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FPGA for Edge Computing and Artificial Intelligence

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***Abstract*— The growth of mobile devices and the expansion of data sources and communication infrastructure, including the Internet of Things ecosystem with modern devices controlling billions of sensor nodes, cloud technologies, highlight the issues that need special attention. The traditional distributed control scheme with centralized data processing based on cloud technologies has serious limitations in terms of security, power management and latency for reliable low-latency communication that meets 5G standards. This leads to the need to move data processing to the periphery, sharing computing resources to reduce the costs associated with network congestion. This approach, in turn, works on network flexibility and scalability.**

Keywords — DNN, FPGA, PPA, ML, ASIC, LUT, PLC, PAC, IPC, IoT.

I. Introduction

Recent advances in machine learning (ML) and deep neural networks (DNN) with artificial intelligence can enable some of the workload to be shifted to the edge, but this solution comes with a huge computational burden that cannot be met with traditional software and embedded processor-based approaches. In addition, designing application-specific integrated circuits (ASICs) is extremely challenging as the reduction of process geometry pushes the cost of development and manufacturing beyond the edge. Moreover, the lack of ASIC reconfiguration severely limits any potential system upgrades. At the same time, traditional FPGA-based approaches are usually too expensive and power-intensive for next-generation edge applications [1].

II. Challenges in power integrity and electromagnetic compatibility

The edge computing niche requires components with extremely low power consumption, small size, flexibility in changing data sets, and the ability to evolve with changing AI capabilities through remote upgrades – all at a reasonable price. This is essentially a natural area for FPGAs, with their inherent excellence in accelerating compute-intensive tasks on a flexible hardware platform. However, most of the available off-the-shelf FPGAs are targeted at data center applications, where the power and cost profiles justify the bloat of FPGA technology. However, solutions have now emerged that can address the low-power edge computing requirements based on reconfigurable structures.

Efinix has developed a fundamentally different approach to FPGA architecture, called quantum technology. Unlike traditional FPGAs from well-known vendors that dedicate fixed silicon regions for either logic or routing, Efinix FPGA devices use their innovative eXchangeable Logic and Routing (XLR) cells. Each XLR cell can dynamically function either as a logic element (containing a LUT, register and adder) or as a routing matrix. This flexibility allows software tools to optimize crystal usage based on actual project requirements rather than worst-case assumptions.

Practical research results [2] show improved performance, especially in power-constrained peripheral computing scenarios, although of course the actual improvement depends on the specific application.

Advantages over traditional FPGAs:
- 4x better power and performance (PPA);
- 7 metal layers vs. 12+ layers in traditional FPGA;
- Unified architecture, scalable to over 1 million logic elements (LE).

Architectural features:
- Flexible, fine-grained architecture;
- Software-defined logic/routing;
- High-performance adaptive interconnects;
- Hybrid placement and routing algorithm;
- Standard manufacturing process.

III. CRITICAL APPLICATIONS. INDUSTRIAL SOLUTIONS

Modern industrial applications generate vast amounts of data. FPGAs are widely used in industrial applications, enabling real-time sensor integration, data analysis, and machine control.

Sensors monitor not only every product parameter on the production line, but also the performance of the production line itself. Machines are equipped with tools to detect any signs of wear or potential failure (PDM), allowing for preventive maintenance and avoiding costly downtime. Speed-critical processes require computing and AI tools to be moved closer to the source of the data, where it can be analyzed and interpreted in real time [3].

The Efinix features, as well as the range of power and performance, allow for their widespread adoption in industrial environments to meet the computing needs of next-generation industrial automation.

IV. DRIVES AND MOTOR CONTROLS

Drives and motor control systems are integral to a wide range of industries, helping to improve the efficiency, accuracy and reliability of motorized systems in industrial, commercial and residential sectors. FPGAs enhance these applications by providing real-time processing, configurable control logic, high-speed communication interfaces and efficient parallel processing capabilities.

V. PLCS, PACS AND IPCS

Programmable logic controllers (PLCs), programmable automation controllers (PACs) and industrial PCs (IPCs) are key components for controlling and automating processes in industrial automation and control systems. With their flexible I/O and high-speed data processing, FPGAs are commonly used to expand I/O and Industrial Ethernet in these control systems.

VI. I/O MODULES AND INTELLIGENT SENSORS

In the Internet of Things (IoT) ecosystem, I/O modules and smart sensors provide network connectivity, seamless data collection, and scalability to help manage and optimize energy consumption. Efinix FPGAs are commonly used in I/O modules and smart sensors to provide flexibility, high-speed I/O, and low power consumption.

VII. 3D, INDUSTRIAL PRINTERS

3D printing, also known as additive manufacturing (AM), is rapidly developing in many industries, from prototyping and manufacturing to medical equipment. FPGAs can provide motion control, parallel processing, and high-speed data I/O between system components, increasing the performance, accuracy, and versatility of 3D printing applications.

VIII. MACHINE VISION

Machine vision is the foundation of Industry 4.0, revolutionizing manufacturing with real-time quality control, intelligent automation, advanced defect detection, and data-driven analytics. Cameras, sensors, and thermal imaging systems seamlessly integrate to deliver advanced machine vision solutions. With support for MIPI, LVDS, SLVS-EC, Ethernet, and PCIe® interfaces, FPGAs are ideal for industrial cameras and frame capture devices.

IX. SMART SECURITY

With the rise of security concerns and the advancement of technology, smart security systems and smart traffic cameras are crucial to creating a safer and more efficient urban environment. By integrating artificial intelligence or machine learning, smart cameras can analyze and process video data as it is captured. Small form factor, low power FPGAs are optimally suited for these smart security systems

X. KEY FEATURES AND BENEFITS

Efinix FPGAs are designed from the ground up with the needs of edge AI and machine vision in mind. The Trion family features enhanced MIPI interfaces for seamless connectivity of video sensors, making them a natural fit for vision-based applications. The Trion Titanium family features a redesigned quantum compute fabric with enhanced digital signal processing (DSP) capabilities optimized for neural networks and AI architectures. The small physical size, dense compute, and low power consumption of Efinix FPGAs make them ideal for edge computing and data processing applications. Available in densities ranging from 4,000 to 1,000,000 logic elements, and in packages including both FBGA and wafer-level packages, Efinix FPGAs are ideal for the most demanding edge applications [4].

XI. RISC-V INTEGRATION: SAPPHIRE SOC

Efinix provides full RISC-V support through its Sapphire SoC IP framework. Based on the VexRiscV core, Sapphire includes a 32-bit processor with configurable pipeline stages, user peripherals (SPI, I2C, UART) on the APB bus, and memory controllers on the AXI bus. This allows for the implementation of complete embedded systems within the Efinix FPGA framework [5].

The presence of the IP framework simplifies the use of FPGAs for AI/machine learning with additional customization capabilities, allowing the RISC-V instruction set to be extended with hardware accelerators for TensorFlow Lite operations, which will significantly improve inference performance compared to pure software implementations.

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