

RECOPS: Reconfiguring Programmable Devices for Military Hardware

Electronics

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Abstract

This paper presents the RECOPS project that aims to study the use of reconfiguration in military applications. The project explores the new potentials and possibilities offered by reconfigurable components like FPGA. It identifies specificities related to the use of this technology in military applications and proposes solutions to support them. Specific techniques like dynamic reconfiguration or high speed serial I/Os are also covered.

The paper gives a description of the project and then presents preliminary results on the advantages and impacts of using reconfiguration in military applications. It also gives a synthetic view of the needs and challenges that need to face this technology to be integrated in professional and military electronics applications. They are based on a study made over a broad range of seven demonstrators covering most of the fields of military applications.

Keywords: reconfiguration, FPGA, defense, military, dynamic reconfiguration, partial reconfiguration, reconfigurable computing, high speed I/O.

1. Introduction

Reconfigurable components are nowadays common in many electronics applications and the most usual are the Field Programmable Gate Arrays or FPGA. They allow making entire systems based on a generic bit-level configurable platform delivering computation capabilities up to one or two order of magnitude faster than a fully programmable processor approach.

Upon this bit-level reconfigurable platform recent researches show interesting opportunities to use it at application-level and use this reconfiguration capabilities to modify the hardware dynamically [1]. This allows for example to implement more efficiently more functionalities or to adapt the application according to environmental constraints [2].

The RECOPS project [3] presented here aims at studying the opportunities to use reconfiguration in military applications. For this, it investigates the new potentials and possibilities offered by the reconfigurable components in this field and identifies the specificities that

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need to be fulfilled by a reconfigurable platform. It also aims to propose solutions to support these specificities. In order to study the concepts on a broad range of military applications, it involves seven demonstrators ranging from communication radio for land equipment to high performances radar front-end processing.

In this paper, we first introduce in section 2 backgrounds on reconfiguration and reconfigurable components. We present then in section 3 specificities related to military applications. In section 4 the RECOPS project is detailed. And finally section 5 gives preliminary results on reconfiguration advantages and impacts for military applications.

2. Backgrounds

2.1. Reconfiguration

The reconfigurability of a system is its ability to change its functionality depending on the application. It allows a platform to use the same resources to achieve several functions. As shown in Figure 1, those systems have two different execution modes: a normal operation mode and a reconfiguration mode.

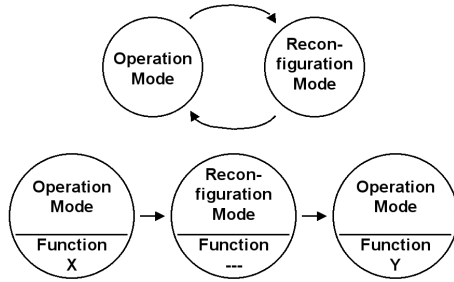


Figure 1: Reconfiguration modes

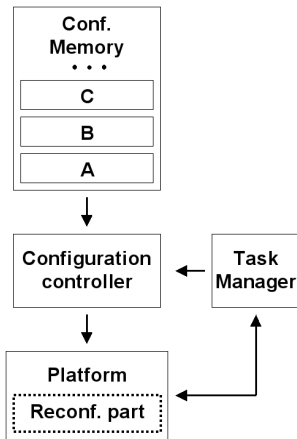


Figure 2: Reconfigurable system

To change from function X to function Y, the system

needs to go by a reconfiguration mode in order to adapt its resources.

Figure 2 shows the general implementation of a reconfigurable system. It relies on a platform with one or more reconfigurable parts, a configuration memory and a controller. The reconfigurable part allows the platform to change its functionality. The configuration controller acts as the configuration loader, it performs the transfer from the memory to the platform. It also aims to manage all the actions that have to be completed during the reconfiguration process like saving the state. Depending on the task required by the application, the configuration with the suited functionality is loaded from the configuration memory to the reconfigurable part of the platform.

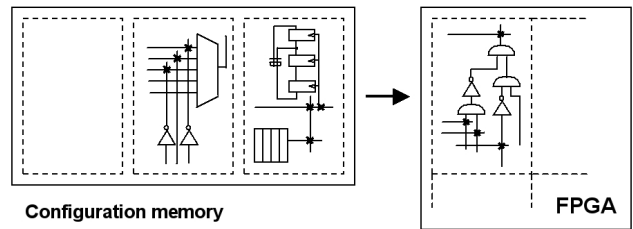


Figure 3: Partial reconfiguration of a FPGA

From the application point of view, the reconfigurability can be performed statically or dynamically. A reconfiguration is static when the application needs to be stopped to change the configuration. It is dynamic when the application can still run during the reconfiguration process.

The reconfiguration can be applied at several levels. The lowest one is the fine grain logic cells level. It is the most common level of reconfiguration when working with FPGAs. One part, as shown in Figure 3, or the entire content of the FPGA can be reprogrammed. For the rest of this paper, we will consider fine grain reconfiguration as reconfiguration.

2.2. Reconfigurable components

Most of the components available on the market integrating reconfiguration are FPGA. They are able to perform reconfiguration at bit-level. Nevertheless there are very few other components able to perform coarse grain reconfiguration and they are mainly used to implement accelerators for specific applications like multimedia. One of them is the XPP from PACT [4]. It offers a matrix of 64 tiles designed for multimedia applications.

The project targets high-end applications using FPGA integrating reconfiguration not only at component-level but also at application-level, thus requiring dynamic reconfiguration capabilities. There are only two FPGA

vendors providing big matrices able to integrate entire systems. They are Xilinx [5] and Altera [6]. Among them, only Xilinx provides FPGA with capabilities of doing dynamic reconfiguration. For this, the components have an internal hardware configuration port that allows the user-logic plane of the component to modify the underlying configuration plane [7]. The components supporting this feature belong to the Virtex family including the latest Virtex 5. The tools provided by the vendor supporting dynamic reconfiguration for those components are more or less working but are not as mature today as those for the static flow [8]. Nevertheless, recent efforts made by Xilinx regarding dynamic reconfiguration in the field of Software Defined Radio would probably improve this situation [9].

3. The use of reconfiguration in military applications

Military applications are far from the usual consumer electronics market directed by battery-autonomous-like applications sold in high volume. Indeed if they also require high integration, they require a high level of interoperability because they are mostly strongly coupled with other components inside complex systems. Military applications have a high level of reliability and security and they need further validations, tests or certification.

The current military applications demand more and more performances while keeping a long life cycle. Furthermore they need to have intelligent capabilities and a high level of flexibility to be able to adapt in real-time to environment changes during a mission. The high level of flexibility is also one of the best ways to cope with the long life cycle. Indeed, the life of a military product is longer than consumer electronics, reaching often several decades. In the meanwhile the applications need to be upgraded to still deliver high-end performances in order to meet their operating requirements.

In this scope, the reconfiguration is an interesting approach either to meet the adaptability requirements on the field, or to fill the gap between life cycle and high-end performances.

4. The RECOPS project

The RECOPS project [3] aims to study the use of reconfiguration in modern military applications. It involves ten partners from the military industry and from research centers. The partners are from France, Italy and Belgium. The project is highly application oriented. It uses seven demonstrators chosen among the broad range of military applications. The goals are to investigate the new potentials and possibilities offered by the reconfigurable

components in military applications, to identify the military applications specificities that need to be fulfilled by a reconfigurable platform and to propose solutions to support these specificities. The project focuses on three main objectives.

1) Analyze the impacts of reconfigurable technologies upon system architecture within military applications. Analyze the specificities of this kind of applications and identify opportunities to use dynamic reconfiguration.

2) Assess the state of the art and trends in configurable devices (mostly FPGA). Evaluate technical solutions to support HW reconfigurability within military equipments. Identify the requirements for using dynamic reconfiguration. Propose techniques and development methodologies to implement HW reconfigurability.

3) Demonstrate it through experiments.

The RECOPS project is partly based on the completed RECONF project [10] that studied methodologies to efficiently use dynamic reconfiguration of FPGA.

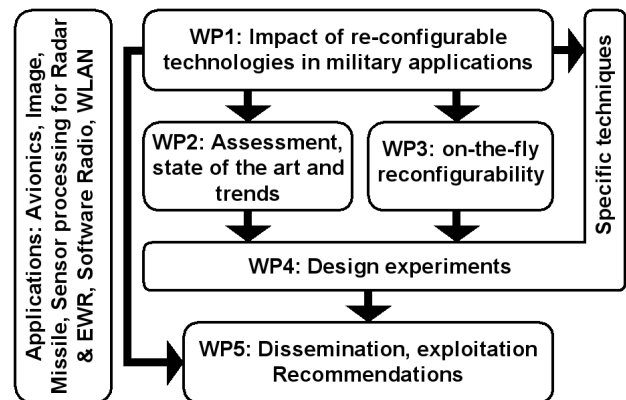


Figure 4: Project organization

4.1. Organization

The project is organized in 5 work packages as shown in Figure 4. WP0 is devoted to the project management. WP1: "Impact of reconfigurable technologies in military applications" studies the specificities of using reconfiguration with military applications. It will also provide guidelines and recommendations at the end of the project. WP2: "Assessment, state of the art and trends in configurable device" studies the state of the art and future opportunities of using reconfiguration. WP3: "on-the-fly reconfigurability specific issues" studies the dynamic reconfiguration and proposes solutions at application level as well as at device level for using this technology in military applications. WP4: "Design experiments supporting military applications" uses seven demonstrators

in different fields of military applications to validate the results obtained in all the other work packages. Finally WP5: " Dissemination, exploitation" promotes the use of the reconfiguration technology to other industrials and provides recommendations for using the technology.

The project duration is 30 months, from the 1st of March 2005 to the 31st of August 2007. The consortium is composed of 10 partners from 3 countries. They are from: France:

- THALES Communications France
- THALES Airborne Systems
- MBDA France
- CEA List

Italy:

- THALES Italia
- ELETTRONICA
- Tecnopolis CSATA
- CESVIT Microelettronica

And Belgium:

- THALES Communications Belgium
- Université Catholique de Louvain

4.2. Technical outputs

The outputs of the project are:

- Requirements for military applications
- Recommendations for integrating reconfigurable HW in military systems
- State of the art and trends in reconfigurable devices and tooling
- Report on real-time issues with reconfiguration
- Partitioning methodology, data management and organization of the blocks for dynamic reconfiguration

Furthermore, specific techniques regarding reconfiguration are tried and evaluated in the demonstrators in order to identify their bottlenecks risks and solutions, they are:

- New methodologies for algorithms
- Impact of a reconfigurable process on the main sequencer of the application
- Interconnection and set-up of reconfigurable structure with a processor core (bus, real-time OS, driver...)
- High speed I/O technology and related reconfiguration
- The reuse of IP
- Design flow compliant with ED80/DO254

- Test and debug technology and tooling
- Validation methodology
- Configuration management including HW/SW drivers

4.3. Experiments

The project uses seven demonstrators in order to evaluate the reconfiguration technology and the specific related techniques. The demonstrators cover a wide range of applications. For each demonstrator mentioned below, the specific application implemented is first given followed by its related domain.

Image acquisition and transfer / Soldier land

Electronic warfare / Naval electronics

Image processing / Missiles

Front end processing / Airborne radar

Short range radio modem / Communications

Software defined radio transmitter / Communications

Software defined radio receiver / Communications

An interesting approach of the project is that all those applications are intended to be implemented in a common reconfigurable platform. The platform chosen so far is based on a high-end Virtex 4 component from Xilinx. This will assess the high flexibility offered by the latest FPGA platforms.

5. Results

The results presented here are based on the study made in the project using the demonstrators. They are thus highly application oriented. They are intended to fill the gap between academic research and industrials. The advantages of using reconfiguration at application-level for military applications or more generally for professional electronics are presented first; the impact of using this technology is discussed then.

5.1. Reconfiguration advantages

The advantages of using reconfiguration and dynamic reconfiguration in the general research area are mostly focused on speed, power and flexibility. In order to integrate reconfiguration in military applications, a broad view of the potential improvements in this specific domain is given here.

Task speed

This is the most usual advantage. The speedup can be obtained by implementing a function performed in software in a hardware accelerator or co-processor. The use of reconfiguration for a co-processor region makes it possible to migrate more functions without being constrained by the amount of hardware available. Another

way to obtain speedup is by reconfiguring a region with a more optimized function in order to achieve a given task more effectively than by using a generic implementation.

Power optimization

The power optimization by means of reconfiguration has two aspects. The first one is the reduction of the static leakages of the component by having less hardware instantiated at the same time. This will be especially interesting for the future deep sub-micron components. The second one is the reduction of dynamic power consumption by the use of a dedicated and optimized design for the high computational tasks.

Survivability

Military applications need to be able to operate in harsh environments. Therefore, the survivability of the applications is a crucial issue even when exceeding the operating ranges limits. The reconfiguration can be used to detect, correct or relocate damaged functions. The damage can be due to a failure in the hardware itself or it can also be caused by a soft error in the configuration memory.

Mission change

Nowadays, an entire system like a plane or a ship is composed by many interoperating subsystems. Depending on the mission, the entire system is customized by modifying its set of subsystems. The mission change is the higher level of variability for a military system. Reconfiguration can be useful to adapt the system and its components depending on the configuration used for a given mission. It is important to notice that here the timescale for reconfiguration is very long. Indeed, it is performed once for an entire mission.

Environment change

Due to a change in its environment, a system needs to adapt its functionality. The variability is performed in a lower level than mission change. The time to reconfigure is also shorter and is critical.

Algorithm adaptive change

The choice of the implementation of an algorithm is dependent on the size of the data set to process, the real-time constraints and some other parameters. It is for example the case for the well-known FFT or image compression algorithms. The use of reconfiguration allows changing the version of an algorithm used to fit the task requirements instead of having a generic implementation. Moreover, automatic adaptive techniques like those based on neuronal networks can be used to choose or optimize the implementation dynamically.

On-line system test

The dynamic system test is a major issue for critical application in harsh environments. Upon the survivability requirements, a control of the functionality of the

application by an external process is suitable to evaluate its ability to continue to operate. In this scope reconfiguration can be useful to evaluate the correct behavior of each function of the system by allowing generating Built-In Self Test at runtime.

Hardware virtualization

Because of the use of reconfiguration, the hardware configuration is under the control of the user's application. In normal operation, some parts of the design are in the configuration memory and some others are effectively present and running in the component. All the functional blocks don't need to be physically present at the same time in the component. So that the application can virtually use more hardware than really available. Moreover, with multiple reconfigurable regions, several blocks can be assembled to build a custom hardware. This is very useful for example for the Software Defined Radio.

5.2. Impacts of using reconfiguration

The use of reconfiguration for military applications and more generally for professional electronics needs to face some challenges mainly due to the novelty of this technology. The more relevant ones according to the applications and the customer point of view are given here.

Feasibility/Portability/Maintainability

Today, only one vendor allows making dynamic reconfiguration inside a high-end FPGA matrix. This can cause problems in strategic application as well as for redundant systems in high reliability equipments where several instances of one equipment are fabricated with components from different sources. The life cycle of the products is quite long and spare parts need to be available for more than a decade. A same application is also often ported to a new platform to be integrated in new systems. For this, there is a demand of portability on the new upcoming components of a family. In this scope, the dynamic reconfiguration is not an easy technology. Indeed the design needs to incorporate low-level hardware features to enable it as well as higher-level application management.

Performances

Applications using reconfiguration can benefit from several advantages brought by this technology as shown in §5.1. Nevertheless the overall performance of the application needs to be maintained or improved to cope with the increase of complexity and the cost of using this technology. The most important drawback on performances is the reconfiguration speed, which is the speed for loading a new configuration into the component. Indeed, the hardware in reconfiguration state cannot be used. Another key issue regarding performances is the

power consumption of the reconfiguration itself. The configuration memory is addressed like a big SRAM with very long lines that are not power efficient at all. The reconfiguration process is thus power hungry.

System configuration interface

In order to apply reconfiguration, an interface is required between the configuration memory and the application. It gives access to the underlying hardware on the one hand, but is controlled at application-level on the other hand. Up to now there is no standard interface to reconfigure the hardware. So that, it is necessary to design a custom interface completely, and no IP can be used.

Security

The security of the design needs to be preserved when using reconfiguration. As the different configurations are usually saved in memories outside the component, their encryption and secure manipulation is mandatory.

System Scheduling and partitioning

The applications need to be partitioned in order to use reconfiguration. New methodologies, algorithms and tools are necessary to perform this particular "hardware/hardware" partitioning. Furthermore, the configurations need to be scheduled dynamically and a dedicated scheduler is needed to perform this at application level.

Data management

During the reconfiguration process, the state of the application needs to be preserved or saved and restored in the reconfigurable region.

Tools

To be able to use reconfiguration in industrial applications, all the design aspects of using this technology need to be supported by tools. More specifically tools enabling reconfiguration of a component are provided by the component vendor and those enabling the partitioning and scheduling of the application can be provided by a third party.

Simulation and validation

Using reconfiguration poses a challenge for simulation and validation. Indeed, the usual design flow uses HDL language that does not natively support reconfiguration. In this context, the deep validation required by professional electronics is not easy to achieve.

Certification

In professional electronics, some application fields require special certification of the designs. It is for example the case for civil aviation. The component as well as the tools needs to be certified [11].

6. Conclusion

In this paper a research project on reconfiguration for military applications is presented. The project explores the new potentials and possibilities offered by reconfigurable components. It studies the needs and requirements to integrate this technology and explores specific issues like dynamic reconfiguration. It is strongly application oriented since it uses as many as seven demonstrators from different fields of military applications.

Preliminary results are presented. They are based on the representative set of applications and give a complete view of the advantages and impacts of using this technology in military and professional electronics.

Future works include the validation of the techniques exercised in the project, the completion and evaluation of the developments required by the demonstrators, and finally the synthesis and analysis of the results obtained into guidelines for the use and exploitation of reconfiguration in military applications.

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