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Imaging system design for measuring pointing error of solar tracking

Li Hui-Duan[1]

[1]**Department of Chemistry and Life Science, Chuxiong Normal University, Chuxiong 675000, (CHINA)**

E-mail: lhd08@cxtc.edu.cn

ABSTRACT

Imaging system design is presented in this paper for measuring pointing error of solar tracking for a long time. An industrial computer with large hard disk is chosen as central processing unit instead of a digital signal processor for storing and processing massive image data of the sun. An advantage of the proposed imaging system is that it stores all the sun images grabbed. The imaging system consists of an optical head, A CCD image sensor, SAA7111A, FPGA, EZ-USB 8051 microcontroller, an industrial computer and so on. The optical head is constructed with a pinhole aperture and no lens is used for simplification. Sun's image formed by the optical head is detected by the CCD image sensor. Analogue signals from CCD image sensor are converted in to digital ones by SAA7111A. SAA7111A is configured and controlled by FPGA. Digital image signals are finally sent to the industrial computer via EZ-USB 8051 microcontroller. Experiments have indicated that the proposed imaging system is able to obtain and store massive image date of the sun.

KEYWORDS

Sun sensor;
Imaging system;
Digital image.

INTRODUCTION

Several solutions are available now to measure sun's position in the sky, such as sun sensors[1-6]. Since sun sensors provide pointing direction towards the sun, sun sensors are essential components for space missions, such as satellites and spacecrafts[1,2]. Accurate measurements of pointing direction towards the sun are necessary for autonomous attitude determination in nearly all the phases of a space flight[6]. Sun sensors is also used for solar tracking[7], desiring high tracking accuracy, and it is a core component for the solar tracking. According to detector types located in focal plane, sun sensors could be generally divided into two categories, digital sun sensors and analog sun sensors[1]. Image sensors are employed for the focal plane detectors for the digital sun sensors, while the analog sun sensors don't use image sensors[7-10].

Quantity evaluation of pointing error of solar tracking is absolutely needed for design of solar tracking device, such as choice of coders, selection of transmission set, controller design and so on, no matter the solar tracking device is used underground or works in the space. As accurate feedbacks of sun's position are provided by sun sensors, sun sensors are good choices for measuring pointing errors of solar tracking. However, sun sensors needed for measuring pointing errors of solar tracking is quite different from conventional sun sensors developed

Full Paper

for satellites, spacecrafts or solar tracking device.

Development of sun sensor has some specific requirements to obtain pointing errors of solar tracking. Sun images should be stored as much as possible in the solar tracking. It is best to store all images obtained by the sun sensor for further investigation. It is noted that running time of the sun sensor may be quite long. Hence, massive image data of the sun needs to be stored in real-time. Memory size of the sun sensor should be large enough to store the massive sun images, probably millions. As a result, an industrial computer with a hark-disk of large capacity is chosen as central processing unit instead of a DSP (Digital Signal Processor). This computer-based solution is proposed for storing massive image data.

Imaging system design is illustrated in this paper for measuring pointing error of solar tracking. The proposed imaging system includes an optical head, A CCD image sensor, SAA7111A, FPGA, EZ-USB 8051 microcontroller, and so on. One feature of the proposed imaging system is that the system stores all the sun images grabbed in the solar tracking. Overview of the imaging system is given in Section 2. Hardware design and software design of the imaging system is described respectively in Section 3 and Section 4 respectively.

OVERVIEW OF IMAGING SYSTEM

The imaging system grabs sun images for the digital sun sensor. The imaging system includes an optical head, A CCD image sensor[7], enhanced video input processor SAA7111A, Xilinx's Spartan-II FPGA XC2S200, EZ-USB microcontroller CY7C68013, SRAM memory and etc. Schematic of the imaging system is shown in Figure 1. The optical head consists of a filter, a pinhole aperture and so on. Since no lens is introduced, no distortion exists in the optical system. The filter is in front of the pinhole aperture and it is used for attenuating solar irradiance. The optical head is illustrated in Figure 2.

Sun's image produced by the optical head is detected by the CCD image sensor at the focal plane[5]. Analogue signals from CCD image sensor are further decoded by SAA7111A. And SAA7111A is configured to the proper settings and further controlled by FPGA. Digital image signals from SAA7111A are finally sent to the industrial computer via EZ-USB 8051 microcontroller.

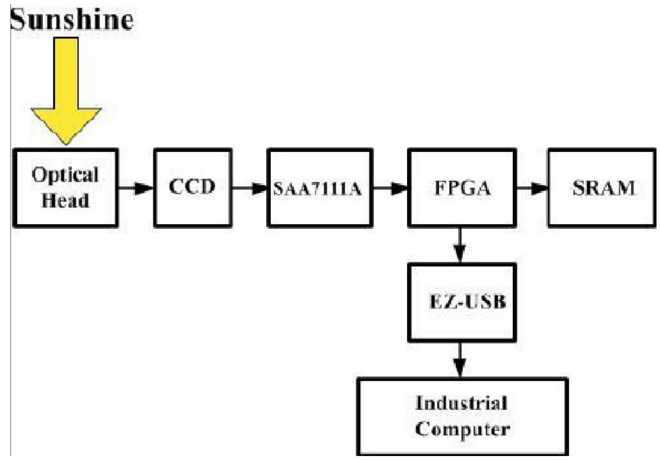

Figure 1 : Schematic of the imaging system

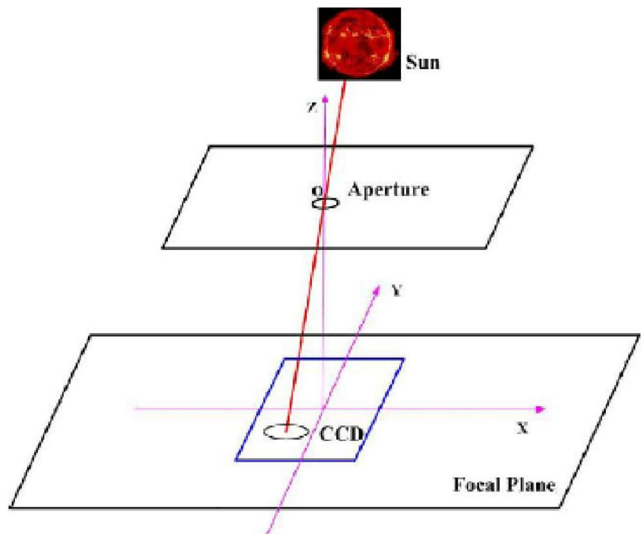

Figure 2 Optical head of the imaging system

HARDWARE DESIGN

Hardware block diagram of the imaging system is shown in Figure 3.

The enhanced video input processor SAA7111A from Philips Semiconductors is used to obtain digital images from CCD sensor. SAA7111A is a low-cost and highly integrated pure 3.3 V CMOS circuit for desktop video applications. It has two-channel analog preprocessing circuits including source selection, anti-aliasing filter and ADC, a clock generation circuit, unit of automatic clamp and unit of gain control, a digital decoder of multi-standard, a brightness/contrast/saturation control circuit, a color

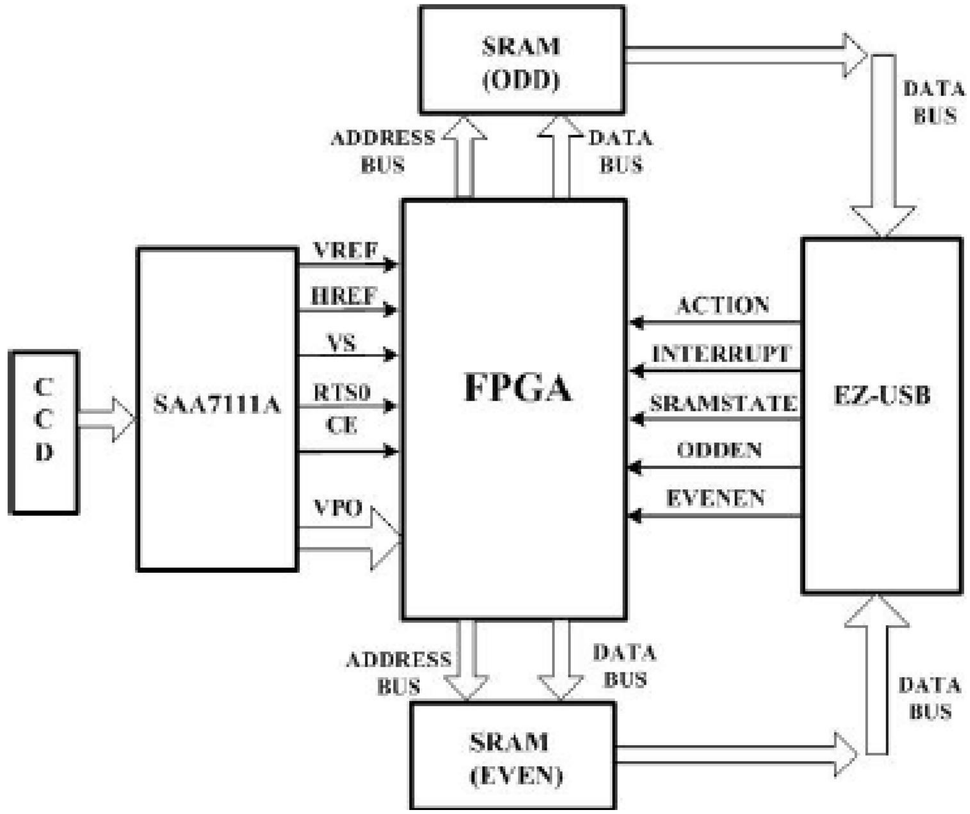

Figure 3 : Hardware block diagram of the imaging system

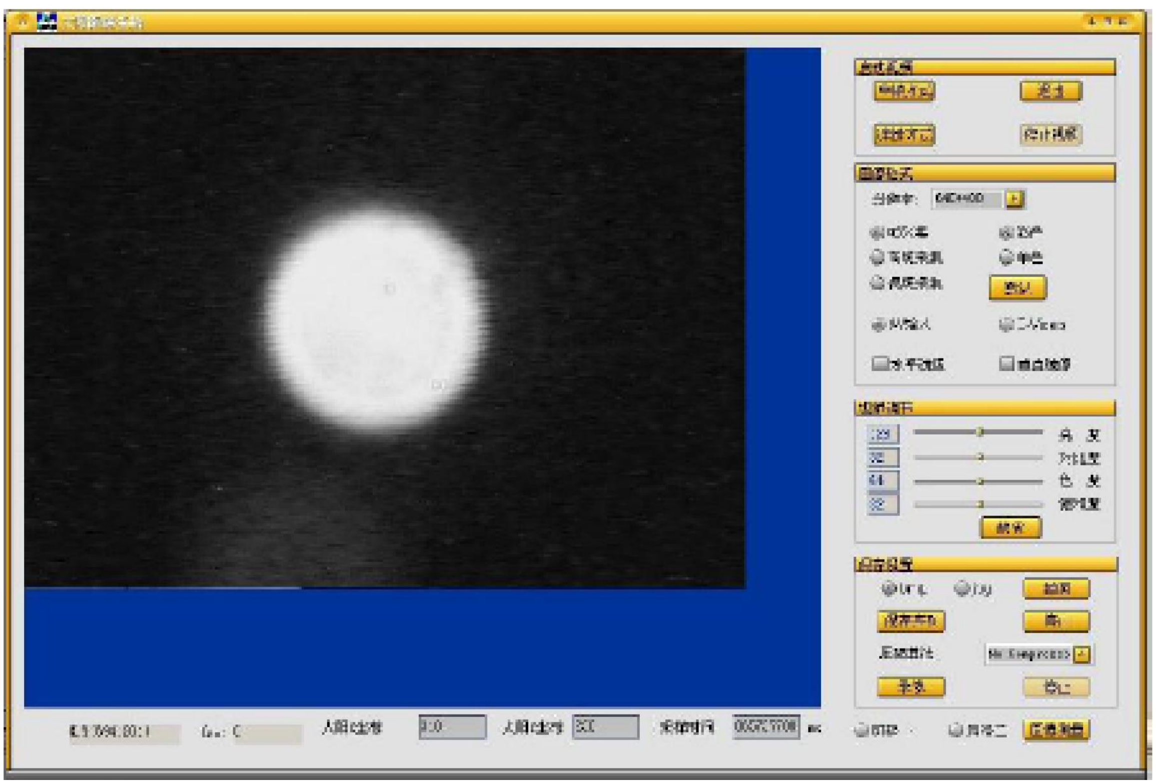

Figure 4 : Software interface

space matrix and a 27 MHz VBI-data bypass. The enhanced video input processor SAA7111A is a good choice for fast and economical prototype developments of image acquisition. External circuits design is simplified with chip SAA7111A. The multi-standard decoder inside SAA7111A is based on the principle of line-locked clock decoding. The decoder is able to change the color of PAL, SECAM and NTSC signals into CCIR-601 compatible color component values. The circuit SAA7111A is I2C-bus controlled. Digital video signals and control signals provided by SAA7111A are connected respectively to FPGA, for example, vertical reference signal VREF, horizontal reference signal HREF, vertical synchronization signal VS, odd/even field identification signal RTS0, chip enable signal CE, video port out signals VPO and etc. In order to control the SRAM chips, read/write pin, chip enable pin, data bus, address bus of two SRAM are all connected to FPGA. As soon as acquisition command is sent to FPGA from the industrial computer via USB interface, FPGA makes SAA7111A to decode analogue image signals from CCD image sensor. And FPGA puts digital image signals decoded by SAA7111A into odd field SRAM or even field SRAM due to odd/even field identification signal RTS0.

Pins ACTION, INTERRUPT, SRAMSTATE, ODDEN, EVENEN are connected between FPGA and EZ-USB. ACTION pin is used to send image acquisition command from EZ-USB to FPGA. When one frame of digital image data is ready in the SRAM, FPGA will set INTERRUPT pin to high to inform EZ-USB to get current frame of digital image data. While SRAMSTATE is low, it indicates that USB is reading image data from SRAM; while SRAMSTATE is high, it indicates that FPGA is writing image data into SRAM. When ODDEN is high, EZ-USB is reading image data in odd field SRAM; when EVENEN is high, EZ-USB is reading image data in even field SRAM. FPGA runs as a data buffer among SRAM and EZ-USB.

Cypress's EZ-USB FX2 micro-controller is used as the USB interface. EZ-USB FX2 is a micro-controller with USB interface and it is quite cost effective. USB 2.0 transceiver, enhanced 8051 microcontroller, serial interface engine and a programmable peripheral interface are all integrated in a single chip. Data transfer rates of EZ-USB FX2 is able to reach 56 Mbytes per second and it is the maximum allowable USB 2.0 bandwidth. However, the chip still uses a low-cost 8051 microcontroller structure. Most of the USB 1.1 and 2.0 protocols could be handled by EZ-USB FX2 in hardware. As a result, the embedded microcontroller provides

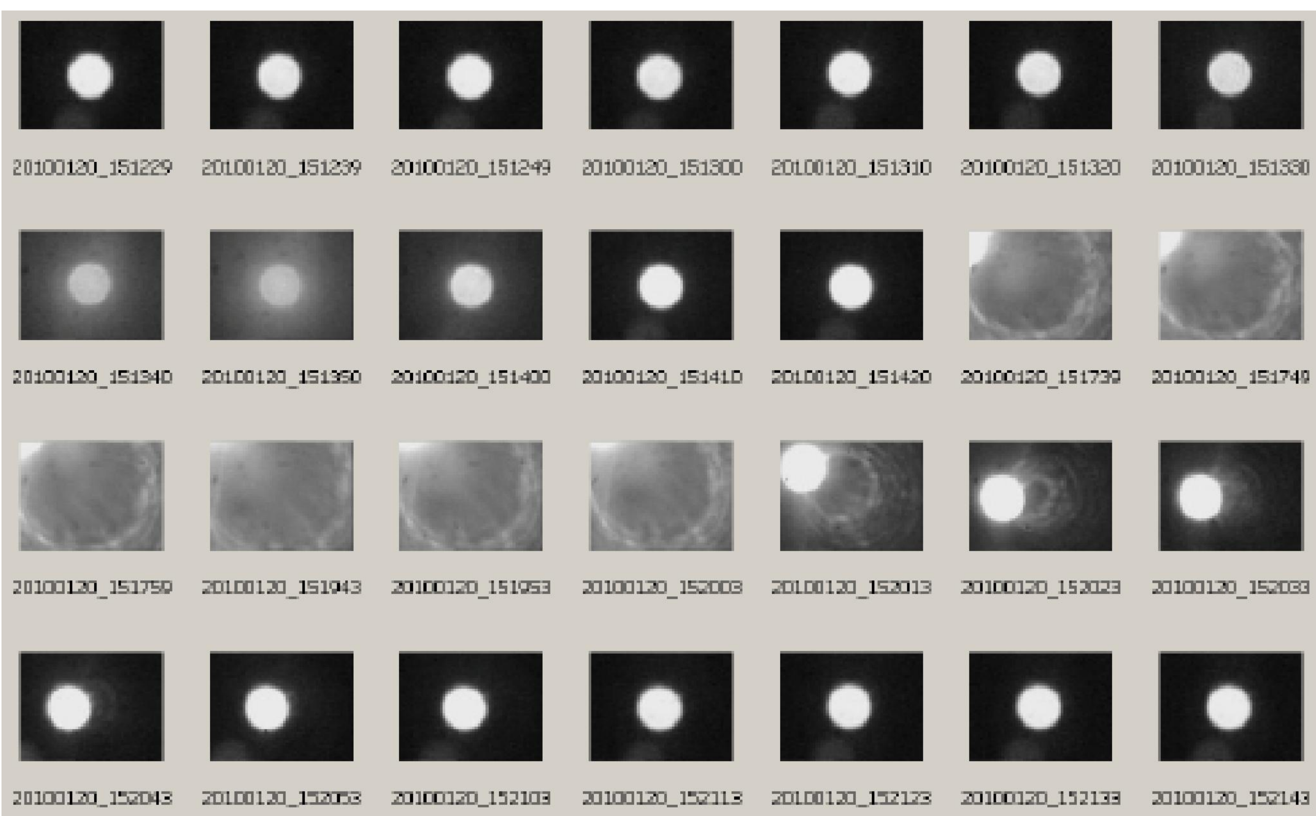

Figure 5 : Images obtained by the digital sun sensor

economical solution for specific USB application and development time is decreased to guarantee USB compatibility. Fast transfer mode of EZ-USB is used in this imaging system design. When the imaging system is connect to the industrial computer, device driver of the imaging system will be automatically loaded into EZ-USB by the windows operating system. And then the 8051 microcontroller core inside EZ-USB begins execution from internal RAM which performs the enumeration. Software development for EZ-USB includes development of firmware, windows device driver and etc.

SOFTWARE DESIGN

After SAA7111A, EZ-USB and etc are initialized, imaging system grabs sun images via desktop software for the digital sun sensor. When odd field data and even field data of one frame image are received respectively, the software puts these two sets of image data together.

Object orientated techniques are introduced to develop the software by Visual C++ 6.0. One image class named as “CDib” is constructed. Operations such as saving image in BMP file format, threholding, filtering[10] and etc are all integrated in an image class CDib.

Images grabbed by the imaging system are saved in BMP file format. The BMP files are named according to their grabbing time, following the format YYYYMMDD_HHMMSS. And “YYYY” means year, “MM” means month, “DD” means day, “HH” means hour, “MM” means minute, “SS” means second.

EXPERIMENTS

SAA7111A is initialized via I^2C pins SDA and SCL of EZ 8051 microcontroller. SAA7111A is initialized to working modes as following, one analogue video signal, automatic gain control, YUV 16 bits output, PAL(50 Hz, 625 lines), default brightness, default contrast and default saturation. Memory size of the hard disk for saving images is 320G.

CPU of the industrial computer is AMD Athlon II X2 250, 3.01GHz, memory size is 2G. And memory size of hard disk is 500G.

The imaging system for the digital sun sensor works well and all the images grabbed by the imaging system are recorded successfully into the hard disk of the industrial computer.

Software interface is shown in Figure 4. Images obtained by the digital sun are presented in Figure 5. Sun images were obtained every 10 seconds, and it meets requirements of calculating solar tracking accuracy for a sun tracking system.

CONCLUSION

Imaging system design of a digital sun sensor is presented in this paper. The digital sun sensor is developed for obtaining pointing error of solar tracking. It is required that all images obtained by the sun sensor should be stored for further investigation. These sun images are necessary for calculating pointing error of solar tracking. An industrial computer is chosen as central processing unit instead of a DSP-based solution. Sun’s images are finally recorded in a hard disk of large capacity. Main components of the imaging system include an optical head, A CCD image sensor, SAA7111A, FPGA, and EZ-USB. Design of the imaging system has been validated by experimental results.

ACKNOWLEDGEMENTS

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