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Design of a Grating Generator for Three-dimensional Scanner

He Xingzheng
China Academy of Safety Science and Technology, Beijing 100012, China
e-mail: hygehy@126.com

Abstract

In the three-dimensional scanners (3D scanners) based on structured-light technology, the commercial video projector was always borrowed to act as the electronic grating generator, which is a key hardware to the device. But there were some defects existed. For example, the size was too large for setting in the case of the device, and it could not be controlled by a single chip microprocessor conveniently, etc. To solve these problems, a new grating generator was designed. The gratings were numbered and encoded in computer instructions, and then a complex programmable logic device (CPLD) chip was used to control a liquid crystal on silicon (LCOS) video chip, to write its data ports directly corresponding to the instructions. It has small size, simple interfaces, prompt response, clear instructions, and it worked well.

Keywords*: grating generator, 3D scanner, structured-light, electronic grating, CPLD*

1. Introduction

Three-dimensional (3D) scanning technology belongs to computer vision field. The 3D coordinates of the surfaces of an object can be non-contact measured by this technology rapidly and accurately. In the recent years, three-dimensional scanners (3D scanners) have been applied among a wide field [1-3]. They play more and more important roles in economic and social life. In industry, be useful in reverse engineering to create complex automotive parts and a variety of mechanical models. In orthopedics, to prostheses fabrication and in Robotics, make possible the artificial vision to mobile robots. In forensic medicine, they help to construct digital 3D models of accidents. 3D scanners gather information of an object and represent it graphically in three dimensions using different techniques [4, 5].

Usually, the key hardwares of a 3D scanner based on structured-light technology include digital cameras and a grating generator, as shown in Figure 1. The purpose of the grating generator is to project a serial of gratings to the surfaces of the object to be measured. These gratings are usually electronic gratings. Commonly, they are about 10 to 15 regular patterns with black-white strips, including several Gray-code patterns and several Cosine-function patterns. A pattern example of the gratings is shown in Figure 2. During the measurement, these gratings are modulated by the surface of the object to be measured, and then the images of the modulated gratings are captured by digital cameras. Via these images, the 3D coordinates of the surface can be calculated with proprietary algorithm. The assemblage including all of the coordinates is called point cloud [6, 7].

The commercial video projector is often borrowed to generate and project the electronic gratings for common 3D scanners, but there are some obvious problems. For example, the size is too large, it is not convenient to setup, the RGB lights come from the projector cannot focus exactly, the internal parameters of gratings can not be adjusted easily, the interfaces are not convenient for external control, the internal circuits for video signal treatment are very complicated. Due to these factors, it becomes difficult to meet the demands of miniaturization and automatization to the device, and also limit some applications in certain fields [8-10]. In this paper, a new grating generator is designed to solve these issues.

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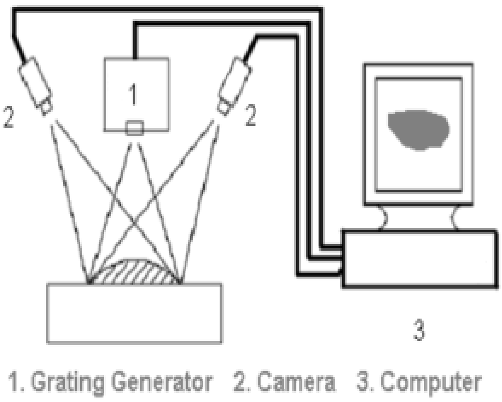

Figure 1. Schematic Diagram of a 3D Scanner

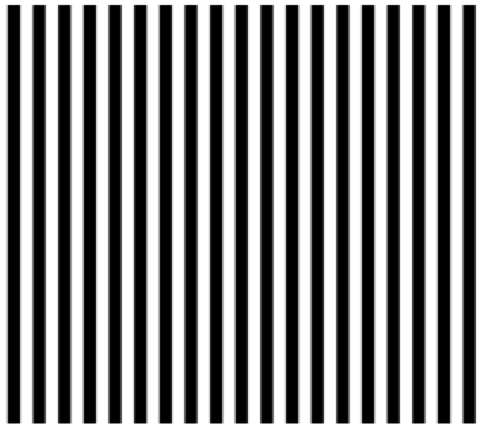

Figure 2. An Example of Gray-code Gratings

2. Grating Generator Design

To 3D scanners, the gratings to be projected depend on the specially designed system algorithm and vary from product to product. But for a certain commercial 3D scanner, the number of the gratings and all of the grating patterns are fixed. So it is possible to use the complex programmable logic device (CPLD) chip to generate and control these gratings and avoid the before-mentioned problems. The CPLD chip is high-integrated with convenient I/O ports, it is programmable and easy to control. Moreover, it is high-performance with proper price. Based on these, in this paper, a CPLD chip was used to write the input ports of a grating chip directly, to get the gratings required. The Block diagram of the system is shown as Figure 3.

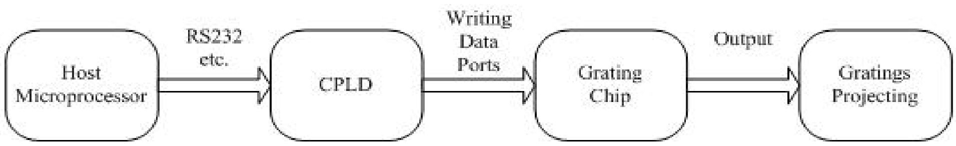

Figure 3. Block Diagram of the System

2.1. Grating Chip

There are 3 main technologies for image projecting, they are digit light processing (DLP), liquid crystal display (LCD) and liquid crystal on silicon (LCOS). LCOS is sort of a hybrid between LCD and DLP. It uses liquid crystal chips with a mirrored backing. So it's reflective, like DLP, but blocks light using liquid crystal, like LCD. In this paper, a LCOS video chip HX7027 serves as the grating chip. It is a production of Himax Display Inc. It is an active matrix liquid crystal display with resolution of 640 by 480 pixels. It receives 8-bits RGB data (3 dots per pixel) input per clock simultaneously and generates corresponding voltage output of 256 level gray scales. It is ideal for the performance demands of light weight, small size, high speed, excellent contrast ratio and good resolution applications. The chip size is about only 0.44 inches diagonal. It is suitable for 3D scanning.

2.2. Control Chip

A CPLD chip EPM3256ATC144 from Altera Corporation is chosen to drive the above-mentioned HX7027 chip. It owns 256 macro cells and Maximum 161 I/O ports for user, and its counter frequencies are up to 127MHz. It can be re-programmed for quick and efficient iterations during design development and debugging cycles.

2.3. Light Source

Usually, proper selection for the light source of the grating generator is often ignored because the importance is not really realized. In fact, it affects the measuring results a lot. One of the reasons is that the optical system cannot focus the color light exactly. The commercial projector is usually for color images, every pixel consists with at least 3 color dots, i.e. tri-chromatic colors of red, green and blue (RGB). Normally, it is difficult to get ideal grating patterns, especially to Cosine-function gratings. The diagram of light focus error is shown as Figure 4.

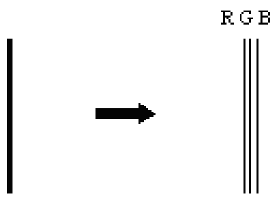

Figure 4. Diagram of Light Focus

A single white-color LED (light emission diode) is used to be the light source of the grating generator to deal with this issue. For LED, the other advantages are its features of long-life and low power consumption meanwhile.

2.4. System Design

Firstly, list all the grating patterns needed, and then label them to serial numbers. The serial numbers are encoded in computer instructions with simple grammar. Secondly, for each grating, the corresponding softwares are embedded in the CPLD and be related to the above-mentioned instructions.

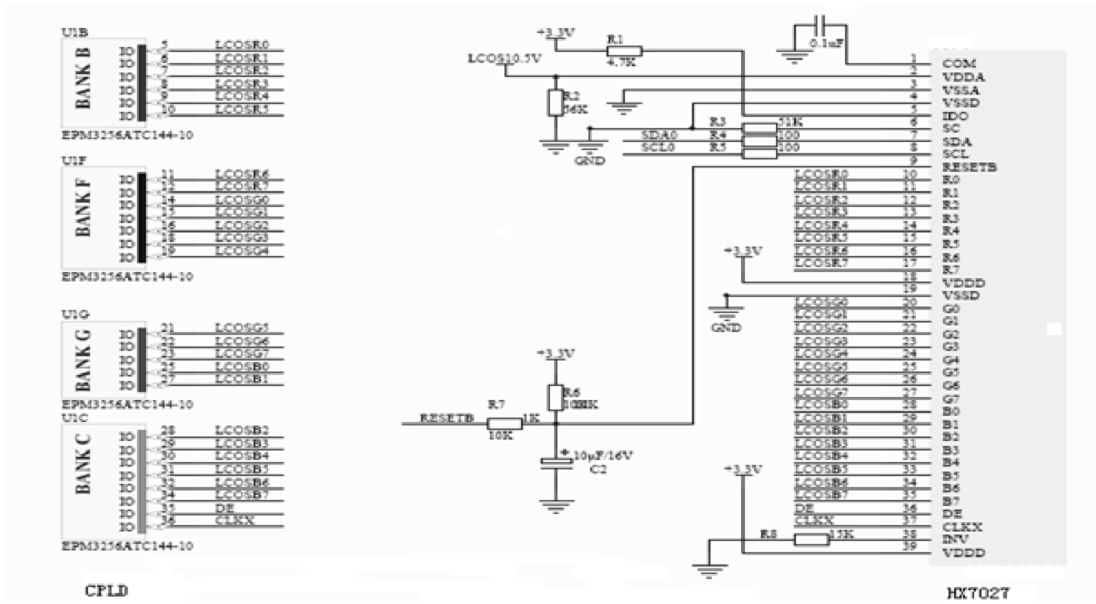

Figure 5. Electronic Circuit Diagram of the System

In 3D scanning processing, the above-mentioned instructions are sent to the CPLD chip on-demand, via RS232 or USB interface, by the host computer (or microprocessor) of the 3D scanner. Then the serial numbers of the gratings are decoded from the instructions, accordingly, the CPLD writes the corresponding 1 or 0 to each data input port of HX7027 simultaneously. HX7027 is a dot-matrix chip, due to its high-speed feature, the required grating patterns can be projected without flicker. Of course, a projecting optical system is necessary. The electronic circuit diagram of the system is shown as Figure 5.

2.5. The Software of CPLD

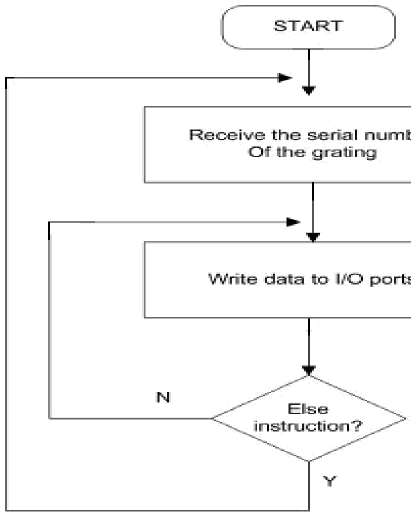

Figure 6. Simplified Software Flow Chart of CPLD

```
always@ (negedge clkout)
begin
    if (counten == 1'b1)
       begin
       if (linecount < 480)  //image line count
          begin
             case (datain)  //any data input
             8'h1:begin
                if (columncount < 320)  //image column count
                   begin
                   de <= 1'b1;  //enable data input
                   dataout <= 24'b111111111111111111111111; //white line
                   end
                else if (columncount >= 320 && columncount < 640)
                   begin
                   de <= 1'b1;  //enable data input
                   dataout <= 24'b0; //black line
                   end
                else
                   begin
                   de <= 1'b0;  //disable data input
                   dataout <= 24'b0;
                   end
             end
          end
    end
end
```

Figure 7. A segment of the Software of CPLD

The main function of the software embedded in the CPLD chip is to write data 1 or 0 to each data input ports of HX7027 per timing clock, with high-speed. In each procedure, CPLD writes data to every matrix dot (Total 640×480 dots) of HX7027 constantly and repeatedly according to the instruction received from the host computer (or microprocessor). Data writing process will continue until a new instruction coming. The simplified software flow chart of CPLD is shown as Figure 6. A segment of the software of CPLD is shown in Figure 7.

2.6. Heat Management

In this design, the CPLD chip works very busy, and writes data to I/O ports constantly in very high frequencies. A design reasonable software architecture of CPLD to reduce the power consumption becomes very important for the system stability. Moreover, sometimes a small ventilation fan is also necessary for chip cooling.

3. Results and Tests

3.1. Output of Electronic Gratings

The grating generator been designed works well, only simple computer commands are needed for projecting specified gratings. The size is about 80mm long, 70mm wide and 40mm high, so it is easy to set in limited space. 2 examples of the projected gratings are shown in Figure 8 and Figure 9.

Figure 8. Projected Gray-code Grating

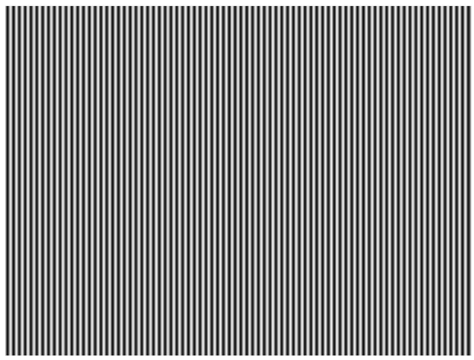

Figure 9. Projected Cosine Grating

3.2. Scanning Results

The grating generator above was installed in a 3D scanner for testing. It was easy to be controlled by host microprocessor and responded promptly. The measured data was good, as shown in Figure 10.

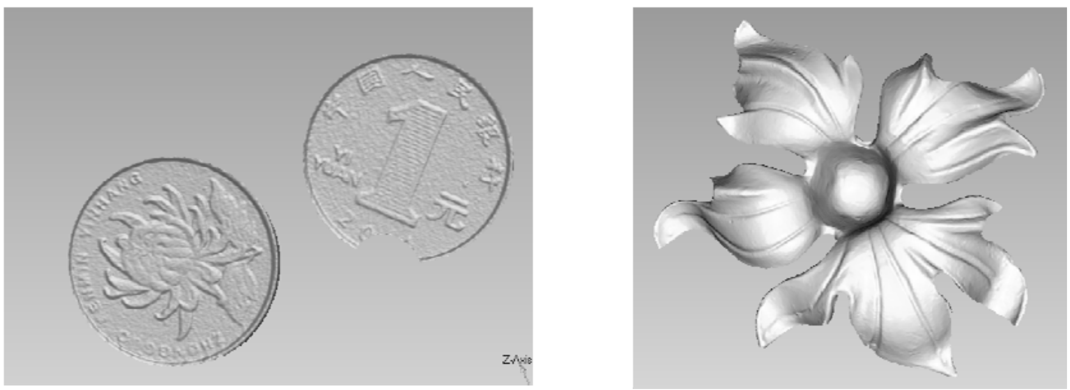

Figure 10. Examples of Scanned Data

4. Conclusion

In this paper, a new grating generator based on LCOS technology for 3D scanner is designed, with a CPLD chip being used to instant of the traditional video-processing chip. The new grating generator is smaller and easy to setup in the case, and its internal parameters can be easily adjusted according to the customer requirements. The interfaces and control instructions are simple, the design of the electronic circuits and the software are clear. It was installed in 3D scanners and performed well.

Acknowledgements

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