HARDWARE HIERARCHY

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ÍNDICE

ÍNDICE DE FIGURAS

ÍNDICE DE TABLAS

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1 INTRODUCTION

In the current era of digital world Silicon development boards plays a vital role for testing any real time application, or to go for a new architecture in hardware etc. There are so many silicon boards available in the market, they are categorized into different types like microcontrollers, CPUs, Single Board computers, Accelerators, FPGA etc. Based on the parameters like speed, processing capability, power consumption, each of them has their own significance. Based on our requirement we can choose a video processing board, signal processing board etc. Let us look at some of them in detail.

Any electronic device or system contains a functional unit or a processing unit namely a micro-processor. For a better understanding of the any unit or board we need to know what is a microcontroller and a micro-processor.

1.1 Micro Processor

Microprocessor is the brain of all computing systems (such as your PC, smartphone, home assistant, blood sugar measuring device etc). It's the unit responsible for all necessary calculations which allow a system to work and produce the expected output. A system alone with Microprocessor can't work alone because it needs to receive data from other units, and this is why you'll need other parts such as registers, memory units and Input/Output ports (at least).

1.2 Microcontroller

Microcontroller is an embedded system, and this means it embeds several unit in one single chip: Microprocessor, Memory units (RAM, ROM, FLASH), Input/Ouput Ports, other peripherals (such as Analog-to-Digital Converter or Analog-Comparator or Timers..etc). Microcontrollers are special because they allow developers to build a functioning system in short time, since you don't need to choose several parts and make sure that they are compatible with each other.

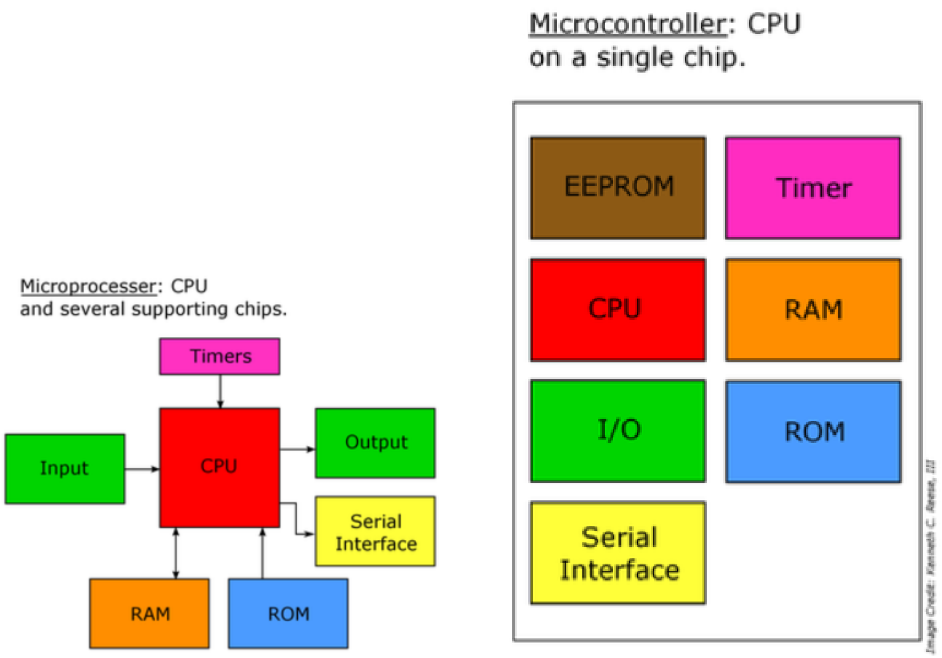


Figura 1: Micro processor and a Micro controller

2 DEVELOPMENT BOARD

Take a microcontroller (or a microprocessor) and provide it with usb-port, HDMI-port, power input port, display unit such as Alphanumeric-LCD or other meaningful ways to display information (such as LEDs or Seven-Segment) and this entire unit is called a development board. Using these development boards we can build simple projects like controlling a system based on given conditions.

2.1 Arduino Board

Arduino is a development board containing 8-bit Alf-Egil Bogen Vegard Wollan RISC (AVR)AVR microcontroller as its functional unit. Arduino consisting of three major features. The first one being the Hardware prototype platform, the second is Arduino language and last but not the least Integrated Development Environment (IDE) & libraries. An Arduino board cannot run an operating system, but the code can be written and executed as their permanent software program interprets it. The primary function of the Arduino board is to interface with secondary devices and sensors, which makes it ideal for projects which require minimal complexity and just function on the sensor or manual inputs. Generally AVR processors are 8 bit some are 32 bit processors. The speed of general AVR is 20 MHz. Clock speed of Arduino board is 16 MHz .

Board	Processor	Memory	Digital I/O	Analog I/O
Uno	16MHz ATmega328	2KB SRAM, 32KB flash	14	6 input, 0 output
Due	84MHz AT91SAM3X8E	96KB SRAM,512KB flash	54	12 input, 2 output
Mega	16MHz ATmega2560	8KB SRAM,256KB flash	54	16 input, 0 output
Lenardo	16MHz ATmega32u4	2.5KB SRAM,32KB flash	20	12 input, 0 output

Tabla 1: Different Types of Arduino Boards Available and Their Specifications

3 SINGLE BOARD COMPUTER

A single board computer is a complete computer built on a single circuit board, with microprocessor(s), memory, input/output(I/O) and other features required of a functional computer. The first SBC developed was MMD1 called dynamicro by E&L Instruments in 1976. General applications include gaming, robotics, computation tasks etc.

3.1 Raspberry Pi

Raspberry Pi (series) is a fully functional computer, as it has dedicated memory, graphics card, and a processor. The board can even run the Linux OS (specially designed version), and it is easy to install in most Linux software. The boards were developed by the Raspberry Pi Foundation to encourage basic computer science learning in schools, along with developing countries. Even though designed for just teaching, the boards have become popular more than predicted and have been used in high-end applications such as robotics. All Pi devices contains a System on Chip(SoC) which is from Broadcom which consists of an ARM processor, Graphical Processing Unit(GPU) and RAM. It supports SD Card . The raspberry pi boards are used in many applications like Media streamer, Arcade machine, Tablet computer, Home automation, Carputer, Internet radio, Controlling robots, Cosmic Computer, Hunting for meteorites, Coffee and also in raspberry pi based projects. The Raspberry Pi is a powerful tool when it comes to artificial intelligence (AI) and machine learning (ML). Its processing capabilities, matched with a small form factor and low power requirements, make it a great choice for smart robotics and embedded projects.

	Raspberry Pi 1 Model A	Raspberry Pi 1 Model A+	Raspberry Pi 1 Model B	Raspberry Pi 1 Model B+	Raspberry Pi 2 Model B	Raspberry Pi 3 Model B	Raspberry Pi Zero
Release Date	2013	2014	2012	2014	2015	2016	2015
SoC	Broadcom BCM2835	Broadcom BCM2835	Broadcom BCM2835	Broadcom BCM2835	Broadcom BCM2836	Broadcom BCM2837	Broadcom BCM2835
CPU Speed	700 Mhz ARM-1176JZF-S	700 Mhz ARM-1176JZF-S	700 MHz ARM-1176JZF-S	700 Mhz ARM-1176JZF-S	900 Mhz ARM-Cortex-A7	1.2 Ghz ARM-Cortex-A53	1 Ghz ARM1176JZF-S
Cores	1	1	1	1	4	4	1
SDRAM	256 MB	256 MB	512 MB	512 MB	1 GB	1 Gb	512 MB

Figura 2: Types of Raspberry Pi Available and Their Specifications

4 ARDUINO VS RASPBERRY PI

The main difference between them is Arduino is microcontroller board while raspberry pi is a mini computer. Thus Arduino is just a part of raspberry pi. Raspberry Pi is good at software applications, while Arduino makes hardware projects simple.

4.1 Learning Curve

Arduino is much easier to learn & if you have little or no knowledge in computers and programming but wish to begin, Arduino is the right choice for you. On the other hand, people with a background of Unix or Linux computing can easily go with Raspberry Pi as it can easily be loaded with a special version of Linux explicitly created for Raspberry Pi hardware. Once the OS is installed, it is like working on any Linux machine.

4.2 Simplicity

The Arduino board is much simpler to use in comparison to Raspberry Pi. The Arduino board can easily be interfaced with analog sensors and other electronic components using only a few lines of code. Where Raspberry Pi requires knowledge of Linux and its commands.

4.3 Available Programming Languages

The Pi in Raspberry Pi comes from the Python language, which denotes its use in the computer. Although Raspberry Pi has adopted a number of programming languages in the short time it has been around, due to which it has become the primary choice for a vast group of programmers. Some of the languages that are available for use in Raspberry Pi are Scratch, Python, HTML 5, JavaScript, JQuery, Java, C, C++, Perl, and Erlang.

In the case of Arduino, you will meet Arduino IDE—a cross-platform UI used to write and upload programs to the board. It is written in programming language Java and helps anyone begin Arduino programming rather easily. But in high-end projects, the Arduino IDE acts as a limit on what can be done. If you do not wish to use the IDE, you can code the Arduino using the C++ language.

4.4 Networking Capabilities

The networking capabilities of Raspberry outpace those of Arduino by a fair distance. The Raspberry Pi 3 has Bluetooth and Wireless connection capability. It can also connect to the Internet using Ethernet. The board comes with 1 HDMI port, 4 USB ports, one camera port, 1 Micro USB port, 1 LCD port, and 1 DSI display port, which makes it ideal for a variety of applications. On the other hand, though, Arduino ports are not built for network connectivity directly. Even though it is possible, it will require an additional chip fitted with an Ethernet port, which will require further wiring and coding.

4.5 Processor Speed

Comparing the clock speed of Arduino Uno board and Raspberry Pi Model B board, we see the values 16 MHz and 700 MHz respectively. Therefore, the Raspberry device is 40 times faster than the Arduino board. Moreover, the Pi board has a staggering 128,000 times more RAM than the Arduino board, which has a RAM of 0.002 MB(UNO).

One important thing to remember is that Arduino is just a plug and play device and can be turned ON and OFF at any time without any damage. But the Raspberry Pi runs on an operating system and is a full computer in itself, which requires a proper shutdown before power is withdrawn. Improper shutdown(s) of Raspberry Pi might damage the board, corrupt the applications and may even affect the processor speed.

4.6 Power Consumption and Storage

Due to its powerful (comparatively) processor, the Pi board requires a continuous 5V power supply and may or may not run ideally when powered using batteries. But the Arduino can run seamlessly with a battery pack, due to its low power requirements. Although, the power consumption may vary as the number of connected devices increase.

The basic Arduino board comes with 32 KB storage to store the code, which provides the boards with instructions. This is just enough as the storage will not be used for applications, videos and photos. The Pi, however, does not come with any storage, but it supports a micro SD port which allows the user to add as much as storage they like.

Device	**Arduino**	**Raspberry Pi**
Family	Alf-Egil Bogen Vegard Wollan RISC microcontroller (AVR)	Advanced RISC Machines (ARM)
Memory (RAM)	0.002 MB (Uno)	512 MB (Model B)
Clock Speed	16 MHz	700 MHz
Operating System	None	Linux Distributions
I/O Pins	20	17
Storage	32 kb storage	No onboard storage (SD card port)
USB Ports	None	4
Languages Used	C/C++	Python, HTML 5 and JavaScript

Figura 3: Arduino and Raspberry Pi Differences

5 SINGLE BOARD COMPUTER WITH ACCELERATOR

A hardware is used to accelerate the performance of a particular task. We have different accelerators like GPU which is an accelerator for machine learning applications. Further FPGAs are also used as accelerators for AI applications as well as general purpose processors also. Other examples of these accelerators are Tensor Processing Unit(TPU) example Google coral TPU , Vision Processing Unit(VPU) example: Intel vison accelerator

ICO Board is a FPGA accelerator commonly used for SBC Raspberry Pi.

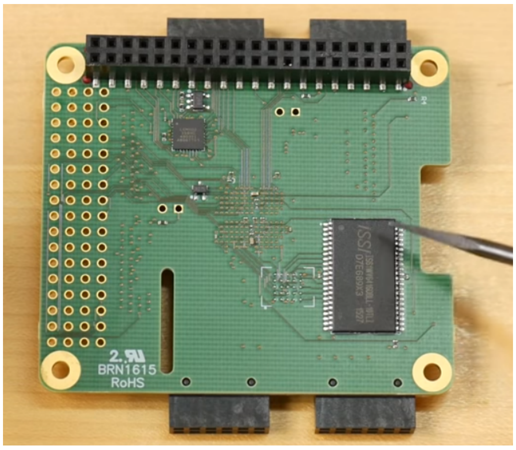
5.1 ICO Board

ICO board is a FPGA board containing ICE40HX8K FPGA which contains around 8000 look up tables. It has PMOD connectors, flat pins, 2 LEDs and 2 switches.

SPI Flash chip-For loading the firmware we have 2 options either loading it from Raspberry Pi or to have it stored in the board itself so for storing it contains a SPI Flash chip, whenever we need to load the firmware from internal memory FPGA automatically download it from flash chip.

8 Mb SRAM- It is useful for FPGA to store the intermediate data while processing. LCMX02- It is also an FPGA controls the connectivity between Raspberry Pi , ICE40 and SPI Flash chip and acts like switch while loading firmware.The clock speed of ICO board is 100 MHz.

(a) ICO board Front View



(b) ICO Board Back View

(c) ICO board with a Raspberry Pi

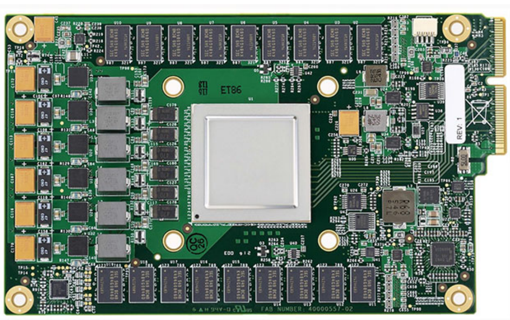
Figura 4: ICO Board

5.2 Tensor Processing Unit(TPU)

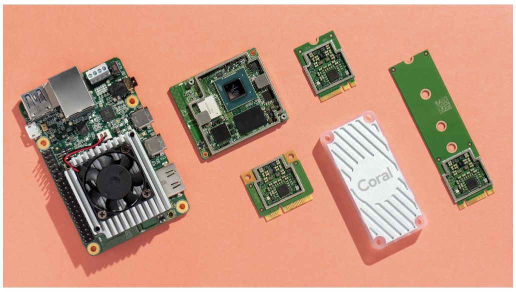
A tensor processing unit (TPU) is an AI accelerator application-specific integrated circuit (ASIC) developed by Google specifically for neural network machine learning, particularly using Google's own TensorFlow software.

The first-generation TPU is an 8-bit matrix multiplication engine, driven with CISC instructions and the clock speed is 700MHz.It is capable of performing matrix multiplications or convolutions, and apply activation functions. The second-generation TPU was announced in May 2017. Google stated the first-generation TPU design was limited by memory bandwidth and using 16 GB of High Bandwidth Memory in the second-generation design increased bandwidth to 600 GB/s and performance to 45 teraFLOPS. Notably, while the first-generation TPUs were limited to integers, the second-generation TPUs can also calculate in floating point. This makes the second-generation TPUs useful for both training and inference of machine learning models. The third-generation TPU was announced on May 8, 2018 an dit is twice powerful than second generation TPU.

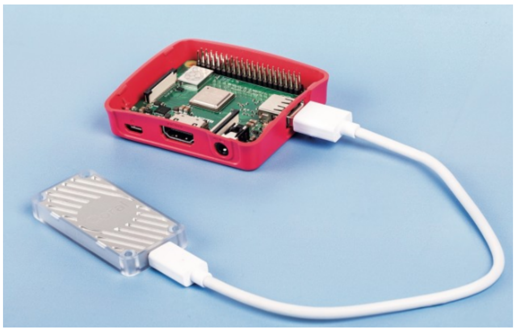
In July 2018, Google announced the Edge TPU. The Edge TPU is Google's purpose-built ASIC chip designed to run machine learning (ML) models for edge computing, meaning it is much smaller and consumes far less power compared to the TPUs hosted in Google datacenters (also known as Cloud TPUs). In January 2019, Google made the Edge TPU available to developers with a line of products under the Coral brand. The Edge TPU is capable of 4 trillion operations per second while using 2W. The product offerings include a single board computer (SBC), a system on module (SoM), a USB accessory, a mini PCI-e card, and an M.2 card. The SBC Coral Dev Board and Coral SoM both run Mendel Linux OS – a derivative of Debian. The USB, PCI-e, and M.2 products function as add-ons to existing computer systems, and support Debian-based Linux systems on x86-64 and ARM64 hosts (including Raspberry Pi).



(a) TPU Chip



(b) Coral TPU Devices



(c) TPU with a Raspberry Pi

Figura 5: Tensor Processing Unit

6 FIELD PROGRAMMABLE GATE ARRAY

Field Programmable Gate Arrays (FPGAs) are semiconductor devices that are based around a matrix of configurable logic blocks (CLBs) connected via programmable interconnects. FPGAs can be reprogrammed to desired application or functionality requirements after manufacturing. FPGA is made up of Configurable Logic Blocks(CLB), Input Output Blocks(IO blocks) and switch matrices. And FPGA are configured using Hardware Description Languages like VHDL/ Verilog HDL programming languages.

Altera delivered the industry's first reprogrammable logic device in 1984 – the EP300. Xilinx invented first commercially viable field programmable gate array in 1985 – the XC2064.which has 64 CLBs. FPGA has wide range of applications some of them are aerospace and defense, high performance computing, consumer electronics, automotive and many more.

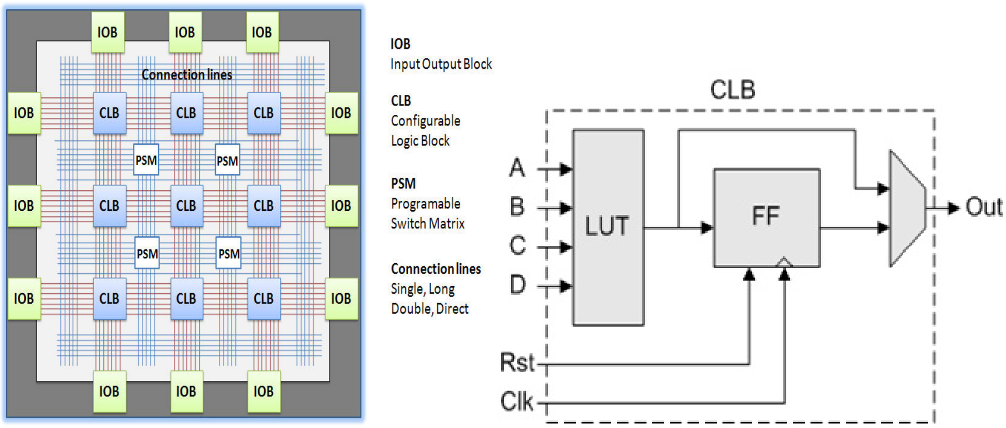


Figura 6: Structure inside FPGA and CLB structure

6.1 NEXYS-4 DDR

The Nexys4 DDR board is a complete, ready-to-use digital circuit development platform based on the latest Artix-7^{TM} Field Programmable Gate Array (FPGA) from Xilinx. With its large, high-capacity FPGA (Xilinx part number XC7A100T-1CSG324C), generous external memories, and collection of USB, Ethernet, and other ports, the Nexys4 DDR can host designs ranging from introductory combinational circuits to powerful embedded processors. Several built-in peripherals, including an accelerometer, temperature sensor, MEMs digital microphone, a speaker amplifier, and several I/O devices allow the Nexys4 DDR to be used for a wide range of designs without needing any other components.

The Artix-7 FPGA is optimized for high performance logic, and offers more capacity, higher performance, and more resources than earlier designs. Artix-7 100T features include:

- 15,850 logic slices, each with four 6-input LUTs and 8 flip-flops
- 4,860 Kbits of fast block RAM
- Six clock management tiles, each with phase-locked loop (PLL)
- 240 DSP slices
- Internal clock speeds exceeding 450 MHz
- On-chip analog-to-digital converter (XADC)

The Nexys4 DDR also offers an improved collection of ports and peripherals, including:
• 16 user switches • 16 user LEDs • Two 4-digit 7-segment displays • USB-UART Bridge • Two tri-color LEDs • Micro SD card connector • 12-bit VGA output • PWM audio output • PDM microphone • 3-axis accelerometer • Temperature sensor • 10/100 Ethernet PHY • 128MiB DDR2 • Serial Flash • Four Pmod ports • Pmod for XADC signals • Digilent USB-JTAG port for FPGA programming and communication • USB HID Host for mice, keyboards and memory sticks

7 SYSTEM ON CHIP FPGA

Processors and FPGAs (field-programmable gate arrays) are the hardworking cores of most embedded systems. Integrating the high-level management functionality of processors and the stringent, real-time operations, extreme data processing, or interface functions of an FPGA (Field Programmable Gate Array) into a single device forms an even more powerful embedded computing platform. SoC FPGA devices integrate both processor and FPGA architectures into a single device. Consequently, they provide higher integration, lower power, smaller board size, and higher bandwidth communication between the processor and FPGA.

Soc FPGA include a rich set of peripherals, on-chip memory, an FPGA-style logic array, and high speed transceivers. The three largest FPGA vendors, Xilinx, Altera and Microsemi (Previously Actel), have all started to manufacture such devices. Although having in common that they all put a hard 32-bit ARM processor together with programmable logic, there are also considerable differences between the designs that will be discussed in this Table1.

Specification	**Altera Soc**	**Xilinx Zynq 7000 EPP**	**MicrosemiSmartFusion2**
Processor	ARM Cortex-A9	ARM Cortex-A9	ARM Cortex-M3
Processor Class	Application processor	96KB Application processor	Microcontroller
Single or Dual Core	Single or Dual	Dual	Single
Processor Max. Frequency	1.05 GHz	1.0 GHz	166 MHz
FPU	Yes	Yes	Not Ava
ACP	Yes	Yes	Yes
On chip RAM	64KB,with ECC	256KB, no ECC	64KB,no ECC
Memory Type Supported	LPDDR2, DDR2, DDR3L, DDR3	LPDDR2, DDR2, DDR3L, DDR3	LPDDR, DDR2, DDR3
FPGA Fabric	Cyclone V, Arria V	Artix-7, Kintex-7	Fusion2
Analog Mixed Signal (AMS)	Not available	2 x 12-bit, 1 MSPS ADC	Not available
Boot Sequence	Processor or FPGA	processor first	Processor first

Tabla 2: Different Types of SoC FPGAs Avalable

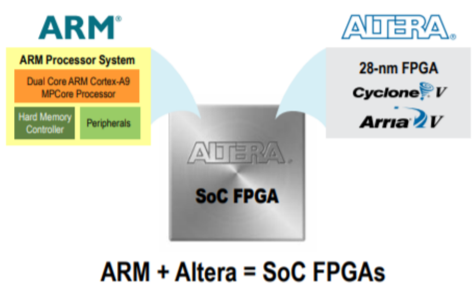


Figura 7: SoC FPGA

7.1 Zed Board

ZedBoard^{TM} is a low-cost development board for the Xilinx Zynq-7000 SoC. This board contains everything necessary to create a Linux, Android, Windows or other OS/RTOS-based design. Additionally, several expansion connectors expose the processing system and programmable logic I/Os for easy user access. Take advantage of the Zynq-7000 SoC's tightly coupled ARM processing system and 7 series programmable logic to create unique and powerful designs with the ZedBoard.

Keyfeatures

- Zynq-7000 SoC XC7Z020-CLG484-1
- 512 MB DDR3
- 256 Mb Quad-SPI Flash
- 4 GB SD card
- Onboard USB-JTAG Programming
- 10/100/1000 Ethernet
- USB OTG 2.0 and USB-UART
- PS & PL I/O expansion (FMC, Pmod^{TM}, XADC)
- Multiple displays (1080p HDMI, 8-bit VGA, 128 x 32 OLED)
- I2S Audio CODEC

8 FPGA VS SOC FPGA

Compared to using a stand-alone processor and a stand-alone FPGA, a solution using a SoC FPGA is cheaper, uses less power consumption, and is easier to put into a design. Two circuits are replaced by one, which means less time for designing and less space on the PCB.

8.1 Performance

If external RAM is used for both the processor and the FPGA, these memory circuits can be consolidated into one RAM chip, saving space, cost and reducing complexity. Communication between processor and FPGA can also go much faster with both units on the same chip.

8.2 Cost

Compared to manufacturing an ASIC, a SoC FPGA is first of all much cheaper and requires much less design time. You will also have a much more flexible design process, as the firmware may be rewritten at any time.

8.3 Hardware

Compared to using a stand-alone processor, a SoC FPGA will be more flexible, since hardware structures can be added throughout the whole design process when needed. It also gives the possibility of parallelising the data processing by allocating computing intensive operations to dedicated FPGA firmware.

8.4 Power

By replacing a stand-alone CPU and FPGA solution with a SoC FPGA, one can reduce the power down to 50 % of the power consumed by the original two chip system. The SoC FPGA can also save a considerable amount of power if it is able to put the FPGA in a low-power standby mode while keeping the CPU alive and running.

9 MULTI PROCESSOR SOC

A multiprocessor system on a chip is a system on a chip (SoC) which includes multiple microprocessors. As such, it is a multi-core system on a chip. The term MPSoC reflects that it comprises a number of different processing elements, each optimised for particular purposes — for instance, a set of applications processors, real-time processor, and a graphics processor, as well as Field Programmable Gate Array (FPGA) programmable logic.

There are mainly three kinds of MPSocs from Xilinx UltraScale+MPSoC architecture.they are

- CG devices: real time processor+ Programmable Logic+ dual application processor
- EG device: real time processor+ Programmable Logic+ dual application processor+ GPU
- EV device: real time processor+ Programmable Logic+ dual application processor+ GPU+ video codec

	CG Devices	EG Devices	EV Devices
Application Processor	**Dual**-core ARM® Cortex™-A53 MPCore™ up to **1.3GHz**	**Quad**-core ARM Cortex-A53 MPCore up to **1.5GHz**	**Quad**-core ARM Cortex-A53 MPCore up to **1.5GHz**
Real-Time Processor	Dual-core ARM Cortex-R5 MPCore up to **533MHz**	Dual-core ARM Cortex-R5 MPCore up to **600MHz**	Dual-core ARM Cortex-R5 MPCore up to **600MHz**
Graphics Processor		Mali™-400 MP2	Mali™-400 MP2
Video Codec			H.264 / H.265
Programmable Logic	103K–600K System Logic Cells	103K–1143K System Logic Cells	192K–504K System Logic Cells
Applications	• Sensor Processing & Fusion • Motor Control • Low-cost Ultrasound • Traffic Engineering	• Flight Navigation • Missile & Munitions • Military Construction • Secure Solutions • Networking • Cloud Computing Security • Data Center • Machine Vision • Medical Endoscopy	• Situational Awareness • Surveillance/Reconnaissance • Smart Vision • Image Manipulation • Graphic Overlay • Human Machine Interface • Automotive ADAS • Video Processing • Interactive Display

9.1 ZCU102

The ZCU102 board is populated with the Zynq UltraScale+ XCZU9EG-2FFVB1156E MPSoC which combines a powerful processing system (PS) and user-programmable logic (PL) into the same device. The processing system in a Zynq UltraScale+ MPSoC features the Arm® flagship Cortex®-A53 64-bit quad-core processor and Cortex-R5 dual-core real-time processor.

The PS and PL can be coupled with multiple interfaces and other signals to effectively integrate user-created hardware accelerators and other functions in the PL logic that are accessible

to the processors. They can also access memory resources in the processing system. The PS I/O peripherals, including the static/flash memory interfaces share a multiplexed I/O (MIO) of up to 78 MIO pins. Zynq UltraScale+ MPSoCs can also use the I/O in the PL domain for many of the PS I/O peripherals. This is done through an extended multiplexed I/O interface (EMIO).and boots at power-up or reset.
To know more about MPSoC ZYNQ7000 refer[1]

10 CONCLUSION

We come across different electronic boards Arduino (Development board), Raspberry Pi(SBC), Raspberry Pi with ICO board(SBC with accelerator), Nexys4 DDR(FPGA), Zed board(SoC FPGA), ZCU102(MPSoC). Development boards or microcontrollers are used for simple automation projects, controlling the machines simply tasks involving use of sensors and with less data storage capacity and with around 15 MHZ clock frequency, Where as SBCs are used for processing applications which involves GBs of data like image processing, signal processing etc with a clock frequency of MHz to GHzs.And when we join these SBCs with accelerators we can do the logical processing using PL section and processing part with the PS section simultaneously it improves the speed and performance.

When coming to FPGAs these are flexible to do complex logical operations with high speed when compared with SBCs and the main advantage of these FPGA devices is they consume very less power than processors. By eliminating the loss of processing capability of FPGAs the SoC FPGA devices evolved, where these boards are capable of doing the processing operations as well as logical operations here the area of two chips is reduced to one chip area and power consumption is also less.On this Soc FPGA boards we can perform various data processing applications.

MPSoC devices are made for high end applications which involve very high data processing. And these devices are faster than FPGA and SOC FPGA as they have very high processing speed. These devices include different processing units for different applications like GPU for video and image applications.

Specification	Microcontroller	SBC	SBC & Acc	FPGA	SoC FPGA	MPSoC
PS	Yes	Yes	Yes	No	Yes	Yes
PL	No	No	Yes	Yes	Yes	Yes
Oth Pro(EX.GPU)	No	Yes	Yes	No	Yes	Yes
Speed	Low	High	High	High	High	V.High
Area	Small	Small	Small	Moderate	Moderate	Large
Pow Cons	Less	Moderate	Moderate	Less	Moderatel/Less	Moderate
Application	Low-end	Mid-end	Mid-end	Mid-end	Mid-end	High-end
Cost	Low	Medium	Medium	High	High	V.High
Est-cost(Rs)	0.5K	3K-9K	10K-15K	20K	34K	2L-3L

Tabla 3: Comparision of Hardware

COMMUNICATION & SIGNAL PROCESSING ALGORITHUMS	HARDWARE				
	Micro Controller (Arduino Series)	Single Board Computers (SBC)	Single Board Computers with Accelerator	FPGA	SoC FPGA
Artificial Intelligence (Data Science)	Basic Data Acq & Sensor Control	1D Signal Processing	2D & 3D Signal Processing	AI Chip Design	AI Processor Design
Deep Learning (Data Science)	Basic Data Acq & Sensor Control	1D Signal Processing (Eg : RNN)	2D/3D Signal Processing (Eg: CNN)		DL based Chip Design or Processor
Machine Learning (Data Science)	Basic Data Acq & Sensor Control	1D Signal Processing	2D & 3D Signal Processing	ML Signal Processing Chip Design	ML Signal Processing Processor Design
Control System Engineering	Basic Auto machine	Auto machine with DSP, ROS (Robotic OS) or RTOS	Auto machine with Data Science Engineering	Auto machine Chip Design	Auto machine Processor Design
Communication Engineering	Cloud Based IoT & Wireless Sensor Network	Cloud / Local Server IoT & Wireless Sensor Network	Narrow Band-IoT or Narrow Band Software Defined Radio (SDR)	Communication Chip Design (Eg : LDPC, Digital Modulator)	SDR Design for RADAR & Wireless Communications Applications

Figura 8: Signal Processing System Design Using SBC and FPGA

REFERENCES

[1] Louise H. Crockett David Northcote, Craig Ramsay, Fraser D. Robinson, and Robert W. Stewart. Exploring zynq mpsoc with pynq and machine learning applications.

https://www.arduino.cc/
https://www.raspberrypi.org/
https://hackr.io/blog/arduino-vs-raspberry-pi-beginners-guide
https://reference.digilentinc.com/reference/programmable-logic/nexys-4-ddr/start
https://www.datarespons.com/soc-fpga-evaluation-guidelines/
https://www.intel.cn/content/dam/www/programmable/us/en/pdfs/literature/ab/ab1_soc_fpga.pdf
https://www.xilinx.com/products/boards-and-kits/1-8dyf-11.html
http://icoboard.org/
https://en.wikipedia.org/wiki/Tensor_processing_unit
https://www.xilinx.com/products/silicon-devices/soc/zynq-ultrascale-mpsoc.html#productAdvantages
https://www.xilinx.com/support/documentation/boards_and_kits/zcu102/ug1182-zcu102-eval-bd.pdf

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