Shape Disparity Inspection of the Textured Object and Its Notification by Overlay Projection

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Abstract. In this paper we describe about use of the projector camera feedback system for shape disparity check of the textured object. Using the negative feedback in the proposed system, we realized real time shape disparity inspection and its visualization at the same time. In the experimental result, we confirmed the system has an ability to distinguish the 2 mm of shape disparity and its response time was 0.2 sec.

1 Introduction

With the factory automation growth, the visual inspection is the most widely used for many applications in the last few decades [1]. For example, the visual inspection is used for inspection of medicine tablet or capsule [2], engine valve [3], metallic industrial workpieces [4], aircraft surface [5], fabric texture [6] and other many applications and it includes apple quality evaluation [7]. In the visual inspection there are two strategies, those are full automatic inspection and semi-automatic inspection. If the inspection is able to implement by easy detection rule and it allows un-detection like a quality checking of the tablet, the automatic detection is suitable. Contrary, if it is complicated inspection and it never allows un-detection such as surface inspection of aircraft, semi-automatic detection that means assist of manual inspection for the operator is more suitable. Almost visual inspection system aims automatic and precise inspection, but the visualization was not considered well. In the semi-automatic process, the operator have to check corresponding defect in the inspected object to make sure its notification by the inspection result that was shown in the monitor display.

Recently, the research of projection based AR system is becoming active and it is useful for visualization of the visual inspection. Bimber et al. [8] proposed high dynamic range imaging technology that used optical projector with printed picture. The system enables boosting of the contrast of printed picture by the overwrap projection of the compensation light from the projector. This technique is proposed for new display technique. However, such like display technique that is projection-based AR technique is helpful not only for display technique but also as using as the inspection assist technique for the operator too. Amano et al. [9] proposed projector camera feedback system for the appearance enhancement of the less saturated picture in the realtime processing. This projector camera system realizes a realtime processing and its system achieved 15 fps processing for the appearance enhancement. Its real time

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processing enables assist of human visual perception in the manufacturing line. However, this system aims to enhance the object's appearance of color difference and brightness contrast caused by defects, so it cannot use for shape disparity inspection of free-form surface. However, its overlaying inspection result of shape disparity by using projection based AR technology is also useful for its visualization. Also, inspection of faint shape disparity is not easy for human perception.

From these reasons, we propose a visualization technique of the shape disparity inspection by the AR technology. Especially, we use a projector camera feedback due to realize realtime visualization that aims to human computer interaction.

2 Shape Disparity Inspection and Visualization

Typical flow of shape disparity inspection and visualization is illustrated in figure 1. In the shape disparity inspection process, we need a shape measurement. A rapid and cheapest shape measurement system is to employ space code projection such as gray code with commercial projector for the shape measurement. In this process, we have two problems. One is we need several times projection and it is processing time expensive for real time inspection. Other one is visually confusing. Because it is hard to distinguish projections for shape measurement and visual notification. Of course, we can use commercial range imaging system that used invisible light and has a capability of high speed measurement. However, it is expensive and whole inspection system is complicated because we need a projector for the visualization besides range imaging system. Therefore, we use a simple projector camera system, and we propose the method that makes whole shape measurement and visualization process more efficiently.

The core process of the shape measurement with the active stereo is calculating disparity between projector screen and camera image. This disparity is translated to 3-D shape by the camera and projector parameters. However, the calculation of calibrated

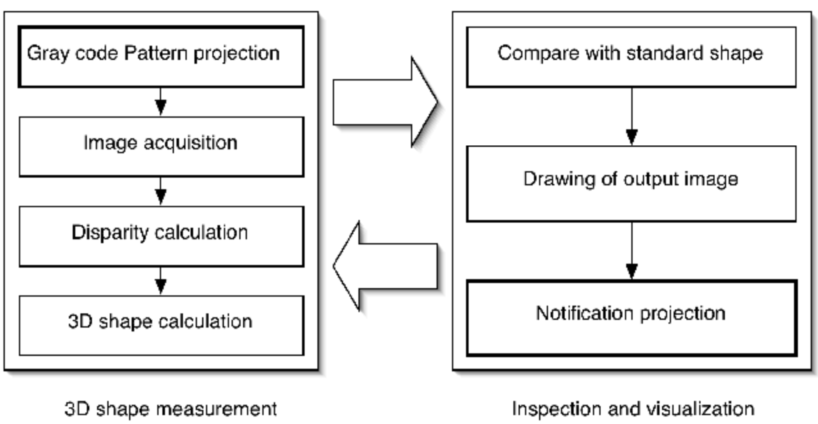

Fig. 1. Typical flow of the shape disparity inspection and visualization

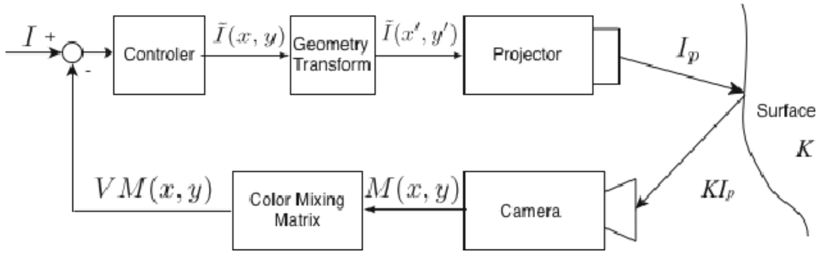

Fig. 2. A concept of projector camera negative feedback system

shape is unnecessary if we need only to check the match with a standard shape for inspecting dents. It is often required by quality check in the manufacturing line. The match of the disparity at a point of image plane is confirmed by checking of the space code, but its cost is equivalent with a conventional gray code projection. If we think about single point check, we can confirm its matching from whether a dot is projected on the corresponding point that is calculated by disparity of standard shape or not. However, in case of cell parallel processing, we have a problem of interference among neighbor projection points. Furthermore the system cannot realize continuous visualization because we need two projections of check and notification step. Therefore, we propose the single step projection method by the projector camera feedback that enables check and notification in the same time.

If we think about negative feedback system that is shown in figure 2, the projected light $\mathbf{I}_p \in \Re^3$ will converge along with to desired brightness $\mathbf{I} = [I_R, I_G, I_B]^T$. The negative feedback projector camera system was proposed by Nayar et al. [10][11], and that enables projection of images onto an arbitrary surface such that the effects of the surface imperfections are minimized.

In this paper, we regard the radiometric relation as rgb-color-channel model and we put compensation light power for time *t+1* as:

$$\tilde{\mathbf{I}}(t+1) = \tilde{\mathbf{I}}(t) + G(\mathbf{I} - \mathbf{VM}(t)) \tag{1}$$

where $\tilde{\mathbf{I}} = [\tilde{I}_R, \tilde{I}_G, \tilde{I}_B]^T$ and $\tilde{\mathbf{I}}(0) = \mathbf{0}$. $\mathbf{G} \in \Re^{3\times 3}$ is a diagonal matrix that gives feedback gain, $\mathbf{V} \in \Re^{3\times 3}$ is color mixing matrix that compensate the difference of color space between projector and camera, $\mathbf{M} = [M_R, M_G, M_B]^T$ is acquired pixel value.

3 Color Calibration

The projector and camera have different color space since they have unique spectral sensitivity functions and non-linear illumination response curve functions. The general polynomial transformation for the camera sensitivity [12] and the calibration of projector response function [13] improve the color matching, but these calculation costs are not reasonable for the realtime processing. Therefore, we use a simple linear RGB to RGB transformation for the inter channel dispersion correction by the matrix $\mathbf{V}$. Usually, the color calibration chart is used for camera color calibration due to get absolute color sensitivity. However, our feedback system is not important absolute color sensitivity rather than the relation between camera and projector color spaces, because it is satisfied for the appearance enhancement if the system can project same color as the object color. Therefore, we compute its color space relation between camera and projector as below.

In the first step we project R, G, B plain color form the projector. At each projection, we get mean pixel value of each channel w_R, w_G and w_B at the whole projected area in the captured image. In the second step, we compute the mixing matrix as:

$$\mathbf{V} = \mathbf{W}^{-1} \det(\mathbf{W}) \tag{2}$$

where

$$W = \begin{bmatrix} w_{R1} & w_{R2} & w_{R3} \\ w_{G1} & w_{G2} & w_{G3} \\ w_{B1} & w_{B2} & w_{B3} \end{bmatrix},$$

w_{*1}, w_{*2} and w_{*3} are meaning pixel values with R, G and B plain color projection respectively. We apply the mixing matrix after the image capture. Thus the color calibration is done by conversion of the camera color space to the projector color space.

4 Per-pixel Mapping Calculation

For the shape disparity inspection, we have to get the stereo disparity among projector and camera beforehand as a standard shape data. This stereo disparity is given by the part of conventional active stereo shape measurement process and is expressed by a per-pixel map between projection screen coordinate (x_p, y_p) and camera image plane coordinate (x_c, y_c). To compute lookup table for the per-pixel mapping, the gray code patterns projection by a complementary pattern projection that is the traditional method of the range image measurement is a robust way to get correspondence of coordinates (figure 3). Thus, we used vertical and horizontal gray code patterns for the calculation of lookup tables $x_p(x_c, y_c)$ and $y_p(x_c, y_c)$. In the actual implementation, we used inverse mapping $x_c(x_p, y_p)$ and $y_c(x_p, y_p)$ to reduce computational cost. These inverse mappings were generated by the voting with $x_p(x_c, y_c)$ and $y_p(x_c, y_c)$.

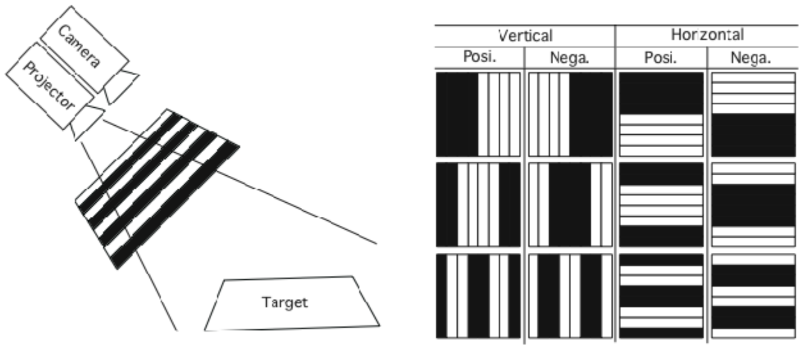

Fig. 3. Per-pixel mapping calculation by the complementary gray code pattern projection

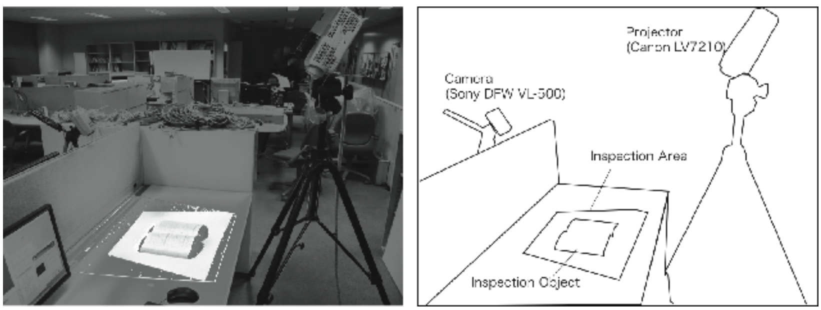

Fig. 4. The setup of the shape disparity inspection based on projector camera system

5 Experimental Result

Figure 4 shows the experimental setup. The camera (SONY DFW VL-500, RGB 8bit, 640 × 480 resolution) is put the front of the projector (CANON LV7210, RGB 8bit, 1024 × 768 resolution) and these were targeted on the same region of the worktable. For the system calibration, we calculate the color mixing matrix by (2) with RGB plain color projections. The feedback gain was set as $\mathbf{G} = diag(0.4, 0.4, 0.4)$ from our experience. The exact behavior of proposed negative feedback system was not considered by above theory. Therefore, in this research we tried to consider from its experimental results. To check its behavior, we used an opened book that is a smooth shape object shown in figure 5(a). The per-pixel map was calculated by gray code projection onto its opened book. With this per-pixel map, the appearance of the original shape is changed to figure 5(b) by the negative feedback and its texture is removed. This result is suitable for checking shape disparity, because often the texture confuses the projected notification. With the upper right 2 mm dent of inspection object the appearance was changed as shown in figure 5(c). The figure 5(d) shows a projected compensation pattern for figure 5(c).

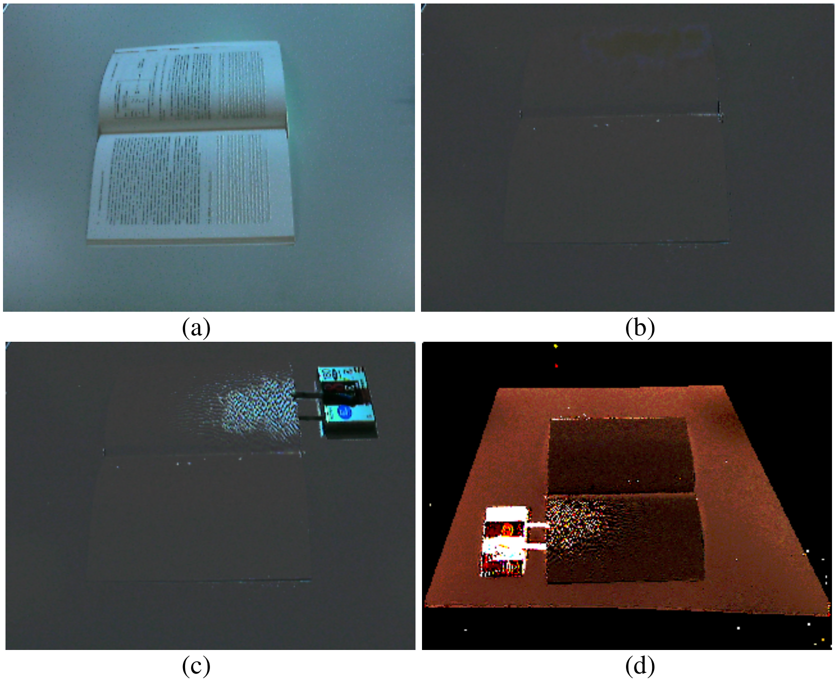

Fig. 5. (a) Inspection object, (b) Negative feedback changes objects appearance and it removes texture. (c) With the 2mm displacement by the pushing, the stripe pattern (d) was projected at the dent area.

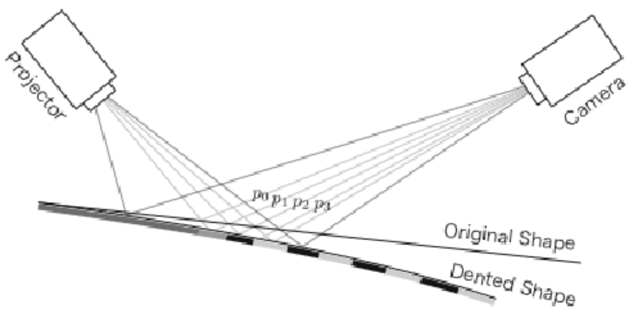

Fig. 6. The mechanism of stripe pattern generation

From this experimental result, we confirmed divergence of compensation light and it makes a striped pattern at the dented region. It is caused by in the figure 6 the projection light becomes over-power/under-power illumination at the point p1 since un-controllable because of a little disparity. For this over-power/under-power illumination neighbor point p2 becomes under-power/over-power illumination since it reference the point p1, and the stripe pattern is generated by its repeat. The width of stripe reflected a magnitude of dents depth geometrically, but it is not calibrated and also plus and minus is not measurable.

Our experiment was performed on a Core 2 Quad 2.66GHz PC with OpenMP library, and its processing frequency was reached 26 fps. We confirmed its striped pattern was stabled within around 5 frames by the step by step checking. Therefore the response time was about 0.2 sec.

6 Conclusion

This work shows the potential of the projector camera feedback system for the assistance system that aims the shape disparity inspection. In the conventional shape measurement method, we need several times of code pattern projection. Additionally, we need a projection of the inspection result for the AR based visualization. However our method integrated both projections by using of the projector camera feedback. In the experimental result, we confirmed the system has an ability to distinguish the 2 mm of shape disparity and its response time was 0.2 sec. In a future work, we need the theoretical analysis and development of inspection method of plus and minus of its dents.

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