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50. Internationales Wissenschaftliches Kolloquium
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Real-time position determination of light spot

ABSTRACT

Optoelectronic systems are widely used in different fields of the modern industry. They allow the automation of many measurement processes like: measurement of distance, diagnostic of rails, determination of optical systems' quality, even measurement of deviation of Earth's magnetic field.

For light spot determination, the optoelectronic system is used. It has a screen, which is viewed with a CMOS image sensor. The information about the frames is processed, and the position of laser spot is calculated. The position of the laser spot depends on the measured value. According to the desired result, the output data after all calculations can be visualized, saved in memory or sent to the computer. To use this system in practice all calculations are made in real time. The results are obtained with delay up to one frame. For this reason all used algorithms are modified. The algorithms for an image processing require many calculations. For this reason in the optoelectronic system a FPGA Spartan II by XILINX is used, and firmware is written in VHDL.

The paper presents the software and hardware characteristics of an optoelectronic system working in real time.

INTRODUCTION

Localization of the laser spot as a function of measured parameter can be used in various applications: measurement of distance, diagnostic of rails, determining an optical systems' quality, even measurement of deviation of the Earth's magnetic field. The centre of the mass (COM) of laser spot is used as its coordinates. The calculation of the centre of the mass can be made in several ways: If the time for the calculations is not critical the object can be shot with digital camera. After that the image is processed in a computer. In this way very exact algorithms for COM calculation can be realized but these systems can not be used in the industry. Other way for realization of that system is a Digital Signal Processor, which processes all needed algorithms, is used. That system can work in real time, but DSPs have other restrictions. In DSP there are no real parallel processes. The digital image sensor generates high speed data. This is not allowing realization of multiplexed data bus, like in typical microprocessor systems. With the developing of the electronics, programmable logic was invented. It has high performance and allows implementation of really parallel processes. In the programmable logic device a very flexible optoelectronic system can be realized. Figure 1 shows common block diagram of an optoelectronic system for calculations of a position of a laser spot in real time.

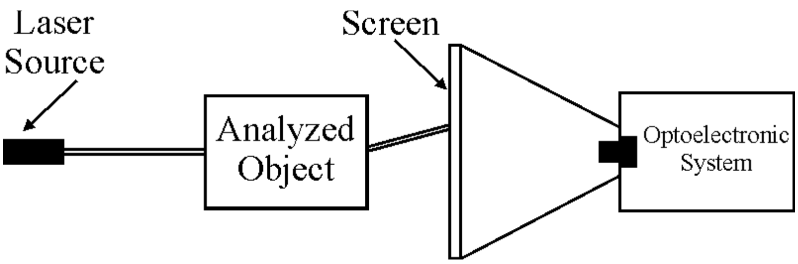

Figure 1 – Common block diagram of system for laser spot coordinates calculation

HARDWARE IMPLEMENTATION

For more flexibility, the system is realized in four different modules shown in figure 2.

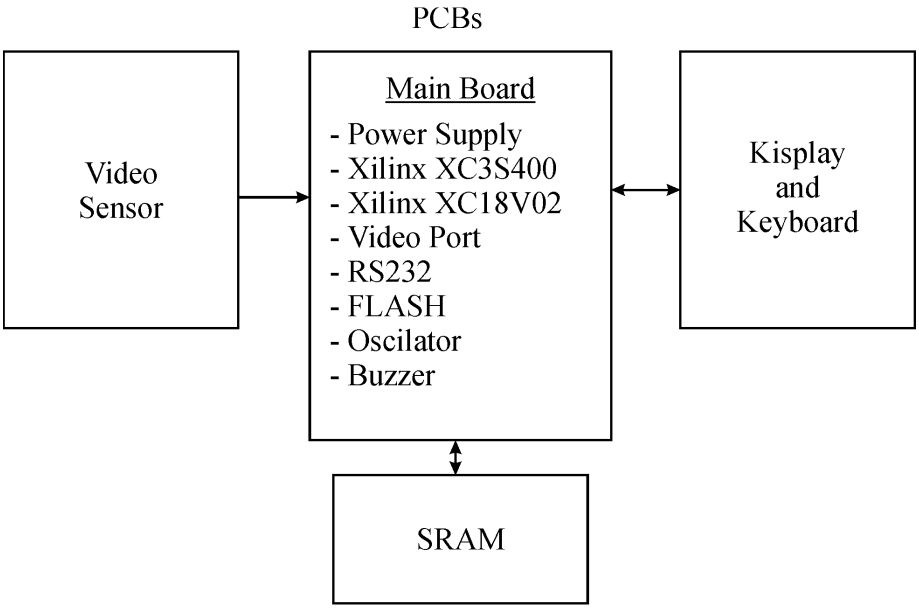

Figure 2 – Modules in the optoelectronic system

In the first module a CMOS image sensor is located. The information from the image sensor is read pixel by pixel and line by line. Used image sensor is OV2610 by OmniVsion [1]. It has a sensor matrix with resolution of 1600x1200 pixels. The pixels for each one of the three common colors: Red, Green and Blue are located uniformly in it. There is possible to work with two resolutions: UXGA (1600x1200 pixels) and SVGA (800x600 pixels).

The data proceeding in the image sensor is made in analog signal processor. It makes color separation, color correction, AWB (Auto White Balance), AEC (Auto Exposure Control), AGC (Auto Gain Control), color balance, black level calibration. In the sensor there are two ten-bits ADC, analog multiplexer, digital data formatter, I^2C interface for management of the internal configuration registers, synchronization block. In UXGA maximal speed is 10 frames/s, but in SVGA maximal speed is 40 frames/s. All data about the frame is processed in the FPGA which is located in the main board. For full control over an image sensor, all configuration pins are directly connected to the FPGA and they are managed by the software in the system.

The next module is the main board. The FPGA Spartan 3 is located in the board. It performs all processes in the system: reads the data from the image sensor, manages the sensor, executes the processes for image processing, manages communication with the computer via RS232 interface, manages writing of the frame in to memory and reading the frame from it, generates RGB video signal to a monitor, saves the calculated COMs into FLASH memory, manages a LCD display, manages a keyboard. All used algorithms are modified. They do not use any memory. The memory is used only for generation of the RGB video signal.

There is a 25 MHz oscillator on the main board. From this frequency all needed clock signals are produced with build in the FPGA DFS (Digital Frequency Synthesizers). In the optoelectronic system only one source is used as main clock. This is the only way for synchronization of all functional blocks and software processes.

For proper work of the FPGA following regulated voltages are needed: 1,2V; 2,5V; 3,3V. They are produced by different regulators located in the main board. 3,3V is used for supplying the rest of the system. The input voltage for the optoelectronic system has to be in a range 9V - 12V and can be unregulated.

In the next module LCD indication and keyboard are realized. The indication of the system shows the coordinates of the laser spot and the system status. The dynamic indication has 12 discretes. The keyboard is used for set the optoelectronic system.

In the last module RAM memory is located. The data from the sensor must be restructured to be sent to the monitor as RGB signal. For this reason the data from the sensor is saved in this memory, and after the RGB video frame is generated. The RAM memory has to be very fast, because the sensor generates high speed data. For a UXGA frame almost 2MB fast RAM memory is required. The communication synchronization with the memory is solved in this way: reading the data from memory is executed by the rising edge of the clock signal and write to the memory is performed by the falling edge of the clock signal. Using this communication with the memory, there is no needs to use Dual port RAM, which is expensive.

In the most of the applications, the optoelectronic system works in uninterrupted mode – the data from the image sensor is uninterrupted read. Some applications require from the optoelectronic system to be able to synchronize the moment for the shot by external strobe signal. The signal for external control is provided for these kinds of applications.

SOFTWARE IMPLEMENTATION

For solving the task of calculation of laser spot coordinates a programmable logic device is used. All used algorithms are adapted for hardware implementation, for working in real time and minimum used resources. The software in the system is written in VHDL [2]. Web Pack ISE 6 by Xilinx is used.

The viewed object is a laser spot. It consists of a small number of pixels compared to the entire frame. The spot consists of bright pixels collecting together, which are obtained from the image sensor together with the pixels belonging to the background. There is electronic noise and it has to be reduced, because it makes object finding difficult. For this reason before the segmentation and the COM calculation, a filtration process is executed. The structure of the software model is shown in figure 3.

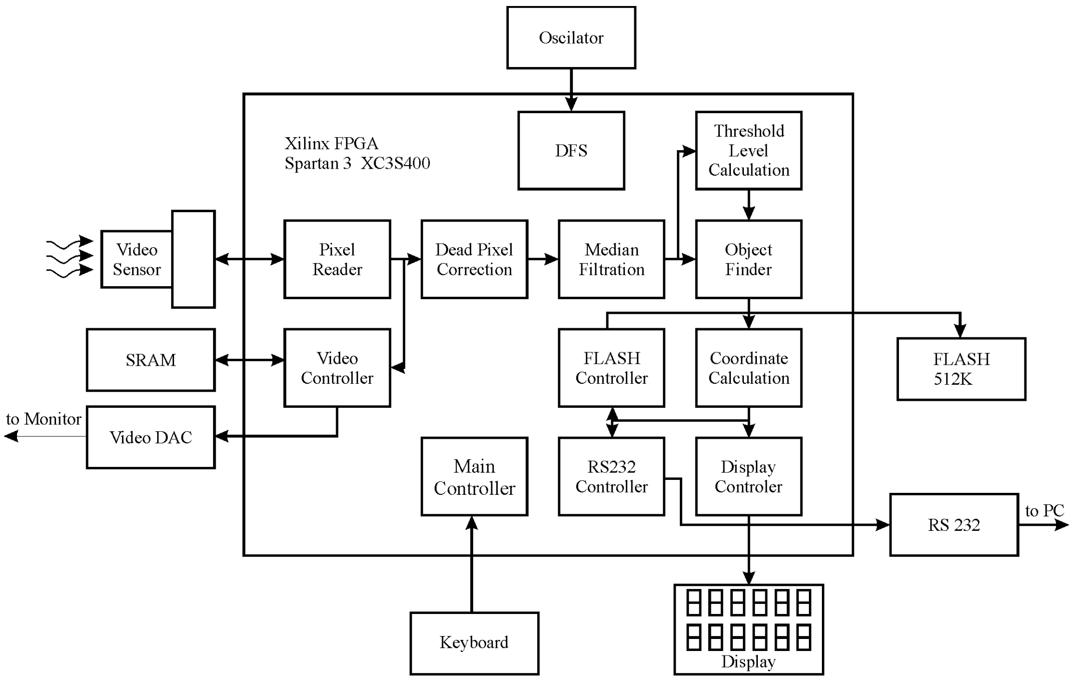

Figure 3 – Software model structure

Pixel reader – This module reads the output data from a sensor, calculates the coordinates of each pixel and its intensity.

Dead Pixel Correction – This module corrects defect pixels in the image

Median Filtration –Makes median filtration over the image. It reduces noises in the frame [3].

Threshold Level Calculation – This module calculates Threshold level used for object segmentation.

For object segmentation method of Hamadani [4] is used. This is a statistic method which uses mean value and standard deviation in the frame - Equation (1):

$$T=k_1m + k_2\sigma \quad (1)$$

The coefficients k_1 and k_2, depend on the image type. They can be changed with the keyboard. Mean value m is given by Equation (2):

$$m = \frac{1}{M.N}\sum_{i=1}^{M}\sum_{j=1}^{N}\varepsilon(i,j) \quad (2)$$

The image is described with $\varepsilon \in R^x$, M and N are the number of columns and rows in the image. Standard deviation σ is given with Equation (3):

$$\sigma = \sqrt{\frac{1}{M.N}\sum_{i=1}^{M}\sum_{j=1}^{N}(\varepsilon(i,j)-m)^2} \quad (3)$$

Object Finder – This module processes image segmentation and separates the object from the background according to the Threshold Level.

Coordinate Calculator – This module calculates Centre of the Mass – COM of the object. It uses coordinates and intensity of each pixel belongs to the object – Equation (4).

$$Xc = \frac{\sum_{I=1}^{p} XiEi}{\sum_{i=1}^{p} Ei} \qquad Yc = \frac{\sum_{I=1}^{p} YiEi}{\sum_{i=1}^{p} Ei} \quad (4)$$

X and Y are the coordinates of the pixels; E is the corresponding intensity of the pixel; **p** is the number of pixels belongs to the object; Xc and Yc are the coordinates of the object.

Display Controller – It manages a dynamic LCD indication with 12 seven-segment discretes.

FLASH Controller – Storage the coordinates of the object in a Flash memory.

RS232 Controller – This module establish serial communication with the computer.

Video Controller – This module manages a RAM memory and generates RGB video signal. On the monitor can be visualized either original image from the sensor, or binary image after thresholding.

Main Controller – This module manages the entire optoelectronic system. It receives commands from the keyboard and sets the other modules in the FPGA.

DFS (Digital Frequency Synthesator) – Using the frequency from the external oscillator, this module generates all needed clock signals for the system.

CONCLUSION

An optoelectronic system for real time object finding and location was presented. This system is based over CMOS image sensor and FPGA Spartan 3. In this way many measurement processes can be automated. Some of these processes are: measurement of distance, diagnostic of rails, determination of optical systems' quality, even measurement of deviation of Earth's magnetic field. It was realized as a flexible system separated into modules. In this way each module can be tested and improved independent of the others. The software is programmed via JTAG interface. It is allowed to change software of the system every time it is needed.

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