Technology Trends based on Embedded System Design

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***Abstract*—This paper presents the advancements in embedded systems technologies and trends in five parts. In the first part, the paper introduces the notion of embedded systems, the use of embedded technology and the different classifications of embedded systems. In the second part, it discusses the evolution of embedded systems over the past half a century and how its popularity grew over the years. In part three, circuit structure and working mechanism of an embedded system is explained in detail.The paper further discusses the application of embedded systems from basic home and personal gadgets to high-tech industries such as IoT, autonomous cars, defense systems, space exploration and medical devices in part four. In the fifth part, future trends of embedded systems, and key areas that will drive the growth of the technology over the next couple of decades including the 4.0 industrial revolution are explored. Finally, the paper concludes by highlighting key information about embedded systems from all the five parts.**

***Index Terms*—Embedded systems, IoT , Autonomous cars, Microcontroller, Industry 4.0**

I. Introduction

FOR more than half a century now, engineers in top tech companies and academic research institutions have been working tirelessly to incorporate powerful computer processors into very small circuit boards, called PCBs with aim of achieving more dependable, cheap, size-conscious, and efficient specialized computer systems. These stand alone and small computer systems, which are intended for specific tasks, are called embedded systems or embedded computers. The term embedded is used because these small computers are usually embedded into other large systems to accomplish a specific tasks that the system is designed for[1].

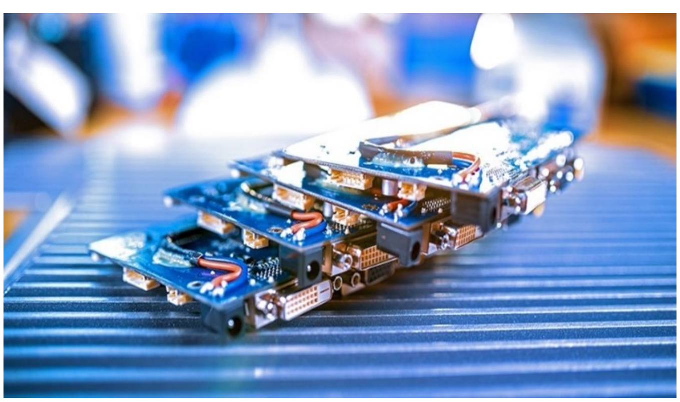

Fig. 1. Embedded systems devices

Embedded systems constitute hardware and software units such as microprocessors, GPUs, memory cards, communication interfaces, application code and a power source, and are classified based on their purpose of use, design, price, and autonomy of operation. Further more technical classification of embedded systems is also made based on the systems performance and functional requirement such as real time embedded systems, standalone embedded systems, network, and mobile embedded systems[1].

Nowadays, embedded devices are widely used in consumer gadgets, enterprises appliances, industrial machinery, healthcare, automotive, robotics, defence and telecommunications devices[2].

II. The Evolution of Embedded Systems

The history of embedded systems dates back to as far as six decades ago, when Charles Draper, an American scientist and engineer, invented an IC in 1961 to reduce the size and weight of the Apollo direction navigation system. This was the first embedded system ever, and it was designed with a specific aim of collecting the lunar mission's real time data to assist astronauts.

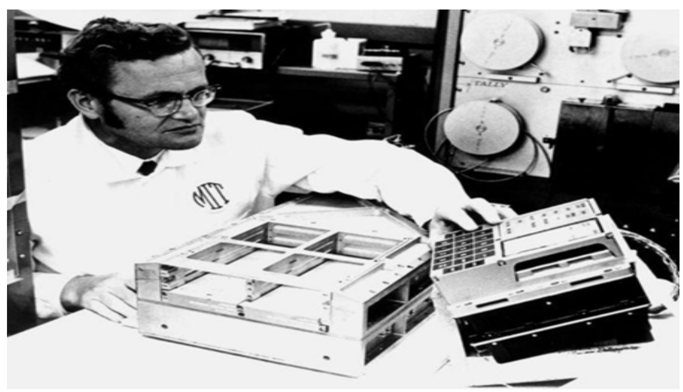

Fig. 2. Apollo 11 Navigation module

Five years after the first IC development, Autonoetic, which is integrated with Boeing at this time, developed D-17B, which is an embedded computer used for missile guidance system. The D-17B is widely regarded as the beginning of mass production of embedded systems. In 1968, the first embedded device for automotives was developed and deployed in Volkswagen model 1600, which used microprocessor to control its electronic fuel injection system[3]. Starting from the early 1970's, multipurpose embedded devices started to get produced in large quantities, which in turn resulted in the dropping of embedded microprocessors prices and surge in the usage of embedded systems. In 1971, Texas Instruments produced their first microcontroller, TMS1000 series, which contained 4-bit processor, memory card (both ROM

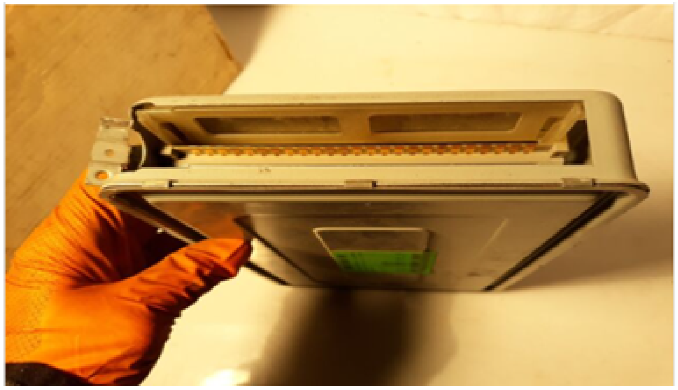

Fig. 3. 1968-1969 VW Type 3 Fuel Injection Computer CU 10x 0280000003

and RAM). In the same year Intel released its first processor, the 4004 with the same processing speed as TMS1000, but with external peripheral devices requirement such as memory, and other supplementary chips. Two years later, Intel released their second generation of processors, the 8-bit Intel 8008 with 16 KB of memory which was eventually upgraded to 64kb in 1974 [3]. This was followed by the x86 processor series which is still on the market and widely used till this day. In 1987, the first real time embedded operating system, VxWorks, was developed and released by Wind River. VxWorks was intended for embedded systems that require real-time and deterministic performance and it supports many computers systems architectures such as the AMD/Intel architecture, the ARM architecture, the POWER architecture, and the RISC-V architecture. VxWorks was followed by Microsoft's Windows Embedded CE in 1996 and later embedded Linux systems. Currently, Linux is used by almost all embedded devices.

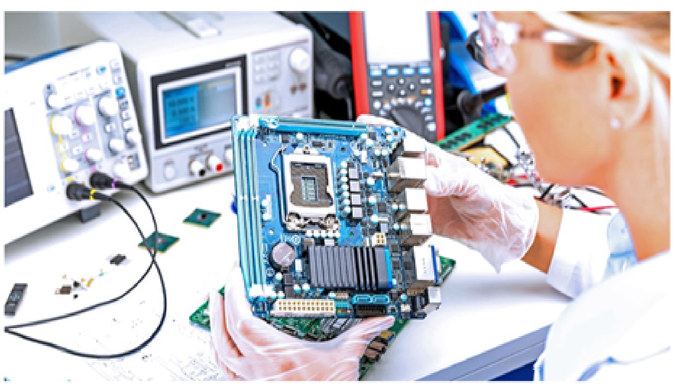

Fig. 4. Modern Embedded system

Modern embedded systems are sophisticated and more specialized devices that are characterized by small form factor (SFF), high power efficiency, highly specialized functionality, and cheap cost.

III. Structure and Working Mechanism of Embedded Systems

Embedded systems are designed to accomplish a specific task, which can be as a standalone or as part of a bigger system. To serve this purpose embedded systems work as a fully operational small-scale computer system that comprises hardware, software, and firmware. The hardware of embedded systems is mainly composed of microprocessors, power supply units as well as data storage and dissemination peripheral devices. Microprocessors are the CPU of embedded systems and it's more like microcontrollers, but with externally integrated computing peripherals such as memory chips and digital signal processors (DSP) unlike microcontroller, which is defined as a computer on a single chip or system on a chip (SoC). Most modern embedded systems use microcontrollers, often referred to as SoC, as the former requires more circuitry support because of less system integration on a single chip. Nowadays, some of the commonly used microcontrollers or SoCs are application-specific integrated circuit (ASIC) and the field-programmable gate array (FPGA)[1].

In general, embedded system hardware has sensors to convert real world data (e.g., temperature) to analog electrical signals, analog to digital converters (A-D converters), digital to analog converters and finally actuators to achieve the target task. Below is basic structure and signal flow diagram of a simple embedded system hardware[2].

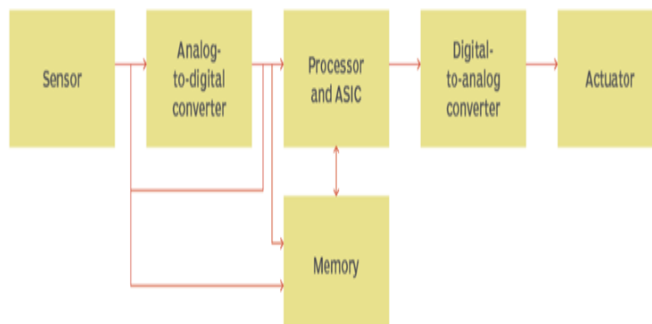

Fig. 5. Basic structure and flow of information in embedded systems.

The software or firmware part is the code which is stored on the system memory and executed by the microprocesses to accomplish the specified task. Embedded system firmware can vary in complexity but most of the currently available industrial-grade microcontrollers and IoT embedded systems run on simple software that doesn't require large storage and processing capabilities

IV. Real world Application of embedded systems including IoT, Robotics and Autonomous cars

Embedded systems are currently used in almost every device that we know from basic home and personal gadgets to sophisticated cutting edge technologies such as autonomous vehicles, humanoid robots, modern defense systems and aerospace technology. However, for a more organized view, experts of the technology classified embedded systems into four types based on their application and functionality as • Mobile Embedded Systems • Networked embedded systems • Stand alone embedded systems • Real time embedded systems Mobile embedded systems are tiny, embedded devices that are designed for a lightweight portable electronic system such as digital cameras, mobile phones, smart watches, and fitness trackers. Networked embedded systems are connected to the internet or local area networks and are designed to share information with other systems over the internet. These devices include ATM machines, weather stations, home security systems and card swipe systems that are connected to phones via the internet. Standalone embedded systems don't require any supporting system and are designed to fully operate on their own to handle a specific task such as calculator, MP3 players, microwave ovens, washing machines, video game consoles etc. Real time embedded systems are embedded devices which are designed for time critical tasks and usually obtain, process, and share real time data. Some good examples of real time embedded systems are pacemakers, blood sugar and pressure level checking devices, aircraft navigation systems, missile guidance systems and traffic control systems. The application of embedded systems is growing exponentially with the recent advancement in high tech technologies such as IoT, robotics, autonomous cars as well as medical and defense technologies. Below are some of the examples of embedded systems application in these cutting-edge high-tech areas:

A. Embedded systems application in IoT devices

Embedded technology has been around since the early 1960s as discussed in the evolution of embedded systems section. However, IoT technology evolved recently, and it refers to the connection and communication between devices over the internet (Wi-Fi/5G networks) using a networked embedded system, which is discussed under the classification embedded systems. The application of embedded systems in IoT devices gives rise to a new technology called IoT embedded systems.

Fig. 6. IoT embedded systems

Embedded IoT systems are widely used in smart homes, set-top boxes, point of sale terminals, medical devices , parking meters and the infinitely many smart devices that evolved recently such as smart refrigerators, smart fitness trackers, smart go karts etc.

B. Embedded systems application in autonomous cars

One of the very first applications of embedded systems was on automotives when Volkswagen used embedded systems based electronic fuel injection system for their Volkswagen model 1600 in 1968. From that time onward the application of embedded systems in the automotives industry has grown exponentially, and at this time the average car has more than 100 control units that use embedded systems. Recently, several motor companies took extra steps to develop autonomous cars that use advanced technology systems and sensors, whose functionality can't be realized without the use of embedded technology.

Fig. 7. Embedded systems application in autonomous cars

Autonomous cars use specialized cutting-edge embedded technology systems that use artificial intelligence, machine learning and deep learning to perform several tasks such as adaptive speed control, multifunctionality warning and automatic system debagging, objects recognition, merging assistance, airbag control during crashes etc., which are embedded on the car's navigation systems, anti-lock braking system and vehicle entertainment and GPS systems.

Fig. 8. Embedded systems application in autonomous car's GPS system

Embedded systems are also used in autonomous car charging stations to handle self-charging, batteries swapping and vehicle charging status reports.

C. Embedded systems application in medical technologies

Almost all modern medical devices are equipped with advanced electronic systems that use embedded systems. With the recent emergence of wearable health gadgets such as fitness tracking wrist watches, pacemaker, as well as defibrillator which monitors health conditions and tracks fitness activities such as sleeping hours and quality, running speed, walking steps, calories exhaustion using embedded systems that reads body parameters such as heartbeat, blood pressure and temperature etc. These new classes of medical devices use networked embedded to help treat and monitor patients by sending data to a remote server for processing and to communicate results via personal smart phones and with health physicians in some cases.

D. Embedded systems application in robotics

Robots are the modern time laborers that are evolving in complexity, sophistication, functionality, and resemblance to humans by replicating tasks that were previously done by human workers only. Robots, like autonomous cars, use several dozens of embedded systems to sense the environment, share real time data for control and monitoring purposes to perform the assigned task. Currently, robots are used hugely in high-tech industries performing high-precision tasks under extreme conditions from assembly line to quality monitoring, welding, painting, and palletizing with the power of embedded technologies

Fig. 9. Industrial robot equipped with modern embedded technology

V. New technology trends using Embedded systems

With the fruition of industry 4.0 and the advancement in intelligent systems that uses artificial intelligence and machine learning for a more fast, efficient, smarter, and safer decision making that can supplant human decision-making or offers capabilities beyond what humans could provide, the application of embedded systems has been growing faster than ever and embedded technologies have become more and more complex, but smaller and easier to use. Autonomous cars, drones with real time video processing and sharing embedded technologies, IoT devices including smart wearable gadgets, mobile phones, home security systems, 3D printers, smart transportation and smart home appliances are yet expected to drive the application of embedded technologies more than ever in the coming couple of decades[4].

VI. Conclusion

Over the past 60 years, embedded systems grew from merely an idea to an inseparable and crucial component of every device that we use today. Embedded systems are currently used in a wide range of devices from basic home appliances and personal gadgets to the most advanced technologies like autonomous cars, robotics, IoT as well as space, defense, and medical devices. The application and demand of embedded systems is expected to grow with the industry 4.0 and the use of intelligence systems that uses artificial intelligence and machine learning to make better decision-making and execute tasks better than humans.

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