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Open Source Digital Camera on Field Programmable Gate Arrays

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ABSTRACT

We present an open source digital camera implemented on a field programmable gate array (FPGA). The camera functionality is completely described in VHDL and tested on the DE2-115 educational FPGA board. Some of the current features of the camera include video mode at 30 fps, storage of taken snapshots into SDRAM memories, and grayscale and edge detection filters. The main contributions of this project include 1) the actual system level design of the camera, tested and verified on an actual FPGA chip, and 2) the public release of the entire implementation including source code and documentation. While the proposed camera is far from being able to compete with commercial offerings, it can serve as a framework to test new research ideas related to digital camera systems, image processing, computer vision, etc., as well as an educational platform for advanced digital design with VHDL and FPGAs. As examples of that, we report two spin-off projects developed on top of or starting from the presented digital camera system.

KEYWORDS

Digital Camera, Edge Detection, Face Detection, Field Programmable Gate Arrays, Grayscale Filter, Sobel Operator

INTRODUCTION

Field programmable gate arrays (FPGAs) have become extremely popular in virtually all application domains. If in the early days FPGAs were used mostly as digital glue logic or for prototyping purposes, today they are used as integral parts of complex designs ranging from consumer electronics to communications, military, and space systems. The popularity of FPGAs has continuously increased not only because of the reduced performance gap between FPGAs and ASICs but also because of the great flexibility that reconfiguration offers when it comes to product development, maintenance, and updates. Today, FPGAs represent the hardware platform of choice to implement and test digital designs for many circuit designers and educators. These include also contributors to online design resources such as Opencores (Opencores, 2016) who test and validate their open source designs on various FPGA chips. Testing and validation on real FPGA chips increase the credibility and confidence in the correctness of these publicly available design resources.

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In this paper, we present an open source baremetal digital camera completely described in VHDL and tested and validated on an FPGA chip. While one can find portions of the presented camera design publicly available, we are not aware of any publicly available, self-contained open source design that integrates the same functionality presented here. We make our implementation publicly available (including complete source code and documentation) with the hope that it will serve as a framework to test new research ideas related to digital camera systems, image processing, computer vision, etc., as well as an educational platform for advanced digital design with VHDL and FPGAs. Note that an early version of this paper was reported as a conference paper in (Ababei et al., 2016). Here, we report two additional projects, which were developed starting from the digital camera project.

The remainder of the presentation is structured as follows. First, we present details about the current implementation of the digital camera system. Then, we discuss experimental results achieved with an actual FPGA board. Spin-off projects developed on top of or starting from the framework provided by the digital camera design are then reported. We then discuss the main merits of this paper as well as future work. Finally, we conclude our presentation in the last section.

BAREMETAL DIGITAL CAMERA SYSTEM

In this section, we present the proposed baremetal digital camera system. We discuss some of the design decisions and the main features.

Block Diagram

The simplified block diagram of the proposed baremetal digital camera system on FPGA is shown in Figure 1. The main functionality of the camera includes video mode at 30 fps, the ability to take a snapshot and store it on the SDRAM memory or on the SD Card, the ability to fetch a snapshot from

Figure 1. Block diagram of the proposed baremetal digital camera system