Theory And Application Analysis of Embedded Systems

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Abstract. With the rapid advancement of information technology, society has seamlessly transitioned into the digital age, leading to profound transformations in both our productivity and way of life. Among the various forms of information technology, embedded systems have emerged as a ubiquitous presence in our production processes and daily routines. These systems have evolved hand in hand with modern information technology, continually striving for improvement and refinement. Embedded systems represent a specific category of information technology, characterized by their focus on applications, reliance on computer technology, and the ability to be tailored through customizable software and hardware. This article serves as an introduction to embedded systems, shedding light on their structure, distinguishing characteristics, and primary application scenarios in the current era. Furthermore, it explores the trajectory of their future development, delving into the emerging trends that are set to shape their evolution. By doing so, this discussion aims to foster the wider adoption and advancement of embedded systems in various domains. By comprehending the intricacies of embedded systems, this paper can leverage their capabilities to shape a future that is increasingly interconnected, efficient, and technologically empowered.

Keywords: Embedded system, Theory, Application, Analysis.

1. Introduction

The continuous advancement of communication network technology and integrated circuit design has propelled embedded systems into the forefront of the IT industry. These systems have garnered significant attention as they represent a promising avenue for driving economic growth through the fusion of informatization and industrialization. By seamlessly integrating cutting-edge computer technology, semiconductor technology, electronic technology, and industry-specific applications, embedded systems have established themselves as knowledge-intensive systems that foster constant innovation. Embedded systems embody a harmonious convergence of diverse technological disciplines, enabling them to cater to a wide range of industries and applications [1]. Their significance lies in their ability to integrate advanced computer technology, semiconductor technology, electronic technology, and specific industry requirements. By blending these elements seamlessly, embedded systems create an intricate ecosystem that thrives on knowledge integration, empowering industries with technology-driven solutions that continue to evolve and push boundaries.

This article provides an overview of embedded systems. The second chapter of this article provides a detailed introduction to the different development stages of embedded systems from their emergence to their mature application and analyzes the different technical characteristics of each stage. And demonstrated the software and hardware composition and working principle of embedded systems represented by microcontrollers. Chapter 3 provides different application scenarios and specific case studies of embedded systems in modern production. At last, the conclusion summarizes the characteristics of embedded systems and looks forward to the future development trend of embedded systems.

2. Development History and Working Principles of Embedded Systems

2.1. Definition of Embedded Systems

Embedded systems originate from microprocessors and have a complex evolution history of 40 years. The term 'embedded system' only became popular in the late 1990s. In the industry, embedded systems have always been a vague concept, and no one has given it a precise definition. I remember at the National Microcontroller Academic Conference held in Hangzhou in 1999, someone suggested changing the microcontroller to an embedded system, which caused a huge controversy [2]. Even with the word 'embedded', there has been a debate between 'in' and 'to'. In the late 1990s, the term "embedded system" began to become popular, which caused confusion in people's understanding of "embedded system".

2.2. Development History of Embedded Systems

In 1976, Intel invented the earliest single chip 8048, which represent the dawn of embedded system。40 years ago, it was born based on microprocessors [3]. The twin brothers of embedded processors and general-purpose microprocessors have formed the combination of embedded systems and general-purpose microprocessors in the modern computer field the two major branches that run parallel with computers. 40 years later, they intersect and integrate in the Internet of Things, bringing humanity into the Internet of Things and cloud computing the new era of artificial intelligence in computing and big data [4]. In 80 years, modern computers have gone through a complete journey from the embryonic stage of artificial intelligence to its successful development. The development history of embedded Systems is shown in figure 1.

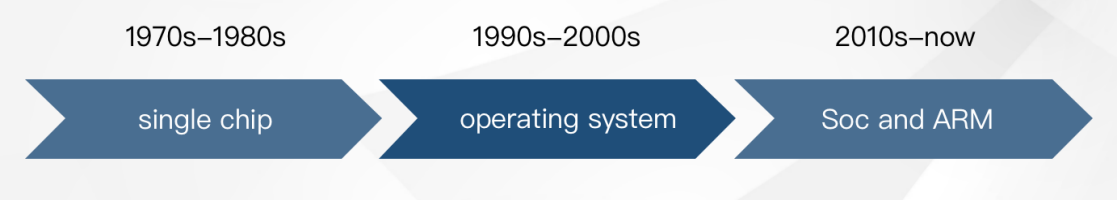


Fig. 1 Development History (Photo/Picture credit: Original)

2.3. Principle Analysis of Microcontroller

2.3.1 Components of Single chip

A microcontroller, commonly referred to as a single-chip microcontroller or simply MCU, is a compact and integrated computer system designed to perform specific tasks within embedded systems. It combines the functions of a microprocessor, memory, and input/output interfaces on a single integrated circuit (IC) chip. Microcontrollers are highly versatile and find applications in various electronic devices and systems, ranging from simple household appliances to complex industrial automation systems.

The key components of a microcontroller include the central processing unit (CPU), which executes program instructions, the memory unit, which stores program code and data, and the input/output (I/O) interfaces, which enable communication with the external world [5]. Microcontrollers are designed to be low-power and cost-effective, making them suitable for applications where space and energy efficiency are crucial. The Structure of Single chip is shown in figure 2.

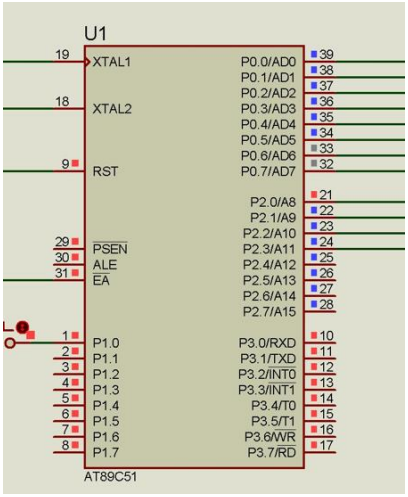


Fig. 2 Structure of Single chip [5]

2.3.2 Principle

The internal processors, controllers, and registers are connected, and the controller sends operation instructions to each component. After receiving the instructions, the processor processes them accordingly, and then stores the calculation results in the corresponding registers. The working principle of the single chip microcomputer is the same as that of the computer CPU. It mainly uses the semiconductor memory inside the single chip microcomputer to store the user's programs and data. Its core microprocessor CPU contains Instruction register, instruction decoder, program counter, etc. It searches for the next instruction to be executed through the program counter, finds it, hands it to the Instruction register, and then the decoder translates it to complete the operation of the instruction function, The final cycle is repeated, forming a working effect. According to the required functional requirements, write program code in advance to ultimately achieve the desired results for users.

2.3.3 Features

Microcontrollers possess several distinctive characteristics that contribute to their widespread usage and popularity. Firstly, their compact size, high integration, and lightweight nature make them highly efficient. These microcontrollers house various functional components on a single chip, resulting in minimal volume and exceptional integration. Furthermore, their chip design is tailored to meet the specific requirements of industrial measurement and control environments, ensuring short internal wiring and superior resistance to industrial noise. The microcontroller's program instructions, constants, and tables are securely stored in ROM, offering excellent protection against damage. With numerous signal channels within the chip, microcontrollers exhibit remarkable reliability.

Secondly, microcontrollers are renowned for their low power consumption, particularly when operated with a single power supply. To cater to the demands of portable systems, many microcontrollers operate at voltages as low as 1.8V to 3.6V, with operating currents in the range of a few hundred microamps [6]. Furthermore, ongoing advancements in microcontroller technology continually prioritize low power consumption, further solidifying their position as a preferred choice.

Ease of expansion is another notable characteristic of microcontrollers. These devices are equipped with essential components necessary for the smooth operation of computers. Multiple external buses and parallel and serial input/output pins facilitate the effortless creation of computer application systems in various scales. The versatility of microcontrollers allows for seamless integration and expansion as per specific requirements.

Lastly, microcontrollers offer a cost-effective solution due to their affordability and high performance-to-price ratio. With impressive capabilities, microcontrollers have embraced technologies such as RISC Assembly line and DSP to enhance speed and operational efficiency. The capacity of microcontrollers has also surpassed previous limitations, with some models reaching

capacities of 1MB or even 16MB for location searches. Additionally, ROM capacities can exceed 62MB, while RAM capacities can reach 2MB [7]. The widespread adoption of microcontrollers and the resulting competitive market have driven prices down significantly, making them an economical choice without compromising performance.

2.4. Dedicated processor

After entering the 1990s, with the development of computer technology, microelectronics technology, IC design, and EDA tools, embedded processors began to develop towards System on Chip (SoC), and a series of processors including 51 microcontroller, AVR microcontroller, MSP430 microcontroller, DSP, CPLD/FPGA emerged. Currently, there are many Embedded operating system, most of which have cross platform migration technology. Under the same system, developers can also choose development tools to use Java, C or assembly language and other languages familiar to developers. WinCE, Palm, WM, Linux, VxWorks, Symbian, etc [8].

2.5. ARM

After entering the 21st century, with the development of related electronic industry technologies, embedded processor related technologies have made rapid progress, with the emergence of 64-bit embedded processors, whose processor cores have also been implemented with 8 cores.

So far, embedded processors can be divided into three categories: ARM architecture family processors supported by MTK, Qualcomm and Samsung, x86 architecture processors supported by Intel, and other special/special processors represented by FPGA. And with the development of embedded processors, the hardware performance of embedded systems has been greatly improved. At this time, Embedded operating system have begun to show some new faces, with Android and IOS as typical representatives, they have occupied the market of most embedded Consumer electronics since their appearance in 2007.

However, Microsoft Corporation did not want to lag. Since 2010, it has successively released Windows Phone (WP) and Windows RunTime (RT) operating systems to seize the Consumer electronics market. In industrial control and other fields, Embedded operating system is still dominated by winCE, VxWorks and Linux based on the principle of stability and reliability.

3. Applications

3.1. Industrial control

In various industrial sectors, the utilization of measuring instruments to monitor and display variables such as pressure, voltage, temperature, or humidity is prevalent. However, manual processes involved in data collection and recording often suffer from human error, necessitating a quick, automated, and accurate means of acquiring such data.

This research presents a digital recognition system that employs Optical Character Recognition (OCR) as its foundation. To ensure real-time services, the system utilizes the embedded Industrial Internet of Things (IIoT) framework provided by the Name Recognition System (NRS). Data reliability is guaranteed through the simultaneous implementation of Digital Image Processing (DIP) and Multilayer Perceptron (MLP) techniques. Moreover, the system addresses the common issue of screen rotation in instrument displays by employing the Histogram of Oriented Gradients (HOG) and Hough Transform (HT) methods. The system also accounts for various noise types, including Salt-and-Pepper noise, Gaussian noise, and speckle noise, prevalent in real-world scenarios. Performance evaluation of the system is conducted using the Fusion Matrix and accuracy metrics.

The NRS system, combined with HOG and HT technologies, exhibits a remarkable capability that adapts to diverse situations, achieving a statistical accuracy rate of 95.13% [9]. Although the utilization of HOG and HT techniques results in longer computation times and increased memory requirements for image processing compared to standard NRS technology, the system consistently

delivers reliable results. Notably, the proposed system is well-suited for real-time services due to its short computation time.

3.2. Intelligent Manufacturing

A microcomputer refers to a chip that incorporates essential components such as a motherboard, video card, RAM, Wi-Fi/Bluetooth connectivity, and input/output ports. These microcomputers are integral to modern operating systems like Micro Linux and Windows. As information technology continues to advance, the conventional performance of electronic systems is being harnessed to enhance the capabilities of the Internet of Things (IoT). The proliferation of interconnected low-capacity devices has resulted in increased energy consumption related to data transmission and latency processes, leading to a data explosion.

In the era of IoT, microcontrollers are poised to play a pivotal role due to their compact size and robust scalability. This trend is set to drive the advancement of high-end manufacturing. Microcontrollers represent a natural and groundbreaking development process for the application and evolution of intelligent appliances in this era [10]. These devices are designed to remotely collect and analyze data, reducing or eliminating the need for manual intervention in applications, data collection, and operational processes. Consequently, production speed and accuracy reach unprecedented heights. The combination of microcomputer architecture and the operational characteristics of the IoT makes microcontrollers an increasingly reliable choice for IoT applications. The utilization of microcontrollers in the IoT ensures enhanced reliability, allowing for seamless integration and communication within connected systems.

To illustrate, a medical embedded controller is a compact and automated system that relies on feedback from the patient and external environment to carry out specific functions related to immediate treatment or overall management of patient health. An important application that necessitates incorporating a feedback control mechanism into integrated embedded medical devices is the artificial pancreas (AP) for patients with Type 1 diabetes (T1DM). T1DM patients face autoimmune disorders that impede the natural secretion of insulin by the pancreas—an essential hormone for regulating blood sugar levels. In the absence of proper insulin synthesis, patients are unable to effectively control their blood sugar concentration, leading to potential complications such as Diabetic foot and hypoglycemic shock, significantly increasing health risks.

Consequently, exogenous insulin must be administered to maintain blood glucose concentrations within a safe range (70-180 mg/dL). The AP serves as a controllable and personalized source of insulin supplementation through a feedback mechanism [11]. It delivers the necessary insulin to the patient based on real-time blood glucose levels, precisely calculating the required insulin dosage using a measurement system. Currently, the most advanced treatment approach for T1DM employs a continuous blood glucose monitoring system (CGM) that regularly measures blood glucose concentration. The control algorithm within the AP leverages these CGM measurements to determine the appropriate amount of insulin infusion. This infusion is facilitated by an Insulin pump, also known as the continuous subcutaneous insulin infusion (CSII) system.

4. Conclusion

The basic characteristics of embedded systems are single chip, embedded, and intelligent control, which are also three basic requirements for achieving tool intelligence. Single chip form is a fixed morphological feature of embedded systems. From the earliest MCS-48 to the improvement of MCS-51, followed by the functional expansion and bus configuration of 80C51, to today's multi-core systems, all follow the maximization development mode of SoC. In the early days, during the period of intelligent transformation of traditional electronic systems, this characteristic was obvious. People referred to household appliances embedded with microcontrollers as household appliances with computers. Later, many innovative intelligent electronic systems emerged, but their embedded objects were not obvious, to the extent that some people confused the boundary between embedded

systems and product systems. Intelligent control indicates that all intelligent tools have similar and relatively independent intelligent control units, which are embedded systems. The three basic characteristics of embedded systems result in different prominent features and forms of nomenclature at different times, such as Microcontroller Unit, Embedded System, etc. Despite their different titles, they are not fundamentally different.

Compared with general computer systems, embedded systems have the characteristics of specificity, encapsulation, externality, real-time performance, and reliability, and are therefore widely used. Its coverage and application fields are very extensive, including almost all electrical equipment. In recent years, the rapid development of the Internet has also created a huge application space for embedded systems in daily life. With the vigorous development of embedded systems, people's requirements for embedded systems are also increasing. From a technical perspective, the future of embedded systems. The system has the following new development trends: further network support; Smaller size, micro power consumption, lower cost; Exquisite human-machine interface; An "intelligent" embedded system. This embedded system can effectively improve people's work efficiency and quality of life and is the development direction of future embedded systems.

References

[1] Zhimin Deng. Research on product decision support system model based on cloud service and embedded system. Journal of Ambient Intelligence and Humanized Computing, 2021, 13(1): 1-13.

[2] Karakish Mohamed, Fouz Moustafa A., ELsawaf Ahmed. Gait Trajectory Prediction on an Embedded Microcontroller Using Deep Learning. Journal Sensors. 2022, 22(21): 8441-8442.

[3] Xin Li. Implementation of USB in Embedded Systems Based on ARM Microprocessor. Applied Mechanics and Materials. 2014, 3335(596): 883-887.

[4] Yannian Zhang, Houqi Sun, Xiaowei Gu, Wenjie Zhang, Bonan Liu. Experimental Study on the Use of Iron Tailings-Based Multicomponent Solid Waste as SCMs. Sustainability, 2022.

[5] Zhigang Ma. The Current Situation and Development Trends of Theoretical Embedded Systems. China Equipment Engineering, 2020, 3(21): 145-147.

[6] Lin Peng, Qiu You, Peng You. Design of the Integrated Performance Testing Device for Electromagnetic and Static Relays Based on Single Chip Microcomputer. Journal of Physics: Conference Series. 2023, 2476(1).

[7] Huang Yahui, Lei Daozhong. Multisource data acquisition based on single-chip microcomputer and sensor technology. Open Computer Science. 2022, 12(1): 416-426.

[8] Du Peng Yuan, Tang Yi Fan, Lv Si Tao, Zhou Guo Fu, Bai Peng Fei. A CO Concentration Detection Platform and Temperature Compensation Method Based on Zynq Series SoC. Journal of Physics: Conference Series. 2022, 2395(1).

[9] Ersoz Alpaslan, Phu Helen, Kim Insoo, Han Martin. A Wireless Neurostimulator System with an Embedded ARM™ Microprocessor. Conference proceedings: Annual International Conference of the IEEE Engineering in Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual Conference. 2019, 4(6): 5200-5203.

[10] Lin Rong-Xia. Design of Mobile Control system for wheeled Mobile Robot based on embedded ARM Technology. Journal of Physics: Conference Series. 2019, 1168(2): 22106.

[11] De Melo Francisco, Neto Horácio C, da Silva Hugo Plácido. System on Chip (SoC) for Invisible Electrocardiography (ECG) Biometrics. Sensors. 2022, 22(1): 348.