MVA'90 IAPR Workshop on Machine Vision Applications Nov. 28-30,1990, Tokyo

SHAPE INSPECTION OF 3-D OBJECTS USING TIME-CODED PATTERN PROJECTION AND NEWLY DEVELOPED IMAGE SENSOR SYSTEMS

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ABSTRACT

This paper describes the accurate shape inspection method of 3-D objects. To make measurement more precisely, we introduce a newly developed composite image sensor system. The image unit of the proposed system has two different type image sensors, area and line types. It is so designed that its pixel composition is overlapped optically, so it is possible to obtain two images provided by two image sensors on the same plane respectively. In the measuring process, first, seven Gray coded light patterns are projected on the objects one after another and each image is inputted by the area sensor and range data are calculated at an accuracy of 2mm along the Z direction. Then the most thin light stripe pattern is projected and only marked regions extracted from the area image are scanned by the line sensor and range data are calculated at an accuracy of 0.3mm. The advantage of proposed system is that the measurement accuracy in marked regions can be improved up to 7 times better than that of conventional ranging systems and amount of image data is much reduced and acquisition time is also shortened.

INTRODUCTION

3-D shape measurement is a very important and useful technology in the fields of recognition of parts' shapes, robot vision or shape of human body, etc[1)2)3)]. Especially shape measurements using image processing techniques have such advantage that non contact, high speed, automatic, reliable, etc, so many effective methods have been investigated[4)]. But, they have a serious drawback that the accuracy of their methods is order of mm in the X-Y plane and order of cm along the Z direction, so that the improvement of the accuracy is one of the significant research theme. To improve the accuracy and to shorten the measurement time, Sato and Inokuchi[5)] proposed range finder with a liquid crystal shutter and improved input times within 3 seconds and also improved the accuracy by double precision method and interpolations of space code. Recently, Uesugi[6)] proposed a new ranging system using slit light scanning method. But, they use a NTSC type TV camera, so the accuracy of system is restricted by the resolution of NTSC formats. If higher resolution is required, specially constructed image input systems must be introduced. But they are expensive and amount of image data are increased abruptly and much more times are necessary in image processing.

In this paper, to enable highly accurate shape inspection of 3-D objects in a short time, we introduce a newly developed composite image sensor system and a time-coded stripe type pattern projection method using liquid crystal shutter. The image input unit of this system has two different type image sensors, area and line types, and its pixel composition is overlapped optically. The area image sensor is used to obtain ranging image and to extract regions necessary for shape inspection. A rough ranging image of objects is obtained by changing seven types of stripe projection patterns one after another. Then marked regions are extracted in the area image by image processing methods and mechanically scanned by the line sensor at an accuracy of seven times better than that of the area sensor. Using both area and line image data, 3-D shape measurement is established effectively.

SYSTEM CONFIGURATION

3-D PATTERN PROJECTION

Figure 1 shows the setup of projector and imaging system for the time-coded pattern projection method. In our system, the composite image sensor is used instead of a NTSC type TV camera. A liquid crystal shutter generates Gray coded stripe light patterns on the surface of objects quickly. Numbers of stripes of the shutter is 128, so seven light patterns are projected one after another and each images is inputted and stored in frame memories within 3

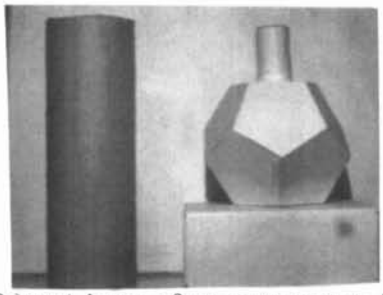

Fig.2 Input image of an area sensor.

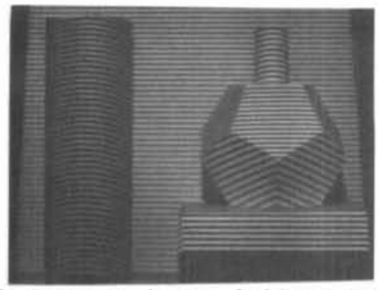

Fig.3 An area image of thin stripe.

. .g.1 Setup of the image input unit.

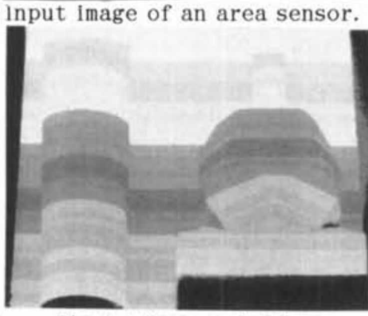

Fig.4 A Gray coded image.

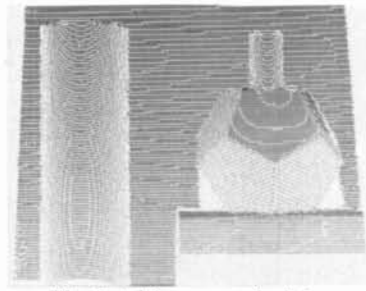

Fig.5 A binary coded image.

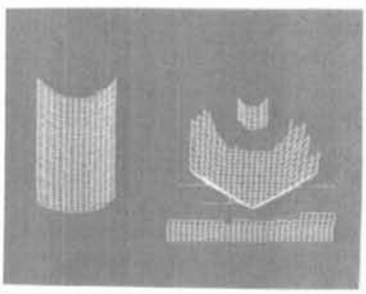

Fig.6 A 3-D display of objects.

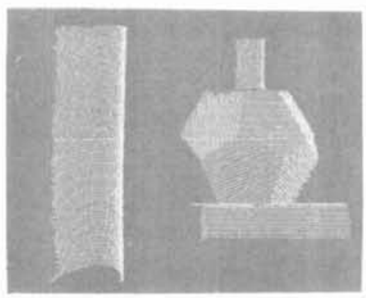

Fig.7 3-D display of objects.

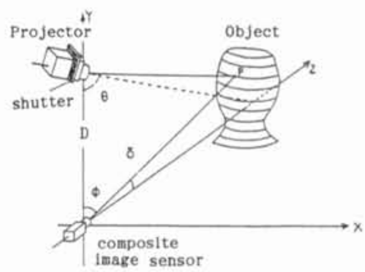

Fig.8 System configuration.

seconds. Figure **2** shows the input image by the area image sensor under uniform illumination. Figure **3** shows the inputted image under most thin light pattern projection. The input image is a 255 leveled grey image , so binarization of each image is necessary. Binarization is done based on the complementary pattern method[5]. This method requires two times much more images than the conventional method, but stable binarization is established for colored or textured objects except black. Figure **4** shows an example of a Gray coded image. Then, the Gray coded pattern image is transformed into a binary coded image. Based on the conventional method, most thin stripe pattern image is not necessary. We use most thin stripe pattern image to obtain sharp and accurate pattern edges. The Gray coded pattern image is constructed by composition of seven binary images, so pattern edges of adjacent codes are distorted by binarization, composition and noise etc. By comparison between two images, a reliable image is obtained as shown in figure **5**. Figures **6** and **7** show examples of 3-D display of target objects along different view angles. Figure **8** shows space co-ordinates and system arrangement. The position of the origin is a principal point of TV camera lens. The position of the principal point of projector lens is (0, D,Zp). Positions of objects (X,Y,Z) are derived based on the triangular method as follows,

$$X = Z \cdot \tan\xi$$
$$Y = Z \cdot \tan\delta \qquad (1)$$
$$Z = (Zp + D\tan\theta)/(1 + \tan\delta \cdot \tan\theta)$$
$$\tan\xi = dx \cdot xi/lc, \quad \tan\delta = dy \cdot yi/lc$$
$$\theta = \theta o - d\theta \cdot Ci$$

D =350mm, Z p =50mm, θ o =70, dθ =0.155, lc=16.3mm and dx=dy=0.0129mm. (xi,yi) is pixel address in the area image plane and Ci is a code number.

COMPOSITE IMAGE SENSOR

To obtain accurate images for two or three dimensional objects, we introduce a composite image sensor system. Figure **9** shows the outlook of the proposed system. Figure **10** shows construction of the image input unit. Both area and line image sensors are designed to photograph same view fields with different resolution as shown in figure **11**. Figure **12** shows the block diagram of the image input unit. The resolution of the area sensor is 512x480 pixels and that of the line sensor is 5000x1 pixels respectively.

In order to make measurement effectively using both two different type image sensors,

Fig. 9 Photograph of system.

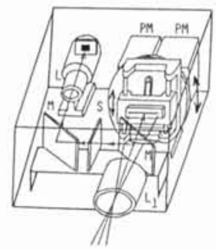

Fig.10 Composite image sensor.

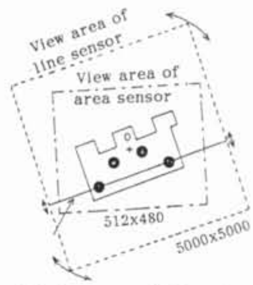

Fig.11 Area and line images.

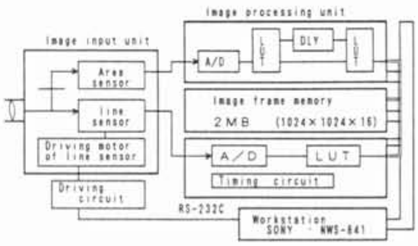

Fig.12 Blockdiagram of image unit.

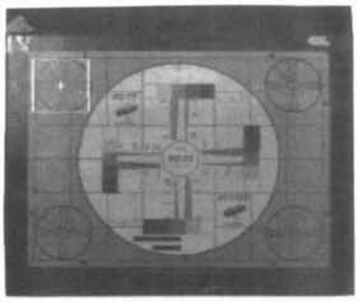

Fig.13 Marked region in area image.

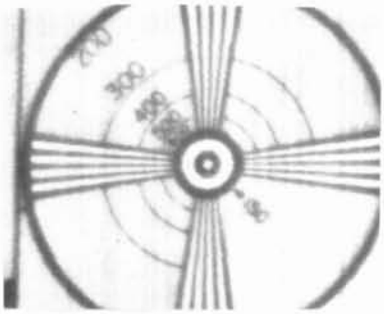

Fig.14 Line image (mode 1).

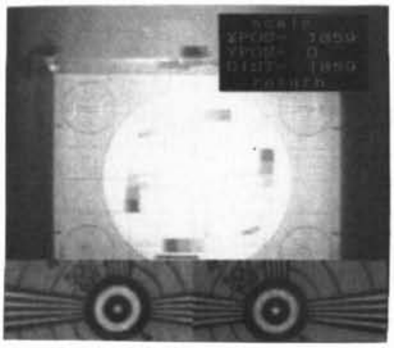

Fig.15 Composite image(mode 2).

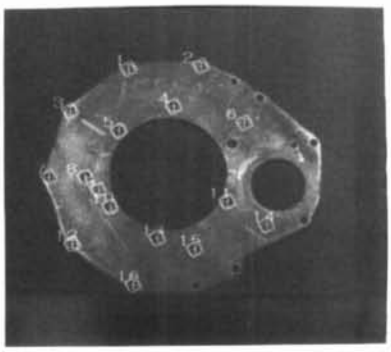

Fig.16 Marked regions in area image.

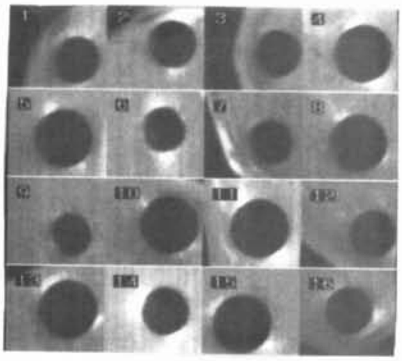

Fig.17 Composite image(mode 3).

first, the target's rough position is inputted by the area image sensor. Then marked regions are extracted in the area image by using image processing techniques. Only marked regions are scanned by the line image sensors and precise information of shapes and sizes is obtained. As the results, the read out regions are limited, the amount of data is much reduced and the time required for image input and processing is conspicuously shortened. Figure **13** shows a marked region in the area image. A white box is the region scanned by the line sensor and figure **14** is an obtained image. The resolution is improved 7 times better than that of the area image. Figure **15** shows an example of two dimensional distance measurement between two points in the area image. The upper part of the image shows the area image and lower part shows the line image. Measured distance between centers of two holes is 1859 pixels (=184.6mm). Figure **16** shows an example of positions and hole diameters of mechanical parts. 16 regions are marked and composed images of each region are shown in figure **17** and the accuracy is within 0.1mm.

3-D SHAPE INSPECTION

In this section, we propose 3-D shape inspection method using both time-coded pattern projection and the composite image sensor system. Figure **18** shows an example of the area image of target objects. First, seven gray code light patterns are projected on the objects one after another and each image is inputted by the area sensor and range data are calculated using eq.(1) at an accuracy of 2mm along the Z direction. Figure **19** shows the 3-D display of objects. Then, the most thin light stripe pattern is projected as shown in figure **20.** Figure **21** shows the line image of the marked region in figure **18** under uniform illumination. Figure **22** shows the binalized image under most thin stripe pattern projection. In order to calculate the three dimensional position of objects using this image, the code numbers of each stripes are required. Based on the definition of the time coded pattern projection method, seven images with different projection patterns must be scanned by the line image sensor. Image input

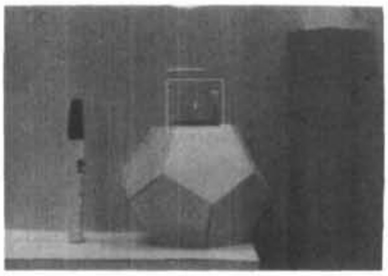

Fig. 18 Marked region in area image.

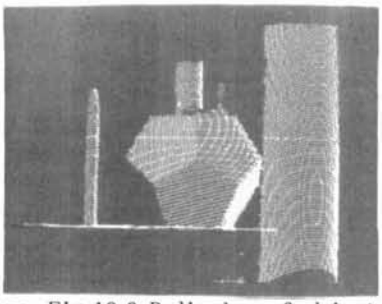

Fig.19 3-D display of objects.

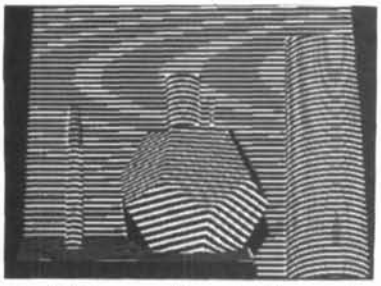

Fig.20 Image of most thin stripe.

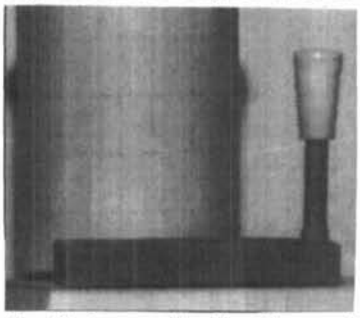

Fig.21 Composite line image.

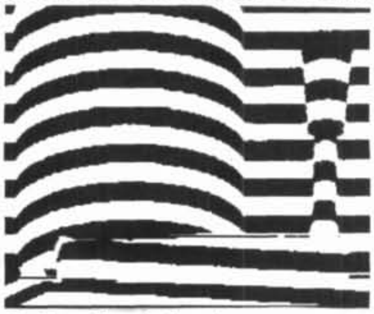

Fig.22 Binalized line image.

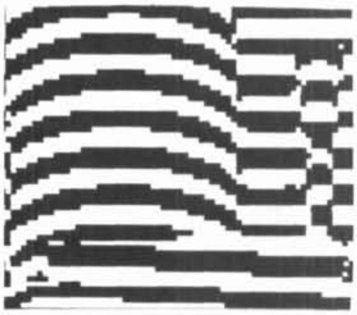

Fig.23 Magnified area image of fig.20.

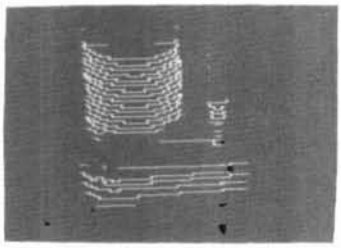

Fig.24 3-D display of an area image.

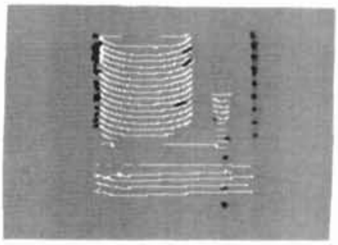

Fig.25 3-D display of a line image.

time of one scanning requires about 9 seconds, so total image input time may be more than 2 minutes. To clear this problem, the space-coded area image data in figure **19** is also used. The marked region in this image is magnified 7 times of the original image as shown in figure **23**. Each stripe has a peculiar code number from zero to 127. By comparing with figures **22** and **23**, code numbers of each pixel is transferred into the binarized image in figure **22**. Code numbers of pixels near pattern edges are decided by interpolation of code numbers of neighboring pixels. As the results, image input time can be shortened within 18 seconds (= two scanning times). Figure **24** shows 3-D display of objects by the area image and figure **25** shows 3-D display of same objects by the method mentioned above. The resolution in marked regions is improved 7 times better than that in other regions in the area image.

CONCLUSION

We have described precise 3-D shape inspection method using both time-coded pattern projection and newly developed composite image sensor system. The area sensor is used to obtain a rough range data by the time-coded pattern projection method at an accuracy of 2mm along the Z direction and also to extract marked regions scanned by the line sensor. The line sensor is used to obtain precise range data in marked regions of the area image at an accuracy of 0.3mm. The acquisition procedure of image inputting and range conversion requires about 20 seconds. The 3-D display of target objects requires about 2 minutes by workstation. This system can be contributed to make shape and size inspections of 3-D parts.

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