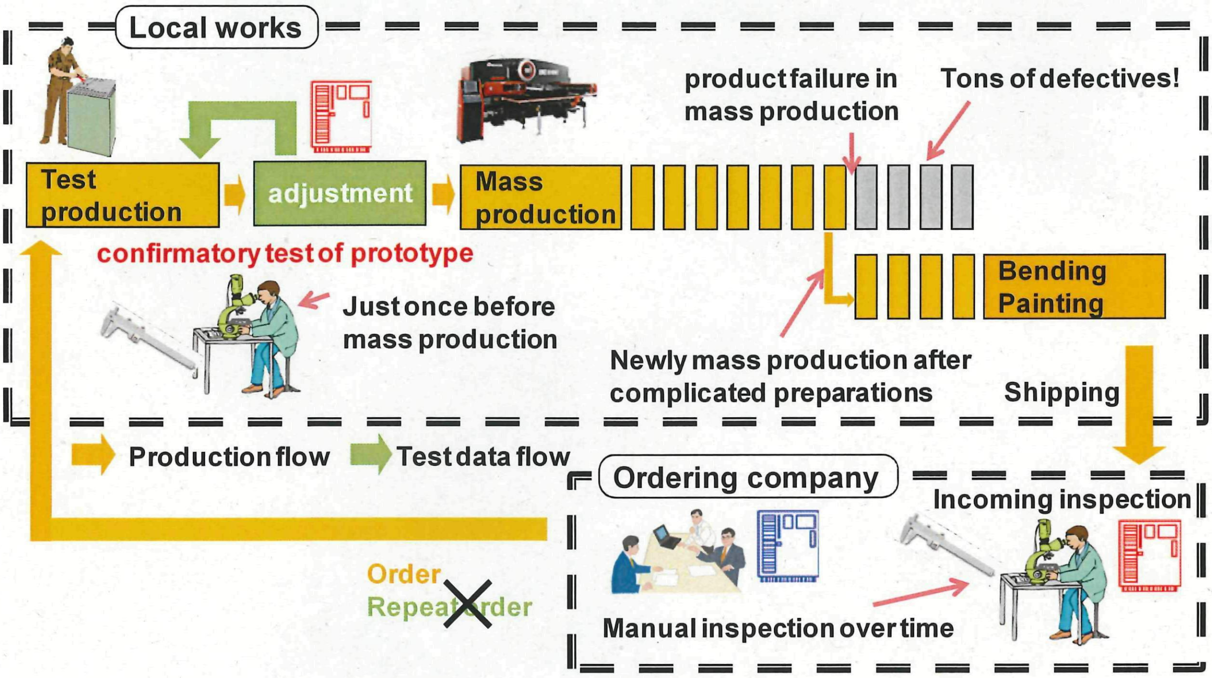


Fig. 1 Conventional sheet-metal production cycle.

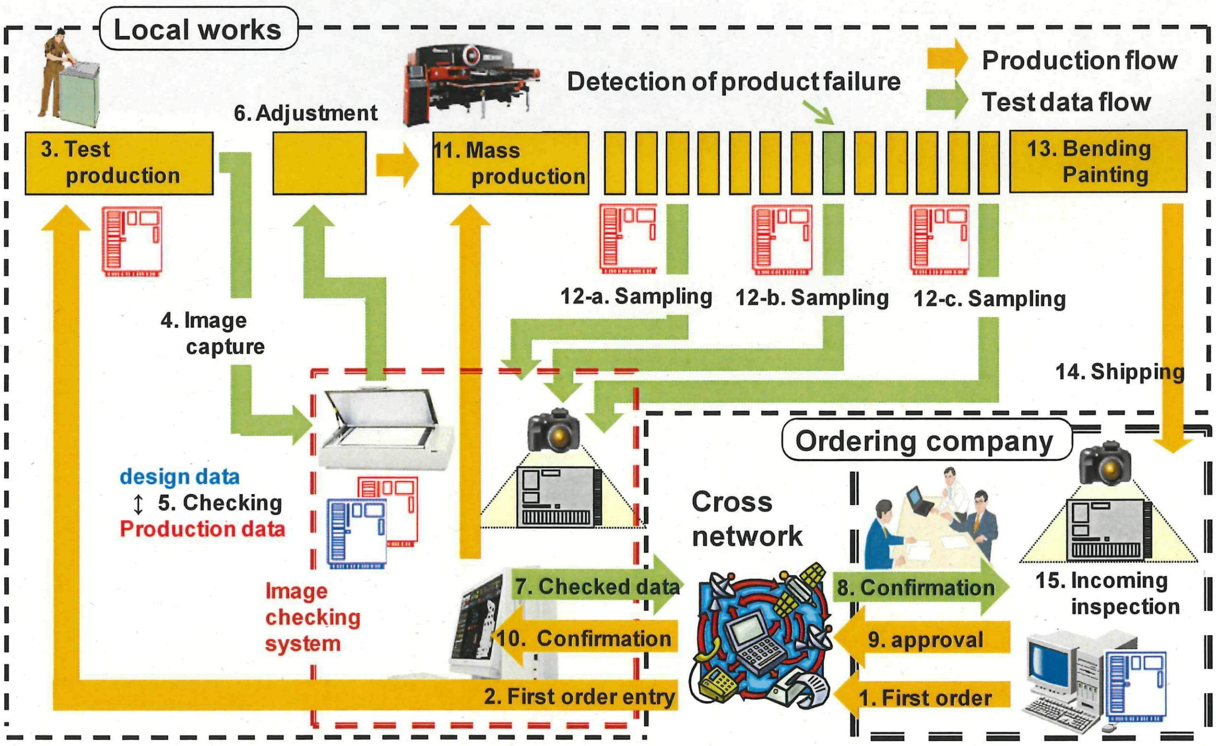
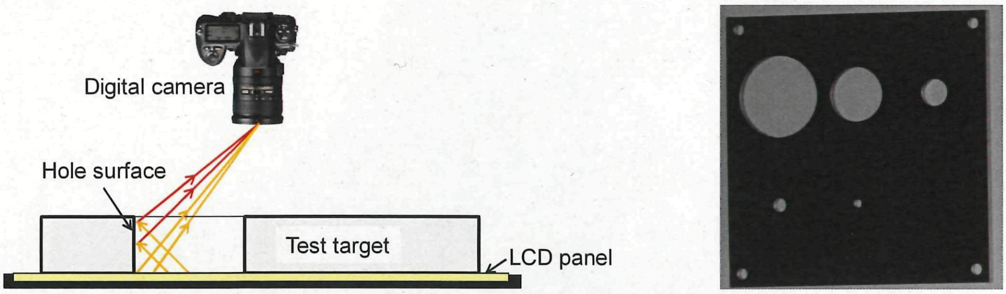


Fig. 2 Proposed sheet-metal production cycle assisted by optical and computerized image processing.

2. IMAGE CAPTURE USING A DIGITAL CAMERA

We can use a flatbed scanner or digital camera for imaging a test target, as shown in Fig. 2. However, a flatbed scanner takes a long time to capture an image because it requires a mechanical scan. In this paper, we focus on a digital camera as an imaging device. Recently, performance of digital cameras has been improving, and prices have been reducing. This makes them suitable for our purpose. Figure 3 shows a simple diagram of the setup of the image capture system using a digital camera, along with a sample captured image. The test object placed on the liquid crystal display (LCD) panel is irradiated by a backlight and imaged by the digital camera. The image capturing speed is very fast compared to a flatbed scanner system because no mechanical scanning is required. However, the digital camera system also captures hole surfaces, as shown in Fig. 3(b), which is undesirable. Sometimes it is difficult to distinguish between the surface of the target and the hole surface because the intensity of the hole surface image depends on the roughness of the hole surface, the in-plane location of the hole, and the tilt of the hole. Thus, this inclusion of these hole surfaces in the image affects image processing for edge detection.



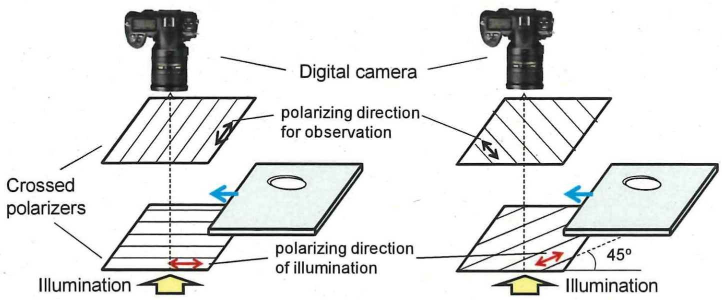
(a) (b)

Fig. 3 (a) Diagram of the imaging system using a digital camera and (b) a sample captured image containing hole surfaces.

3. IMAGING TECHNIQUES FOR HOLE SURFACE DETECTION

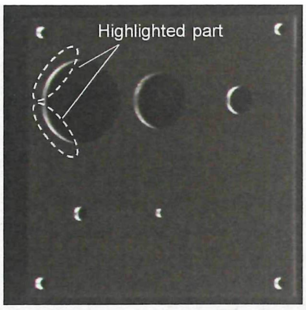
3.1 Hole surface detection using crossed polarizers

We have previously proposed an effective technique for optically detecting hole surfaces in images[1]. It reduces the image processing burden for edge detection. The schematics of the setups are shown in Fig. 4. In both cases, no light is received by the digital camera if the target is absent, because of the crossed polarizers[2]. However, when the target is inserted between the crossed polarizers, a portion of the hole surfaces in the target is highlighted because the light reflected from the corresponding parts is depolarized[3]. In this technique, the highlighted part depends on the polarization direction of the lower polarizer, as shown in Fig. 5. Thus, we have to rotate the lower polarizer to capture the image. However, it is very difficult to rotate the lower polarizer while keeping the target stationary because the polarizer is located immediately under the target.

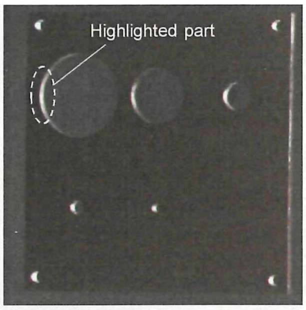


(a) angle of polarization 0 ° (b) angle of polarization 45 °

Fig. 4 Configurations for hole surface detection using crossed polarizers.



(a) angle of polarization 0 °

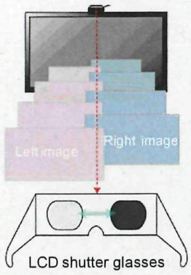


(b) angle of polarization 45 °

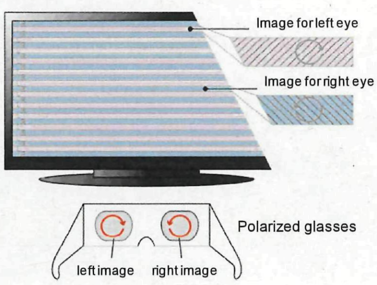
Fig. 5 Images of hole surfaces partially enhanced with the crossed polarizers.

3.2 Hole surface detection using 3D TV monitor

The technique we propose in this paper uses a 3D TV set[4], which can be classified into two types, as shown in Fig. 6. One, called a frame sequential system or a time division system, alternately displays parallactic images to the respective eyes using synchronized shutters (Fig. 6(a)), and the other, called a polarization system or space division system, interlaces left and right circularly polarized images and separates them using similarly polarized lenses for the right and left eyes (Fig. 6 (b)). We use the polarization system for hole surface detection. The basic configurations are shown in Fig. 7. When we display the left image on the TV, a retardation film converts the left circular polarization into linear polarization, as shown in Fig. 7(a). However, the polarization of the right image is converted into orthogonal linear polarization, as shown in Fig. 7(b). This means that the direction of linear polarization can be oriented by means of image selection. No mechanical movement is required for orienting the direction of linear polarization.

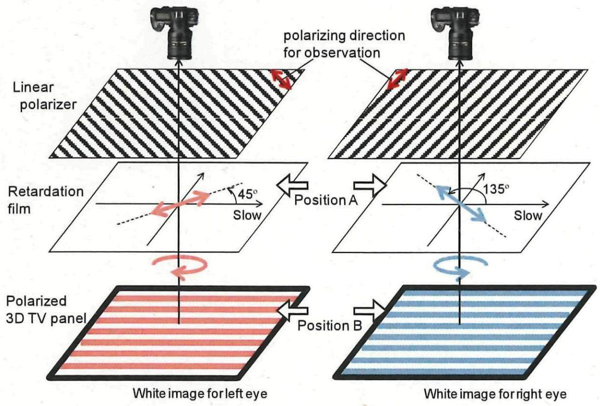


(a)



(b)

Fig. 6 Principles of a 3D TV set: (a) frame sequential system and (b) polarization system.



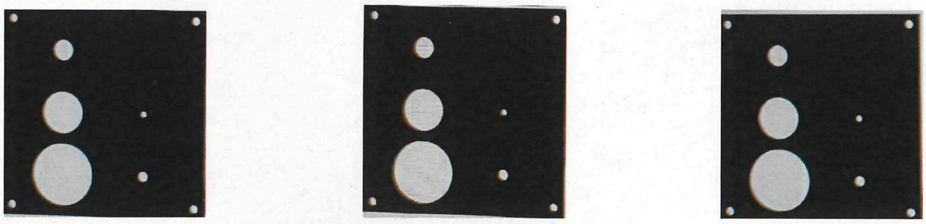
(a) left circular polarization (b) right circular polarization

Fig. 7 Configurations for hole surface detection using polarization 3D TV system.

4. EXPERIMENTS

4.1 Observations without polarization control

We observed the target images without any polarization control. Both images were displayed on the TV. Figure 8 shows the captured images in three kinds of materials, common steel, stainless steel, and aluminum, with thicknesses of 3.2 mm, 3.0 mm, and 3.0 mm, respectively. There images demonstrate that hole surface detection is difficult without any image processing.



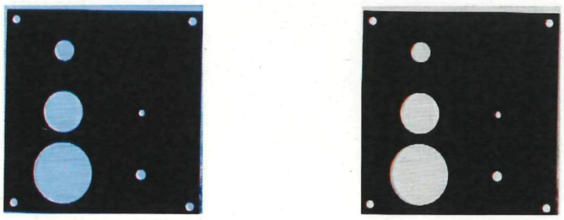
(a) common steel (b) stainless steel (c) aluminum

Fig. 8 Observations of targets composed of three kinds of materials.

4.2 Observations with polarization control

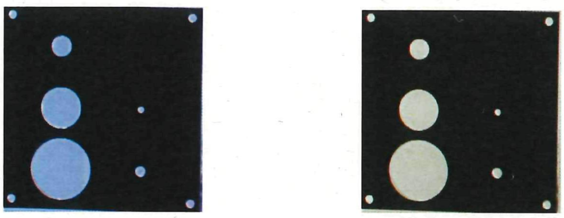
We examined images of the common steel target captured when it was inserted into positions A and B, as shown in Fig. 7. The direction of the slow axis in the retardation film was oriented horizontally. When the target was inserted into position A, the condition of the polarization was almost the same as that in Fig. 4. The results are shown in Fig. 9. We confirmed that the hole surfaces in both images were highlighted. Figure 10 shows the observed images when the target was inserted into position B. In this case, the circular polarization was depolarized at the hole surface, and we found that the hole surfaces were highlighted. We found no significant differences in detection capability between positions A and B. The light intensity at the apertures was not reduced by the polarization control. This indicates that the regulation of the polarization in the TV and the property of the retardation film deviated from the ideal conditions.

Next, we rotated both the retardation film and the linear polarizer by 90° and observed the images of the target placed at position B. The results are shown in Fig. 11. We found that the light intensity at the apertures in Fig. 11 decreased in comparison with that in Fig. 10. Moreover, the hole surfaces can be detected clearly in Fig. 11. When the same observation was implemented at position A, clear hole surfaces were not detected. These results confirmed that a clear hole surface can be detected when the slow axis in the retardation film is oriented vertically, and the target is placed at position B.



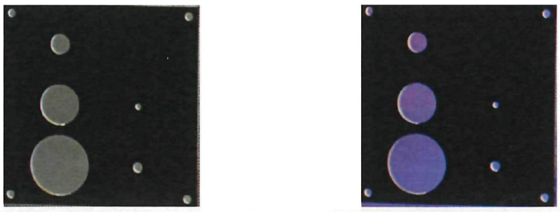
(a) left circular polarization (b) right circular polarization

Fig. 9 Observations of the common steel target at position A (slow axis is horizontal).



(a) left circular polarization (b) right circular polarization

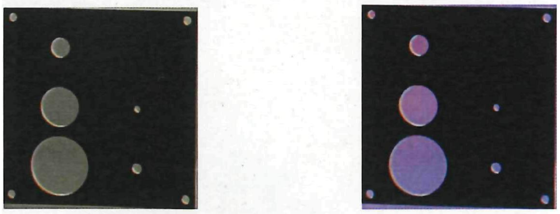
Fig. 10 Observations of the common steel target at position B (slow axis is horizontal).



(a) left circular polarization (b) right circular polarization

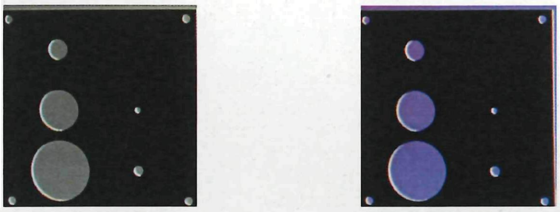
Fig. 11 Observations of the common steel target at position B (slow axis is vertical).

Finally, the other materials were observed at position B keeping the slow axis of the retardation film vertical. The results for the stainless steel and aluminum are shown in Figs. 12 and 13, respectively. While the hole surfaces in the aluminum target were detected more clearly, those in the other targets were detected sufficiently.



(a) left circular polarization (b) right circular polarization

Fig. 12 Observations of the stainless steel target at position B (slow axis is vertical).



(a) left circular polarization (b) right circular polarization

Fig. 13 Observations of the aluminum target at position B (slow axis is vertical).

5. CONCLUSIONS

A novel processing cycle for sheet-metal working based on optical and computerized image processing techniques was proposed, and the optical technique was demonstrated. It automates the inspection of products and reduces the required inspection time. The configuration of the image capture system, which uses a digital camera and a 3D TV set, was presented. The polarizing property of the 3D TV monitor simplified the polarization control. We confirmed that the combination of circularly polarized light and a retardation film improved the operational performance of the image capture system and the clarity of the detected hole surfaces.

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