Ubiquitous Embedded Systems Revolution: Applications and Emerging Trends

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ABSTRACT

This paper describes the various technological revolutions and pinpoints the embedded systems revolution as the most recent and quietest of all. Being a revolution within another, it is seen as embedded into digital revolution. Embedded systems came into limelight with the birth of microcontrollers and have invaded and embedded themselves into all fields of our lives and this ubiquity is increasing in our daily lives. Despite this, the level of awareness of embedded system is low, hence this paper is written. During the survey of embedded systems evolution the point that they perform dedicated functions was brought to the fore. Most embedded systems are encapsulated within the main working frame of the device being controlled. The widespread and diverse natures of the system as seen in the numerous applications confirm the revolution of this ubiquitous system.

KEY WORDS: dedicated function, digital revolution, embedded system, microcontrollers, ubiquitous system

I. INTRODUCTION

The world has witnessed several technological revolutions. The first was the industrial revolution which marked a major turning point in history as almost every aspect of daily life was influenced in some way. It began in Britain and within a few decades spread to Western Europe and the United States. The Industrial Revolution was the transition to new manufacturing processes that occurred in the 18th century. [1]This transition included going from hand production methods to machines, new chemical manufacturing and iron production processes, improved efficiency of water power, the increasing use of steam power and development of machine tools. The transition also included the change from wood and other bio-fuels to coal. This was followed by electronic revolution which refers to the changes that electronic media such as television, radio and now the Internet have introduced into our lives. The changes that have resulted from these technologies have truly revolutionized the way we do everything from communicating to commuting, from reading and writing to listening and perceiving. [2]

Closely following the above was the Digital Revolution, sometimes called the third industrial revolution, which is the change from analog electronic technology to digital technology that took place about 1980 and continues to the present day. The term also refers to the sweeping changes brought about by digital computing and communication technology during the latter half of the 20th century. This marked the beginning of the Information Age. Central to this revolution is the mass production and widespread use of digital logic circuits, and its derived technologies, including the computer, digital cellular phone, and so on .[3] Underlying the digital revolution was the development of the digital electronic computer, the personal computer, and particularly the microprocessor with its steadily increasing performance, which enabled computer technology to be embedded into a huge range of objects.

Actually, the digital revolution prepared the stage for the emergence of embedded system revolution. This is a revolution within another; thus embedded system revolution is seen as embedded into digital revolution. With the advent of microprocessors, several product opportunities that simply did not exist earlier have opened up. These intelligent processors have invaded and embedded themselves into all fields of our lives and this ubiquity of embedded systems is increasing in our daily lives [4]. This is due to the fact that recently embedded systems have gained an enormous amount of processing power and functionality. Now, many of the formerly external components can be integrated into a single System-on-Chip. This tendency has resulted in a dramatic reduction in the size and cost of embedded systems. As a unique technology, the design of embedded systems is an essential element of many innovations. Embedded systems can be regarded today as some of the most lively research and industrial targets. In this field, the ever-increasing demand for computing power and any sort of system resources continuously challenges state-of-the-art design methodologies and development techniques.

According to a report by research company IDC, a division of International Data Group, the market for embedded computer systems, which already generates more than US$1 trillion in revenue annually, will double in size over the next four years. Furthermore, IDC predicted that much of this growth will be propelled by more sophisticated, cloud-connected embedded systems, which will have faster chips, better connectivity and more advanced operating systems and analytical software. [5] The report, equally states that by 2015, more than 4 billion units will be shipped, which will create $2 trillion in revenue. Moreover, embedded systems will require 14.5 billion microprocessor cores by 2015.

The importance of embedded systems is undisputed as embedded systems imply economical power. Thus, with the constant evolution of electronic devices and software technologies, there will be more and more Embedded Systems integrated into any kind of equipment. According to Information Technologies Study on Worldwide trends in Embedded Systems, today, Europe is a major player in the field of Embedded Systems while the US is the worldwide leader in the area of traditional computing and data processing, Thus, Europe has driven the revolution in Embedded Systems. [6]

Despite the fact that embedded technology is now in its prime, the wealth of knowledge available is already is overwhelmingly impressive. Embedded systems are a rapidly growing industry where growth opportunities are numerous. The uses of embedded systems are virtually limitless, because every day new products are introduced to the market that utilizes embedded computers in novel ways. The objectives of this study are to provide an assessment of the current state of the Embedded Systems as a whole and also to provide a better understanding of the trends of embedded systems ubiquity.

The thesis is divided into five chapters. Chapter one deals with the introduction. In chapter two, a survey of embedded systems evolution was discussed. Furthermore, in chapter three, the ubiquitous revolution of embedded systems was studied. The emerging trends in embedded systems are described in chapter four. Finally, chapter five contains the conclusion and suggestions for further work.

II. A SURVEY OF EMBEDDED SYSTEMS EVOLUTION

An embedded system is a computer system designed to do one or a few dedicated and/or specific functions often with real-time computing constraints. It is embedded as part of a complete device often including hardware and mechanical parts. [7] It is the application rather than the hardware itself that defines the embedded system. For instance, a PC used in as a general-purpose computer in an office or home is an embedded system. However, the same type of PC used in the laboratory to log data or control is an embedded processor [4]. Many embedded systems also interact with their physical environment using a variety of sensors and/or actuators. They are typically used over long periods of time, will not be programmed or maintained by its end-users, and often face significantly different design constraints such as limited memory, low cost, strict performance guarantees, fail-safe operation, low power, reliability and guaranteed real-time behavior.

2.1. CHARACTERISTICS

Embedded systems are unique in several ways. First, when compared with PCs, embedded systems are dedicated to specific tasks, hence another name for an embedded microprocessor is a dedicated microprocessor. It is programmed to perform only one, or perhaps, a few, specific tasks. Consequently, changing the task is usually associated with the entire system becoming obsolete and thus will result in redesigning it. Secondly, they are usually cost sensitive. Here, the cost that is mostly considered is system cost , in particular the cost of the processor. That is why microcontrollers are preferred to microprocessors. Another feature of embedded systems is that they have real-time constraints. They are generally are put into two categories: Time-sensitive constraints and Time-critical constraints. If a task is time-critical, it must take place within a set time or the function controlled by the task fails .On the other hand a time-sensitive task can die gracefully. Furthermore, software failure is far less tolerable in an embedded system than in an average desktop PC. This does not imply that that the software never fails in an embedded system. It is just that most embedded systems typically contain some mechanisms such as a watchdog timer, to bring it back to life if the software loses control.

Embedded systems often have power constraints because they must work reliably and for a long time on a set of small batteries. It is unlike the CPU which needs a massive heat sink and fan assembly to keep the processor from baking itself to death. Most desktop PCs have plenty of space inside to allow for good airflow. For efficient performance of an embedded system, the processor is in the sleep mode most of the time and only wakes up when a time tick occurs. In other words, the system is completely interrupt driven. Thus, power constraints impact every aspect of the system design decisions. Power constraints affect the processor choice, its speed and its memory architecture. [8]

Since embedded systems are everywhere, they must be prepared to operate under extreme environmental conditions, for example , run in aircraft, in the polar ice, in the outer space and so on. In addition, since embedded systems are dedicated to fewer well defined tasks and nothing else, they have few resources that they must manage than the desktop. This translates to fewer resources to manage and hence lower cost and simplicity.

2.2. BASIC EMBEDDED SYSTEM

The principles of operation of, system components and design methodologies are essentially the same in all embedded systems although there are an infinite variety of embedded systems. For instance, every embedded system contains a processor and software. The processor may be a microcontroller or a microprocessor. Certainly, in order to have software there must be a place to store the executable code and temporary storage for run-time data manipulations which will take the form of ROM and RAM respectively. In case of small memories they may be contained in the same chip as the processor. Otherwise one or both types of memory will reside in external memory chips. Moreover, all embedded systems also contain some type of inputs and outputs. Inputs to the system generally take the form of sensors and probes, communication signals, or control knobs and buttons. Outputs are generally displays, communication signals, or changes to the physical world. This is illustrated in Fig.1.

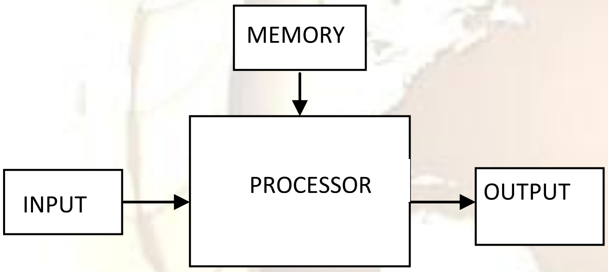

Fig.1 Basic Embedded System

2.3. PROCESSORS USED IN EMBEDDED SYSTEMS

Embedded systems contain processing cores that are typically either microcontrollers (μC) or digital signal processors (DSP). Most embedded systems use microcontrollers.

2.3.1 MICROCONTROLLER

This is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. Microcontrollers make the task easier and possible as they combine several features onto the size of a chip. The chip is almost like a mini computer because it contains all the components that are a part of the latter. It contains an onboard central processing unit, input output interfaces, flash memory for program storage, RAM for data storage, peripherals such as timers and a clock generator. Since all such features are integrated onto a single board, the amount of wiring that was required earlier is eliminated.[12] By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontrollers make it economical to digitally control even more devices and processes.

2.3.2 MICROCONTROLLERS VERSUS MICROPROCESSORS

The main characteristic of microcontrollers is their wide variety of on-chip peripheral functions and memory that enable them to provide a single chip solution to many dedicated embedded designs. On the other hand, microprocessors such as the Pentium inside a personal computer have only the Central Processing Unit. These microprocessors do not have built in memory, input or output functions such as parallel ports or serial ports etc. They are optimized to provide only the raw arithmetic and logic functions required by the operating system at the highest speed. All other components required to make the computer such as memory, input/output ports, serial, parallel, and mass storage are provided by external chips and devices. The Pentium is designed to meet a broad range of general computing needs that are provided with a personal computer. [9]

2.3.3 REAL TIME ISSUES

Embedded systems are often required to provide real-time response. A real-time system is defined as a system whose correctness depends on the timeliness of its response. Real-time system's performance is specified in terms of ability to make calculations or decisions in a timely manner. These important calculations have deadlines for completion. A missed deadline is just as bad as a wrong answer. For example if the real-time system is a part of an airplane's flight control system, single missed deadline is sufficient to endanger the lives of the passengers and crew. Examples of such systems are flight control systems of an aircraft, sensor systems in nuclear reactors and power plants. For these systems, delay in response is a fatal error. [10]

2.3.4 EMBEDDED OPERATING SYSTEM

Embedded operating systems are designed to be compact, efficient, and reliable, forsaking many functions that non-embedded computer operating systems provide, and which may not be used by the specialized applications they run. They are frequently also real-time operating systems.

An important difference between most embedded operating systems and desktop operating systems is that the application, including the operating system, is usually statically linked together into a single executable image.

2.3.5 REAL-TIME OPERATING SYSTEM

Normally, embedded systems do away with an operating system (OS); it has lightweight control program/monitor to offer limited I/O and memory services. However, as the systems become complex, it is inevitable to have OS which offers low latency real-time response. A real-time operating system (RTOS) is an operating system (OS) intended to serve real-time application requests. A key characteristic of a RTOS is the level of its consistency concerning the amount of time it takes to accept and complete an application's task.

2.4 EMBEDDED SYSTEMS DESIGN

Since embedded systems have features that are totally different from other computer-based systems, designing of embedded systems involve a different approach. The objective is to apply a system approach so that the target system may be built to specification functionally and it is easy to maintain. There are four major steps:

- System design
- Design and build hardware
- Design and build software
- Integrate software into the target system

For small projects involving one person the above tasks are carried out in that sequential order. However, for bigger projects, it is possible to develop the hardware and the software in parallel.[4] The design of embedded systems is made by keeping in mind that their main usage is to perform simple tasks, repeated over and over again, without being dependant on the input by the user.[12]

2.4.1 DESIGN CONSTRAINTS

An embedded system is an engineering artifact involving computation that is subject to physical constraints. The physical constraints arise through the two ways that computational processes interact with the physical world: reaction to a physical environment and execution on a physical platform. There are the reaction constraints which specify deadlines, throughput, and jitter and originate from behavioral requirements. Also, there exist common *execution* constraints that bound available processor speeds, power, and hardware failure rates and originate from implementation choices. The key to embedded systems design is gaining control of the interplay between computation and both kinds of constraints to meet a given set of requirements on a given implementation platform.

Embedded systems are often required to function within harsher environments and with fewer resources than general purpose computers. For instance, embedded systems in satellite phones are expected to work at extreme temperatures. Embedded systems are required to work for long periods of time without breakdown. Because of these constraints, embedded systems must be simple, robust and cheap. [10]

2.4.2 DESIGN REQUIREMENTS

Usually, embedded computers operate under tight constraints on both functionality and implementation. Firstly, there must be guarantee for real time system operation implying that the correctness of a computation depends, in part, on the time at which it is delivered. Secondly, they must conform to size and weight limits. Since many embedded computers are physically located within some larger artifact. Therefore, their form factor may be dictated by aesthetics, form factors existing in pre-electronic versions, or having to fit into interstices among mechanical components budget power and cooling consumption, satisfy safety and reliability requirements, and meet tight cost targets. Safety and reliability are very important considerations as some systems have obvious risks associated with failure. Equally it should be noted that embedded systems should be able to walk in harsh environments they can experience from vibration, shock, lightning, power supply fluctuations, water, corrosion, fire, and general physical abuse.

2.4.3 EMBEDDED SYSTEM LIFE CYCLE

An embedded system goes through seven phases and within and in between phases a considerable amount of iteration and optimization occurs. Defects found in later stages often cause one to go back to the starting point. During the first phase called specification, efforts are focused on understanding what the customers want to accomplish and these requirements are incorporated in the designer's requirements to the product. The next stage sees the designer making a decision between which components should be hardware and which will be software. It is known as partitioning decision. The third is the iteration and implementation stage and is a blurred area between implementation and software/hardware partitioning in which the hardware and software diverge.

In the fourth stage, detailed software/hardware design, demands that the designer develops prototypes from available alternatives. During the fifth stage which is the hardware/software integration, there is a convergence of the software and hardware paths. Product testing and release is the crucial sixth stage because embedded system has life or death consequences attached to it sometimes. The final stage involves maintaining and upgrading existing products

III. UBIQUITOUS EMBEDDED SYSTEMS REVOLUTION

Computers have become every day tools that are deeply integrated into all kinds of activities of our life. Today we communicate over computer networks, store and process our information on network servers connected to our personal computers and support and control technical and administrative processes by computers. Digital information technology has revolutionized the world; consequently, our everyday life in business and at home is deeply affected by an extensive digital infrastructure. The invisible revolution of digital technology embedded in all kinds of devices that are more and more connected by networks. The revolution of Embedded Systems is a silent one. Without being conspicuous, it has already affected every sector of the industry and today it will be difficult to find an appliance or device, which does not have an embedded system on board. [6] The embedded systems industry was born with the invention of microcontrollers and since then it has evolved into various forms, from primarily being designed for machine control applications to various other new verticals with the convergence of communications. [11]The development of microcontrollers, therefore, caused the explosion or revolution of embedded systems.

3.1 IMPORTANCE

Embedded systems have so come into such widespread use today that there has been a revolution in the way we perceive our world today. The widespread usage is due to the fact that, since they are dedicated to specific tasks, they can be produced into compact sizes and optimised costs. Furthermore, they are more reliable in terms of long term performance. Their cost is less than that of independent main frame non embedded systems because most of the embedded systems undergo mass production and thus leading to lower cost levels .[12] Consequently, embedded systems have captured an expansive market. Embedding a microcontroller in a product makes the product smart. An embedded system can be programmed to tasks that are very difficult or expensive using technologies such as logic, or time switches and so on. Also, in the business sector, they enable firms to compete on product and service innovation by adding product and service features that customers value, but which would be largely impossible. [14]
Embedded systems are more than part of human life. For instance, one cannot imagine life without mobile phones for personal communication. Its presence is virtually unavoidable in almost all facets of human endeavor.

3.2 DRIVERS OF EMBEDDED SYSTEM

The driving force behind embedded systems was the defence industry during the 1970s. For instance, the United States Navy's F-14 Tomcat fighter which was first launched in 1970 contained arguably the first microprocessor based embedded system.[15]Nowadays, development is driven by a wider group of industries such as health care, aviation, defence, entertainment, and so on. At any rate, in terms of the state of art, consumer products are the drivers of embedded system technology

3.3 APPLICATIONS

Usually an embedded system is encapsulated within the main working frame of the device which it controls. Practical applications of these systems are widespread and diverse. As for the scope of this technology, it is so expansive that it is waiting to be explored.[12] The uses of embedded systems are virtually limitless, because every day new products are introduced to the markets that utilize embedded computers in novel ways. Embedded systems are more than part of human life. Their presence is virtually unavoidable in almost all facets of human endeavor. Consequently, embedded systems are deployed in various applications and span all aspects of modern life. The main application areas of embedded systems are as follows.

3. 3.1 CONSUMER ELECTRONICS

Electronic equipments that are intended for everyday use are known as consumer electronics. Due to manufacturing efficiency and improvements in semiconductor design, consumer electronic products have the trend of ever-falling prices. To stay competitive, manufacturers are under tremendous pressure to be first-to-market with unique products. Most often consumer electronics include such equipment for entertainment, communications, household appliances and office productivity. They now incorporate embedded systems to provide flexibility, efficiency and features. For instance, many household appliances, such as microwave ovens, washing machines and dishwashers have embedded processors. The same goes for entertainment equipment such as music players, digital cameras, DVD players, set-top boxes, PDAs, videogames. Similarly, embedded systems are employed in home automation where wired- and wireless-networking are used to control lights, climate, security, audio/visual, surveillance, and so on.

3.3.2 MEDICAL ELECTRONICS

This is a branch of electronics in which electronic equipment are used for such medical applications such as diagnosis and treatment. Embedded technology is nowadays widely used in medical electronics. Embedded systems make a difference to both patients and the medical staff. Patients respond well to treatment based on the embedded devices, and they can also feel more at ease realizing that their condition may be monitored remotely by their doctor using the technology.[16] Another benefit is that a medical practitioner can now provide a device that will be with the patient 24 hours in place of manual treatment delivery. Furthermore, medical information about a patient can be immediately obtained by the use of embedded technology. Thus, there are embedded systems for vital signs monitoring, electronic stethoscopes for amplifying sounds, and various medical imaging for non-invasive internal inspections.

3.3.3 AUTOMOTIVE ELECTRONICS

Automotive electronics or automotive embedded systems are the electronics used in automobiles. Initially, this branch of electronics was developed in order to meet the need for better control for the engine. It later extended to the control of other parts of the automotive. These electronic control units are referred to as modules and modern automotives and have several modules.[17] They are distributed systems and can be classified into: engine electronics, transmission electronics, chassis electronics, active safety, driver assistance, passenger comfort and infotainment systems. With drive across the world to improve on emission controls and bring in efficiency in usage of fossil fuels, the automotive segment is challenged by various factors and embedded systems are clearly the ways and means of achieving multiple objectives in this segment.

3.3.4 INDUSTRIAL AUTOMATION

The goal of automation technology is to provide partially or totally controlled automated technical processes and plants that are highly flexible. Its use increases reliability and safety of manufacturing processes. Embedded Systems control and manipulate processes. The reliability will be enhanced because individual tasks are standardized. Amongst others, these machines replace people in the execution of monotonous and dangerous tasks. Therefore the safety of plants increases. Industrial automation has different levels.

3.3.5 AVIONICS AND AEROSPACE

Avionics refers to electronics or electronic equipment as applied to aircraft and spacecraft. It is a sector that depends heavily on embedded systems. Today, hardware components and controls are being largely replaced by software-programmed technology. According to the online survey, Embedded Systems in avionics currently constitute about 51% of the total cost of an aircraft, with a slight ongoing growth of this share in the future. [6]

IV. EMERGING TRENDS

Since the embedded systems were born, they have evolved into various forms. Within these systems, there is now a convergence of communications and computing functions, resulting in the creation of new complex systems with new opportunities and challenges. For instance, by converging social networks, city information, local based services and choices and profiles of users, more intelligence is added in the personal entertainment devices.[6] Furthermore, the new trend is to use multi-core processors in the areas of imaging, rendering, compression and so on thereby utilizing its excellent features of higher bandwidth and quicker response times. Again, in wireless sector, the recent trend is to use the embedded systems system-on-chip architecture and power consumption reduction. In the case of the latter, the device remains in sleep mode most of the time especially in applications of “sense and transmit.” Among the characteristics of embedded systems are cost and power sensitivities and these can be achieved by applying various nanoscale device technologies, such as carbon nanotube transistors, nanowires, resonant-tunneling devices and a host of others. [18] Finally, embedded system’s adopting of cloud computing is another interesting emerging trend.

V. CONCLUSION

Embedded systems have silently but consistently revolutionalised the world due to the fact that they are compact in sizes, reliable in terms of long performance, cheaper because they undergo mass production. Their quiet nature results in the users being unaware of their existence making them unable to appreciate their associated enormous benefits. Even up till now in the embedded world changes are occurring with equipment becoming smaller, faster, and superior. However, there is still need to research on nanotechnology, cloud computing and their possible convergence with embedded systems with view to deriving greater dividends of embedded systems revolution.

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