Platform-Based Design Approach for Embedded Vision Applications

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***Abstract*— Implementation of an efficient, complex real-time image and video processing system has many different contrary design needs. These systems require managing and processing a large amount of data in a timely manner. The robust implementation requires design reuse and flexibility, which is very crucial for an ever-increasing application need. A combination of hardware and software which form a platform fulfills the demands of the continuously developing application domain. The platform-based design has recently gained in importance which allows to explore the trade-offs between various designs requirements for the hardware and software implementation of real-time image and video processing algorithms and its systems. In this paper, we present the exploration of platform-based design approach for implementing a real-time vision system. We have used the platform-based design approach to design a configurable real-time image and video streaming module for vision-based systems on an Virtex-5 FPGA. We have also implemented a real-time image and video acquisition module for a smart camera system**.

***Index Terms*—Platform-based design; Embedded vision system; Video acquisition; Real-time image and video streaming; Virtex-5 FPGA.**

I. Introduction

Real-time vision systems have ever-increasing demand for higher performance, lower power requirement and flexibility. These systems also need to process and manage a large amount of data within the constraint of real-time performance [1-3]. Thus, their design as embedded system continues to be a challenging problem. Also, the system design methodology places considerable conflicting constraints on the design of the system. Thus, there is a need for designing dedicated architecture and associated hardware and software modules to meet the expected performance requirement [3-5]. This can be achieved by realizing the computation intensive complex algorithms in concurrently running hardware modules and by implementing the rest on software which provides adequate flexibility [6-7]. The conflicting design requirements, such as, power, performance, flexibility, design time and cost can be met using the platform-based design; and thus it has become an important choice for the realization of these systems [8-10]. It also allows us to investigate various architectural trade-offs.

Depending on the performance requirement and application domain, a platform can be selected optimally. The platform, typically, contains Field-Programmable Gate Array (FPGA), programmable clock generator, memory, microprocessor, common hardware peripherals, etc. along with some of the necessary interfacing ports and connectors to support the necessary protocols for the selected application space. The available resources of the platform can be configured and used as per the design requirements. Thus, in a desired application space, an extensive range of algorithms on the same platform can be run by merely configuring the required peripherals and implementing some of the application-specific modules in custom designed hardware blocks. The platform-based vision systems can support a wide variety of applications including remote surveillance, motion analysis and traffic monitoring [10-13].

The rest of the paper is organized as follows: Section II discusses the background for the need for the platform and Section III describes the platform-based design approach. Section IV gives a brief description of the image and video processing platforms, in general. In section V, we explain our design approach for the image and video processing applications with an example of image acquisition system using FPGA-based platform. Section VI concludes this paper.

II. Background

The generic architecture for the majority of embedded designs consists of microprocessors, peripherals, dedicated logic blocks and memories. The available hardware resources in an FPGA-based platform can be broadly classified as memory resources, functional resources and interface resources. The functional

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resources are used to process vast amount of data. They implement arithmetic or logic functions and can be grouped into three main subclasses: primitive resources, Intellectual Property (IPs) and in the form of application-specific resources. The primitive resources are general purpose sub-circuits that are designed once and often used. Whereas IPs could be a functional IP with domain-specific features or it could be a controller's IP. A fully characterized IP in terms of area and performance can be stored in the design libraries from where we can reuse it as per the need. The application-specific resources are the subsystems designed for the application-specific needs. Most of the functional resources can also be implemented in the FPGA. The interface resources support data transfer and it includes different types of busses, whereas, the different types of memory resources are used to store data. The software resources include device drivers, real-time operating system (RTOS), application-program interface (API) and network communications. A general classification of the different hardware and software component and its resources is shown in Fig. 1.

Thus, to design and implement a modern day complex embedded system; there is a need of system-centric design platform. In this system-centric design platform, applications could be extended with new functionalities and has much wider applicability for the desired application domain. The platform-based design approach allows substantial re-use of hardware and software resources and offers high degree of programmability. The next section illustrates the platform-based design approach in detail.

III. Platform-Based Design Approach

In application-driven architectural design context, the term platform is defined as a collection of subsystems and required interfaces that form a common arrangement of functional units from which a system and its derivatives can be efficiently developed and shaped [10-12]. Platform is an abstraction of a group of varied micro-architectures which are programmable and occasionally, run-time configurable in nature. It offers a universal architectural component that can support a variety of applications as well as the future derivatives of a given application space.

Apart from having vital architectural building blocks it also satisfies the trade-off between a set of essential architectural constraints, such as, power, performance, area, design time, and cost. In Fig. 2 such a platform-based design approach is depicted schematically. The selection of an appropriate platform depends upon the application space. Depending upon the application space, once a platform has been selected, the design procedure for the selected application begins by exploring the design space offered by that platform.

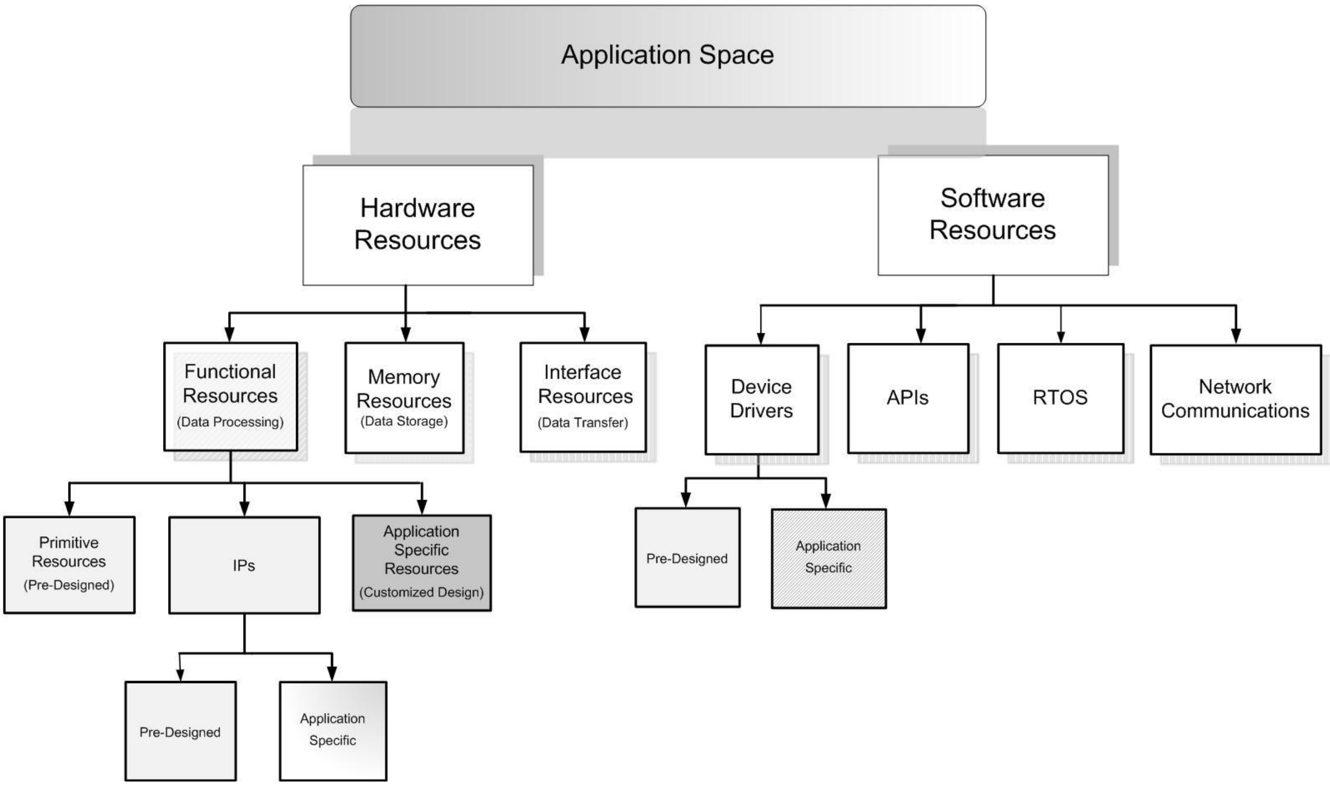

Fig.1. Classification of resources.

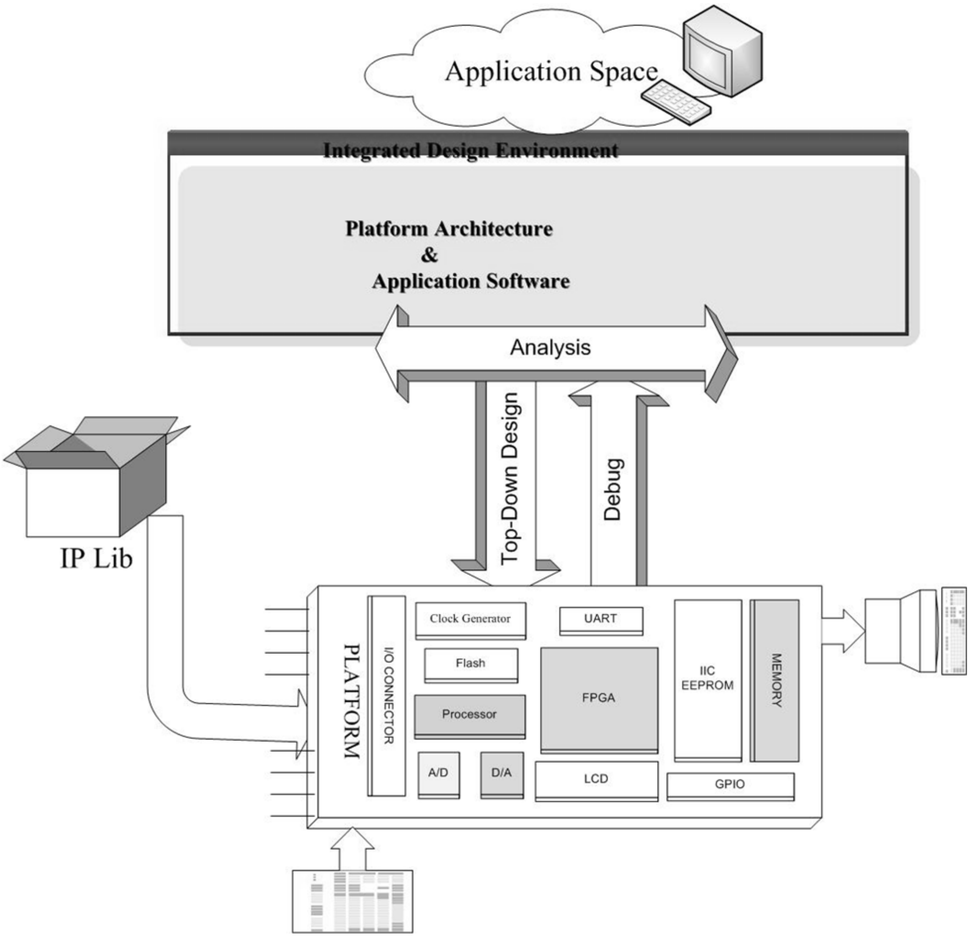

Fig.2. Platform-based design.

In the platform-based design, the software programmability comes from the availability of microprocessor and hardware programmability comes from the presence of reconfigurable blocks of FPGA [10]. The combination of processor and run-time reconfigurable logic makes the platform provide sufficient balance between the demands of application space and the architectural space. With embedded processor inside the FPGA, we can make trade-off between hardware and software to maximize the performance. To facilitate FPGA embedded processor design, Xilinx offers extensive libraries of IPs in the form of peripherals and controllers for their various platforms [14]. One such recent FPGA device available in the market is the Xilinx Vitex-5 FX family which offers hard processor embedded in FPGA fabric such as, PowerPC 440 inside it [15].

The platform-based design approach is an amalgamation of several design approaches which emphasizes systematic reuse for developing multipart products based upon the platform-compatible hardware and software. It offers reduced developmental risks, NRE cost, and time-to-market [10-13]. Every element of the platform can be selected and used through the customization of an appropriate set of design parameters which controls its micro-architecture. The user may not be concerned about the design details of each and every components of the platform, standard bus and what is inside in the application programmer interface (API) as offered by the platform.

The platform-based design provides sufficient flexibility to support an application space for the selected design domain. In this design approach, we can map our application into a conceptual representation which can include a range of micro-architectures that can be optimized for the various design needs. There are various integrated design environments available which offer complete support for the development of platform architecture and associated application software [16-17]. These platforms also offer debugging facility for the design analysis and its refinement. Thus, the platform-based design leverages the performance of most efficient derivative of an architecture and flexibility offered by the programmability of processor. The support of custom design hardware and reuse of IPs and other functional components make the platform-based design approach more favorable for architecture exploration of complex digital system [10-13].

IV. EMBEDDED VISION PLATFORMS

In the context of embedded vision system, an architecture has been presented in [18]. The system is based on a Xilinx XCV2000E FPGA on Celoxica

RC1000 prototyping platform has been implemented which perform image pre-processing functions for embedded vision applications. A general-purpose, multi-tasking, and reconfigurable platform has been presented in [19]. Based on the system level architecture of Xilinx Virtex-II FPGA, the prototype has been proposed and developed, which integrates embedded processor, memory control and interface technologies. The system includes different functional modules, such as edge detection, zoom-in and zoom-out functions, which provides the flexibility of using the system as a general video processing platform according to different application requirements. Table I shows some of the related works.

TABLE I. EMBEDDED VISION APPLICATIONS

Work	Platform Used
An FPGA implementation of a flexible, parallel image processing architecture suitable for embedded vision systems [18]	Celoxica RC1000 with Xilinx XCV2000E FPGA
A general-purpose FPGA-based reconfigurable platform for video and image processing [19]	Xilinx Virtex-II FPGA
The Platform of image acquisition and processing system based on DSP and FPGA [20]	Altera FPGA EP3C25F324 + TI TMS320C6416T DSP
Efficient smart CMOS camera based on FPGAs oriented to embedded image processing [21]	Xilinx Virtex-4 FX FPGA (XC4VFX12)

An embedded platform for real-time image acquisition and processing has been presented in [20]. It contains a Texas Instrument's TMS320C6416T digital signal processor and Altera's FPGA EP3C25F324. The digital image data has been transferred into FPGA fabrics, first. After pre-processing, the data has been transferred into DSP6416 by the interface of FIFO in FPGA and DSP6416 EMIF. Further, the image data has been processed in DSP by real-time algorithms. Bravo et al. [21] have used Xilinx Virtex-4 FX (XC4VFX12) FPGA-based platform, which contains an embedded PowerPC405 microprocessor. In their work, they have presented an architecture for image acquisition and processing using a CMOS sensor, which has been interfaced with FPGA platform for the smart camera.

V. PLATFORM FOR IMAGE AND VIDEO ACQUISITION

In the proposed work the platform-based design approach has been used to design a real-time video streaming and a real-time image and video acquisition module. The image and video streaming module is shown in Fig 3. The design is based on Xilinx ML-507 platform having Virtex-5 FX device which has PowerPC440 embedded processor core. Along with the universal peripherals, the platform contains video decoder, display controller chip with necessary connectors which support wide range of image and video processing applications. By using the ML-507 platform peripherals and some of the customized logic in FPGA fabric, we have realized the image and video acquisition module. It facilitates the streaming of video from a Pan-Tilt-Zoom (PTZ) camera to a VGA monitor through the FPGA logic and DDR2 memory in real-time.

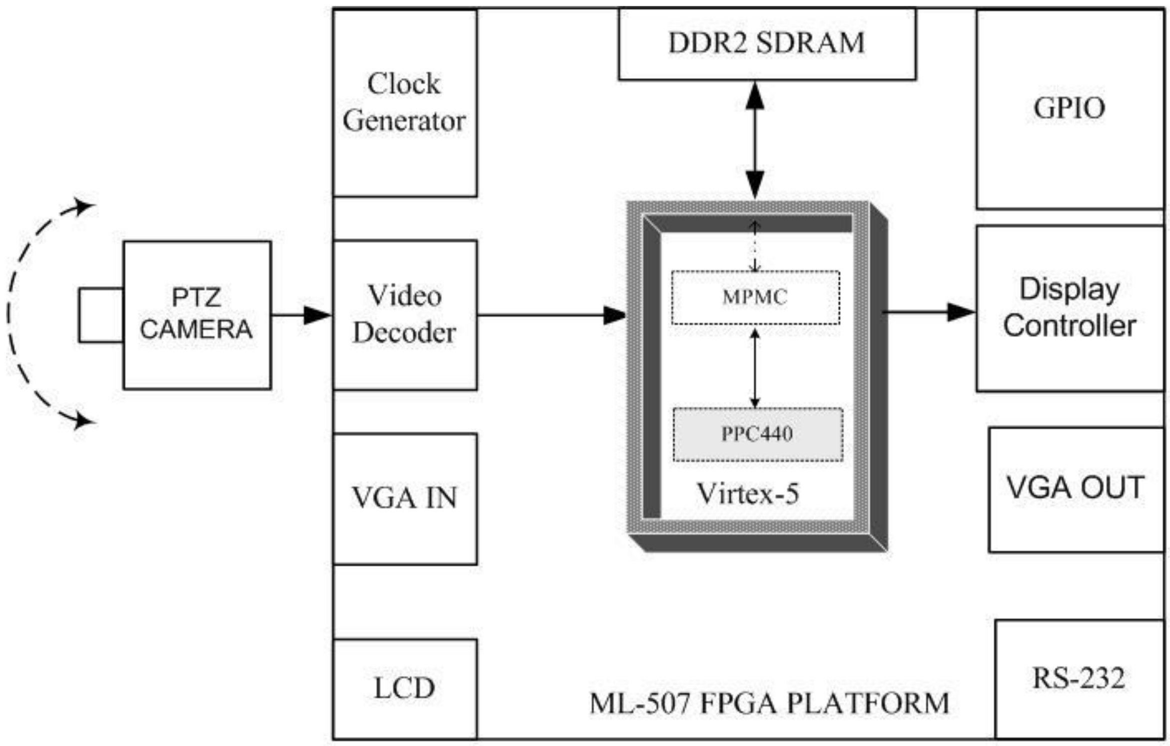

Fig. 3. Platform for image and video acquisition.

In this design, to interface DDR2 SDRAM memory with FPGA, we have used Multi-Port Memory Controller (MPMC) which has been available in the form of intellectual property (IP) module. The control registers of on-board peripherals are configured using the embedded PowerPC 440 processor with Inter-Integrated Circuit (IIC) bus controller's low-level device driver functions. The application software written in C language runs on top of a *standalone* software platform and uses the application programmer interface (API) provided by the software platform.

VI. CONCLUSIONS

We have explored the platform-based design approach for designing real-time embedded vision applications. A hardware-software video streaming module has been implemented to stream the frames on an individual basis through the FPGA fabric using custom designed hardware IPs in real-time. Further, using the platform-based design approach, we have implemented a real-time image and video acquisition module. In this design, the real-time video in RGB analog format has been captured from the PTZ camera. The captured video has been converted into the frames and buffered into DDR2 SDARM memory. The stored frames have been changed back into 640X480 VGA resolutions and displayed on the VGA monitor in real-time. The architecture uses Xilinx ML-507 FPGA board which has Virtex-5 FPGA. The total device utilization summary shows that, apart from the PowerPC 440 processor, the total FPGA resources consumed is around eighteen percent (18%). Thus, the remaining FPGA resources are sufficient for implementing most of the practical real-time vision-based applications.

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