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CUSTOMIZED FPGA SOLUTIONS FOR COMPLEX TECHNICAL CHALLENGES: HOW DEMCON CAN HELP

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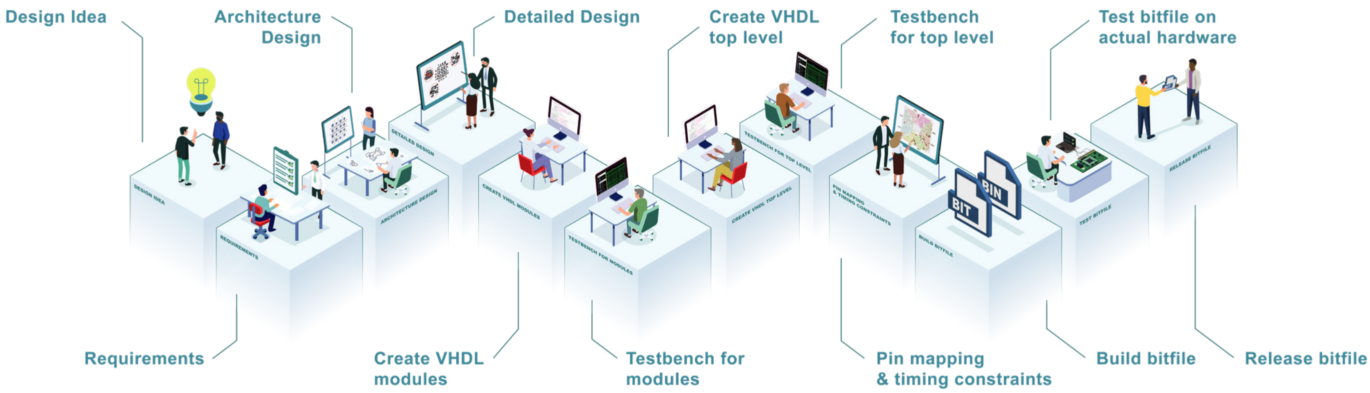
SUMMARY

In this white paper, we aim to elaborate on the strengths of FPGAs and on possible applications and usages in products with which Demcon life sciences & health has experience. Over five chapters, we discuss a handful of considerations to showcase some of our in-house competencies with which we can support your FPGA needs in your next consumer design.

In the first chapter, we explain how FPGAs' unique blend of hardware reliability and software flexibility is ideal for critical applications in medical devices. In chapter two, we discuss how FPGAs support BLDC motors to drive technological innovation. The third chapter describes how our open-source library Libstored makes system integration and testing, control tuning, and production testing more effective and faster. We then explain the use of image analysis and algorithms in FPGAs in chapter four. Finally, in chapter five, we explain how the use of harmonized blocks facilitates precise timing control in FPGAs. Please bear in mind, however, that our FPGA knowledge is broader than the topics in this white paper.



INTRODUCTION

Field-Programmable Gate Arrays (FPGAs) are advanced integrated circuits consisting of programmable logic components that can be programmed with a specific language. Since they first emerged in the early 1980's, FPGAs have enabled the creation of advanced and novel systems to analyze/process large quantities of data in real-time, execute ultra-high-speed application-specific functions, and provide a software-implemented hardware-driven platform. To some extent, they can also emulate the behavior of an application-specific integrated circuit (ASIC). ASIC designs can be tested and validated with FPGAs before creating large batches of chips. FPGAs offer many of the advantages of an ASIC but with more flexibility, as new designs/ software can be installed on the chip. This is generally more cost efficient for low-medium volume products in comparison with ASICs.

Modern-day FPGAs are very powerful, especially when combined with processors on the fabric, thus creating a System on a Chip (SoC) and hardened building blocks to accelerate hardware or enable certain features. Note that some of these features might be brand and model specific. Facilitating the rapid rise of artificial intelligence (AI) and growing interest in advanced algorithms built into devices, FPGAs can also enable real-time embedded AI in devices while keeping their power consumption in check.

FPGAs have proven to be an excellent choice for developing medical applications with updatable and configurable hardware components, as they address real-time and predictable timing processing while being designed for and capable of processing vast amounts of data and images and provide sensor fusion by design. They also provide ultra-scale time resolution in the pico-second ranges, which can be utilized in medical applications for ultrasound and magnetic resonance scanning.

1. ARCHITECTURAL FLEXIBILITY AND MEDICAL REGULATORY STANDARDS

The unique blend of hardware reliability and software flexibility that FPGAs offer, is ideal for critical applications in medical devices. We will now take a detailed look at the four main advantages.

A. Hardware reliability plus software flexibility

Hardware components are typically more reliable and predictable is essential to ensure patient safety and device dependability. Safety mechanisms programmed in the FPGAs can be identified as hardware mitigations. Unlike traditional hardware, however, FPGAs retain the flexibility of software. They can be reprogrammed to adapt to new requirements or to correct issues without needing physical changes to the device. The rapid prototyping and iterative development that this enables significantly reduces the time and costs associated with bringing medical devices to market. Note that FPGA source code development for medical devices must conform to the IEC 62304 standard.

B. Redundancy for critical sensors

One of the significant advantages of using an FPGAs in medical devices is the ability to connect critical sensors twice, utilizing completely separate interfaces. This redundancy eliminates single points of failure, enhancing the overall reliability and safety of the device. In scenarios where sensor data is vital, such as monitoring heart rates or blood pressure, having redundant connections ensures continuous operation even if one interface fails.

C. Extensive I/O capabilities

One of the distinctive features of FPGAs is their extensive input/output (I/O) capabilities. Unlike microcontrollers, which are often limited to a specific number of interfaces, FPGAs can support a vast array of I/O configurations. Whether one or ten SPIs (Serial Peripheral Interfaces) are required, FPGAs can accommodate whatever's needed without limitations. This versatility particularly benefits medical devices, which may require multiple sensors, communication modules, and other peripherals to function correctly.

D. Combining the strengths of the ASP and FPGA

In one of our current projects, we utilize both an Application-Specific Processor (ASP) and an FPGA to combine their respective strengths for optimal performance, reliability, and safety –

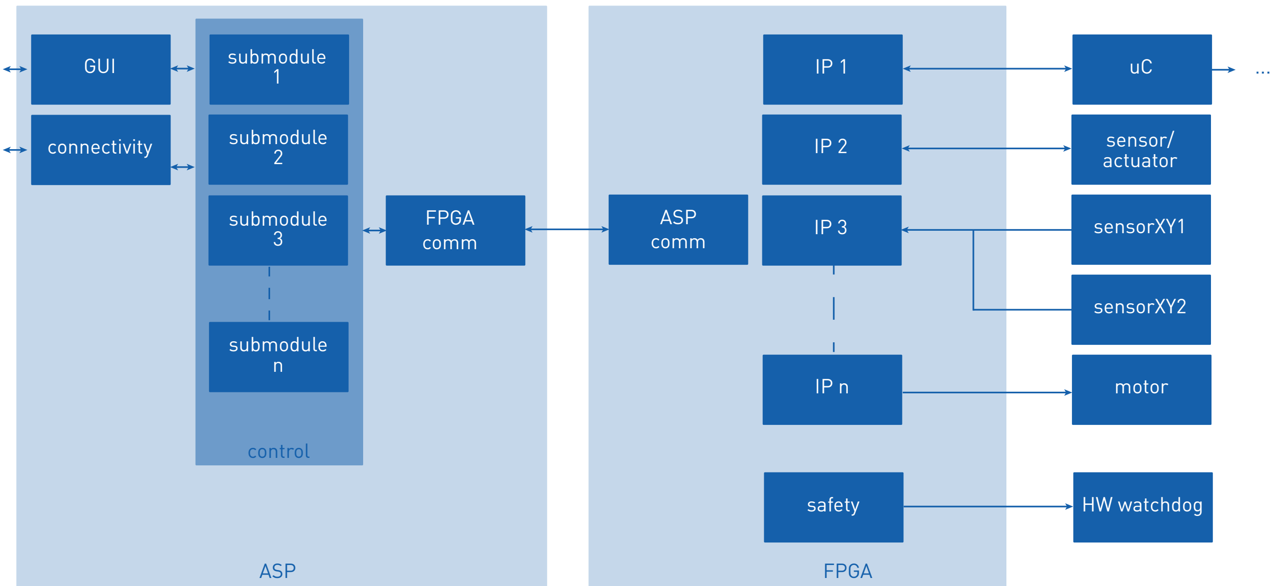
making them well-suited for their intended application. Here, the ASP is responsible for implementing domain-specific knowledge to ensure that the system operates with a deep understanding of the specific requirements and constraints of our application. The main control loop, which orchestrates the overall operation of the device, is also housed within the ASP. Additionally, the ASP handles the Graphical User Interface (GUI) and connectivity functionalities, providing a user-friendly interface and seamless communication capabilities.

Purpose of the FPGA

The FPGA, on the other hand, manages the low-level interfaces to sensors and actuators. This setup allows for efficient and reliable interaction with the hardware components. The FPGA also pre-processes sensor data to reduce the computational load on the ASP and enable faster response. This means that whenever a faster control loop is required, the FPGA will ensure timely and precise control.

Cyclic redundancy check mechanism and safety module

To maintain robust communication between the ASP and FPGA, we implemented a heartbeat and cyclic redundancy check (CRC) mechanism. This ensures that the interface remains reliable, and any communication errors are promptly detected and addressed. Furthermore, the FPGA includes a safety module designed to handle critical failure scenarios. For instance, if the connection to the ASP is lost, the safety module will ensure that all actuators are set to a safe state to prevent any potential harm or damage.



2. HOW FPGAS SUPPORT BLDC MOTORS TO DRIVE TECHNOLOGICAL INNOVATION

Due to the intensified demand for high-speed, precise, and energy-efficient systems, Brushless DC (BLDC) motors have become crucial for the many applications that require precise control and high efficiency – ranging from robotics to embedded control systems. Similarly, ultra-fast feedback systems are essential in fields like optics and real-time imaging. FPGAs offer a powerful solution in these contexts. The customizable hardware, parallel processing capabilities, and low latency they provide are often beyond the reach of traditional microcontroller-based systems.

Outperforming traditional microcontroller solutions

BLDC motors operate with a complex control algorithm that requires precise timing, real-time sensor feedback, and efficient processing power. Vital for the high-speed communication between sensors, controllers, and actuators in such systems is a platform that can handle concurrent tasks without compromising performance. In precision robotics applications, FPGA-based BLDC motor control systems can outperform traditional microcontroller solutions by offering faster processing speeds, reduced latency, and more accurate motor control. This allows for systems which could otherwise not have existed due to certain performance requirements.

Ultra-fast feedback systems

In a similar way, ultra-fast feedback systems in applications like controlling mirrors, cameras, and other optical components, rely on processing and responding to sensor data within micro-seconds. The deterministic performance, low latency, and high throughput that these systems require are often beyond the capabilities of microcontrollers – especially since everything in the FPGA can be done in parallel.

Crucial for next-generation control systems

In short, the significant advantages that FPGAs provide for BLDC motor control and ultra-fast feedback systems facilitate superior performance in applications where precision, speed, and reliability are critical. As the demand for technological innovations continues to grow, FPGAs will become increasingly important for next-generation control systems.

3. EASY READ-OUT/COMMUNICATION AND DEBUGGING WITH LIBSTORED

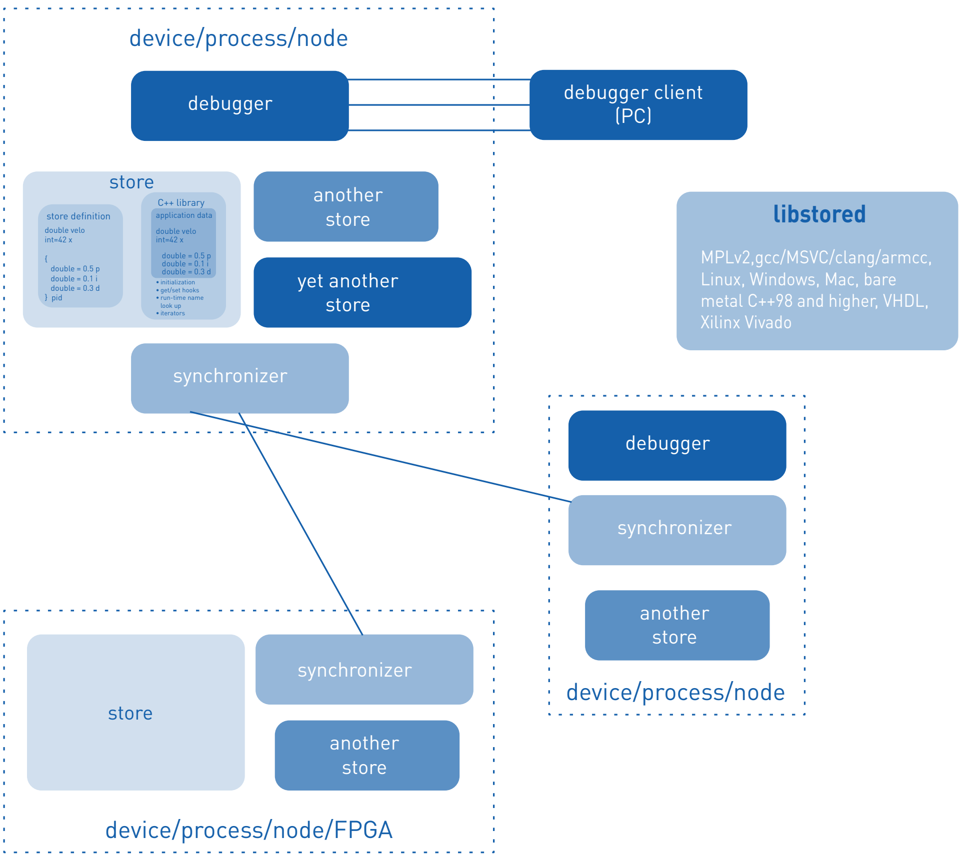
FPGAs are often used in combination with software on a microcontroller. Implementing such a distributed system, with data synchronization between software and the FPGA, is tricky and hard to debug.

What Libstored does

The open-source library Libstored, developed by Demcon, takes a data description of the application and generates data structures for the microcontroller(s) and FPGA(s). It implements transparent synchronization of the application data between these distributed processing nodes, considering atomic data access and causality of changes to this data.

Making tasks more effective and faster

Libstored provides a robust software/FPGA architecture and adds easy debugging to the platform. Data can be visualized and changed easily by PC tooling, communicating via the protocols that Libstored provides. This makes tasks such as system integration and testing, control tuning, and production testing more effective and faster.



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4. IMAGE ANALYSIS AND ALGORITHMS IN FPGAS

FPGAs are ideally suited for real-time image analysis with the use of algorithms. Common applications of real-time image analysis are medical imaging (e.g. ultrasound, MRI, Xray Endoscopy), sorting (e.g. food, waste), automotive, semiconductor positioning, military imaging, video surveillance, biometric recognition, industrial automation, and broadcasting equipment.

Algorithms for FPGAs

Many of the commonly used preprocessing algorithms can be adapted or used for an FPGA, such as:

- chromatic aberration;
- geometrical correction;
- color correction;
- gamma correction;
- filtering;
- image segmentation;
- thresholding;
- background filtering.

Why FPGAs ideally suit real-time processing

FPGAs are ideally suited for real-time processing for many reasons. First of all, their ability to process multiple data streams in parallel allows for high throughput and low latency. The low latency results from FPGAs deterministic behavior, meaning that they can process and analyze image data with minimal delay. Secondly, FPGAs handle complex algorithms and large datasets efficiently, providing fast and more accurate results compared to traditional software-based applications. Thirdly, FPGAs energy-efficient processing makes them suitable for applications that need low power consumption. The fact that FPGAs can be reprogrammed, means you can update your algorithms in the field.

FPGAs vs. GPUs: key differences

There are several key differences between FPGAs and GPUs. Most notably, FPGAs offer more flexibility and can be reprogrammed for specific tasks. They are also better for low-latency applications and much more energy efficient. GPUs, on the other hand, provide higher performance for general purpose parallel processing and excel in high throughput scenarios.

Dealing with limitations regarding algorithms

FPGAs also have some limitations regarding algorithms. For instance, algorithms commonly use divisions and floating-point in there calculations. Division consumes resources and time when it is not possible to translate the division into a power of 2 value. Resource consumption for floating-point location is higher because of the bigger vectors that need to be transferred and also because you need to keep very good track of the point location within the vector. There are multiple ways to work around these limitations. One solution is rewriting the algorithm. Another option is using FPGAs that have an integrated processor (e.g. ARM) where some parts of these calculations can be performed. Specific libraries can handle the tracking of the floating-point location for you at a resource cost.

5. USING HARMONIZED BLOCKS FOR TIMING CONTROL IN FPGAS

Precise timing control in FPGA design is crucial to ensure that signals are correctly aligned and synchronized across different components. Some implementations on FPGAs are not vendor independent and require specific manufacturing and product knowledge. For example, IDELAY and ODELAY blocks are important elements that facilitate precise timing and control in AMD Xilinx products – allowing designers to finetune the timing of signals as they enter or exit the FPGA. This is essential for high-speed designs, especially when dealing with interfaces like DDR (Double Data Rate) memory, high-speed serial communication, or multi-Gigabit transceivers.

Adjusting delays to meet timing requirements

The IDELAY block allows designers to add a controlled delay to incoming signals in the pico second range. Adjusting this delay dynamically during operation provides the flexibility to meet timing requirements. This is especially welcome in scenarios where the timing relationship between the incoming data and the FPGA's internal clock might shift due to variations in temperature, voltage, or process.

Demcon also uses the IDELAY block in different ways. Delaying an electrical signal in FPGAs using IDELAY enables the realization of pulse generators with a very high resolution. An easy implementation of a pulse generator in an FPGA would be the period of its fastest clock - normally somewhere in the nanosecond range. Dynamically changing the delay using the

IDELAY block enables pulse generator resolutions of 156ps. The big advantage here, compared to a clock generator IC, is that the frequency can be changed instantly. Typically, PLL systems need some time to recover after a frequency change. All of this can still be achieved with a relatively low jitter.

Benefits of timing control in various applications

Precise signal timing control is essential in various applications where high accuracy and fast response are critical. In control systems, precise timing can deliver pulse sequences required for high-precision motor control – enabling finer control and faster response times in dynamic environments. In medical applications, it can be used for imaging technologies where precise timing and rapid pulse generation are crucial for high-resolution imaging and accurate diagnostics, such as ultrasound and MRI. In optical solutions, employing the FPGA-based pulse generator in laser control, optical communication, and lidar systems can provide precise timing, rapid modulation, and time-of-flight measurements.

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DEMCON life sciences & health
Enschede
Institutenweg 25
7521 PH Enschede

Eindhoven
Kanaaldijk 29
5683CR Best

Delft
Delftechpark 23
2628 XJ Delft

Maastricht
Oxfordlaan 55
6229 EV Maastricht

+31 88 115 20 00
lsh@demcon.com
lsh.demcon.com

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