Teaching Curriculum Reform of SoC Design and Intelligent Ocean Applications Based on Open-Source Hummingbird Platform

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Abstract. With the development of SoC, ASIC and IoT, traditional education models in these areas are required to undertake corresponding adjustment and even reform. In this paper, the teaching system of the communication department, School of Information Engineering, Zhejiang Ocean University is investigated and teaching curriculum reform of SoC Design and Intelligent Ocean Applications Based on Open-Source Hummingbird Platform is proposed. The reform includes theoretical teaching and experimental teaching and all the teaching contents are targeted to meet the continuously changing industrial demands and technological challenges. This curriculum reform provides students with comprehensive learning resources and practical opportunities to help them adapt to the rapidly developing IoT era.

Keywords:teaching curriculum reform; SoC; ASIC; IoT; Hummingbird.

1 Introduction

Currently, with the relentless advancement of technology and the expansion of application scenarios, there is a growing focus on System on Chip (SoC) design, Application Specific Integrated Circuit (ASIC) design, and Internet of Things (IoT) applications in modern information technology. The progress in these fields demonstrates significant trends, and their technological innovation is vital in addressing the ever-increasing complexity of application needs.

SoC design, serving as the centerpiece of the information technology field, aims to amalgamate system-level functionality with integrated circuits. This entails the integration of various functional units such as processor cores, memory, input/output interfaces, etc., into a single chip with high integration and autonomous capabilities. The objective of SoC design is to pursue higher performance, lower power consumption,

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and reduced size, thereby providing intelligent, efficient, and multifunctional solutions for numerous devices and systems. The influence of SoC technology is ubiquitous, spanning from smartphones to smart homes, permeating every aspect of our daily lives. The advantage of its widespread application stems from its highly customized design, which consolidates various functions onto a singular chip, consequently enhancing device performance and efficiency. Notably, this not only fuels the advancement of modern consumer electronics but also reveals vast potential for application in sectors such as healthcare, transportation, and industry[1,2].

ASIC design refers to customized integrated circuit design tailored to specific application scenarios and functional requirements. In contrast to general-purpose processors, ASICs achieve their intended functions through highly customized designs, facilitating high performance and low power consumption in the smallest possible chip area. ASIC design finds extensive utilization in industries, automobiles, communications, and consumer electronics, benefiting from efficient processing and optimized performance for specific tasks. Its significance in the field of information technology is increasingly prominent, providing tailor-made solutions for diverse sectors and meeting the requirements of varying applications. Compared to general-purpose processors, ASIC design better accommodates the stringent demands of specific sectors for performance, power consumption, and cost, thus enjoying widespread adoption in numerous domains[3-5].

The IoT technology, serving as the core of connecting and interacting with various intelligent devices, is playing an increasingly significant role. The concept of IoT is no longer confined to connecting computers or smartphones but has expanded to encompass various fields, such as home devices, urban infrastructure, healthcare, and agriculture. By bridging the physical and digital worlds, IoT technology has created an intelligent, efficient, and convenient way of life, driving the wave of digital transformation. Within the IoT ecosystem, diverse sensors, embedded devices, and communication technologies collaborate to enable information sharing and intelligent decision-making among devices. This provides people with a wealth of data that allows us to better understand and respond to environmental changes. The profound impact of IoT technology applications is changing our way of life and work, from smart cities to smart agriculture[6-9].

Nevertheless, the rapid development in areas such as SoC design, ASIC design, and IoT applications necessitates the synchronization of traditional education models with technological advancements[10-12]. Currently, the teaching system of the communication department, School of Information Engineering, Zhejiang Ocean University still adheres to the traditional theoretical knowledge system related to the profession. However, there are issues such as insufficient resources for course practice platforms, limited cutting-edge and systematic knowledge, and a gap with enterprise requirements. Students must enhance their engineering practice ability, innovation awareness, and innovation ability, and the collaboration between schools and enterprises must deepen. Therefore, in order to meet the continuously changing industrial demands and technological challenges, it is essential to carry out relevant educational curriculum reforms.

The updates of courses in areas such as SoC design and ASIC design are critical for the development of students' skills. The traditional teaching model may not fully incorporate the latest technological trends and industrial practices, necessitating adjustments to the teaching content. This includes incorporating the latest case analyses, practical projects, and engineering applications. Such reforms can not only enhance students' understanding of the latest technologies in the industry but also cultivate their practical skills and problem-solving abilities. Additionally, as IoT applications become more prevalent in various fields, updates to related courses will aid students in better comprehending and seizing the development of this field. The widespread application of IoT technology requires students to possess interdisciplinary knowledge, such as sensor technology, communication technology, and data analysis. Therefore, curriculum reform plays a crucial role in equipping students with comprehensive learning resources and practical opportunities to effectively adapt to the rapidly developing IoT era.

Taking into consideration the aforementioned backdrop, the individual responsible for curriculum reform has introduced new foundational courses such as "SoC Design Theory and ASIC Design Practice" and "Internet of Things Technology and Application Development" within the college's relevant curriculum system. These courses cover a wide range of integrated circuit basics, including integrated circuit and SoC design technology, basic synthesis, static timing analysis, backend physical implementation, semiconductor technology, and more. As a result, the course content has been significantly enriched. By reforming the traditional approach to curriculum teaching in the college, teachers are not only able to guide students in acquiring knowledge and expertise in SoC design, ASIC design, and IoT applications but also focus on cultivating students' independent development abilities. Consequently, students are empowered to independently develop IoT systems with distinct perceptual functions based on ocean application scenarios. This teaching reform approach has discarded the conventional written test assessment method in favor of primarily using experiments to evaluate students' learning outcomes. Through this method, students are given the opportunity to design specific ocean Internet of Things systems, thereby assessing their developmental capabilities.

In this article, the School of Information Engineering at Zhejiang Ocean University serves as the subject of study. The main objective of this research is to present the specific details of the curriculum teaching reform in SoC design and smart ocean applications, built upon the open-source hummingbird processor platform proposed by the college. The second segment of this article provides a concise overview of the innovative aspects of this curriculum teaching reform. The third section focuses on the reform of teaching content, encompassing both theoretical and experimental teaching methodologies. Finally, the fourth part offers a comprehensive summary of the entire text.

2 Innovative Curriculum Reform

This curriculum reform plan primarily focuses on the close integration of academic development with industrial demand. The limitations of traditional experimental teaching in the personal computer development environment, particularly when handling complex IoT applications, have prompted the need for a course teaching reform. Consequently, this reform is based on the existing teaching resources of the School of

Information Engineering at Zhejiang Ocean University and effectively combines the advantages offered by high-tech enterprises in RISC-V processor IP and overall solutions. The main objective of this reform plan is to reshape the relevant course content by adopting a model of enterprise support, university docking, and co-construction and sharing, thereby aligning it with the current technological development trends in the fields of integrated circuit design and Internet of Things applications. This will ultimately lead to the comprehensive upgrading of teaching content and the course system.

The core focus of this reform plan involves reevaluating the theoretical and experimental teaching content, with special emphasis on the application of ocean Internet of Things and smart agriculture. It aims to explore innovative teaching reforms in the realm of "Internet of Things Plus Ocean". Additionally, the design of Systems-on-Chip (SoC) based on the open-source hummingbird processor platform will be integral in cultivating highly skilled applied talents with innovative capabilities, specifically tailored to meet the demands of the smart ocean industry.

To achieve these goals, the teaching reform will be implemented within the overall structure of the curriculum. This approach will ensure the inclusion of more practical teaching content and provide students with a broader academic perspective, as well as practical experience. By actively collaborating with high-tech enterprises, the school intends to integrate external resources, offering students more practical educational experiences, and fostering a talented team that can effectively contribute to current technological development requirements.

3 Teaching Content

This teaching reform course is a systematic integration of technologies such as SoC design and ASIC design process. It is a comprehensive course that combines theory and experiment. The aim of this course is to enable students to master the process from SoC design to ASIC design, as well as gain relevant knowledge on how foundries produce, package, and test chips. The course utilizes the enterprise's RISC-V CPU in combination with open-source technology resources on the SoC platform. By taking the RISC-V processor IP architecture as an example, students are able to learn about RISC-V instruction set and CPU pipeline design knowledge. The open-source hummingbird processor platform is used to further enhance students' learning in memory subsystem design, AMBA bus design, input/output system design, and the integration and validation of a complete SoC system, thus improving their integrated circuit design abilities. Additionally, this course not only enables students to understand and master the basic knowledge of RISC-V CPU and SoC, but also exposes them to scenarios of the ocean Internet of Things, allowing them to apply the development platform in perceiving actual ocean information. Moreover, this course also trains students in their ability to collaboratively develop and design system software and hardware through experimental assessments. The schematic diagram of the teaching content is shown as Figure 1, and the detailed introduction to the content of the curriculum teaching reform is as following.

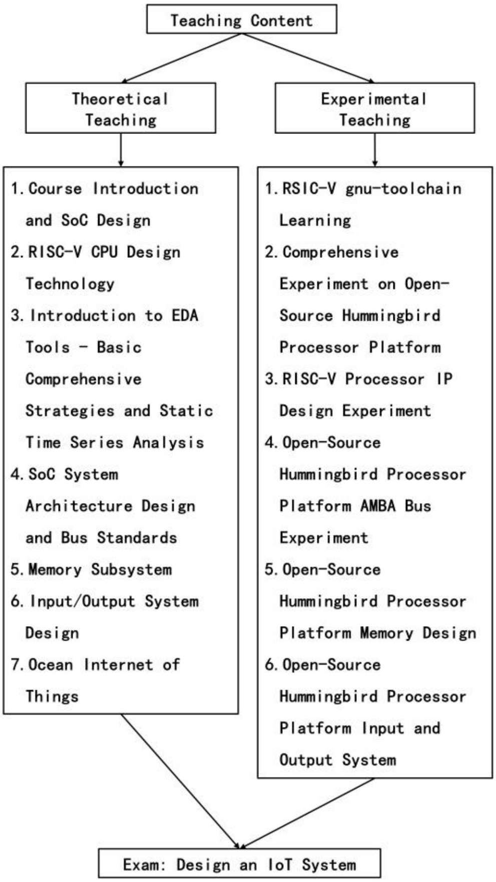

Fig. 1. Schematic Diagram of Teaching Content.

3.1 Theoretical Teaching

The theoretical teaching of this course mainly covers seven parts:

1) Course Introduction and SoC Design: the course introduction provides a brief overview of integrated circuit technology and applications, development history, industry status, as well as fundamental SoC design methods and processes. Additionally, it introduces the enterprise RISC-V processor IP series and open-source hummingbird processor platform, guiding students to learn tools such as RISC-V gnu-toolchain.

2) RISC-V CPU Design Technology: This section delves into the origins of RISC-V processors and focuses on the RISC-V architecture, instruction set, and module design using the enterprise RISC-V processor IP as an example.

3) Introduction to EDA Tools - Basic Comprehensive Strategies and Static Time Series Analysis: This section introduces EDA tools and covers basic comprehensive strategies and static time series analysis. It guides students in using the Synopsys Design Compiler comprehensive tool and introduces the concepts of static timing analysis (STA). Additionally, it explains how EDA software checks timing in STA methodology and provides guidance on writing constraint scripts for STA. This section requires students to conduct comprehensive FPGA experiments using the enterprise RISC-V processor IP and the open-source hummingbird processor platform.

4) SoC System Architecture Design and Bus Standards: This section focuses on SoC system architecture design and bus standards. It provides an introduction to various bus technologies, classifications, and performance. Furthermore, it guides students in analyzing the AMBA bus structure and protocol using the open-source hummingbird processor platform, and designing interfaces to integrate digital IPs based on the AMBA bus protocol.

5) Memory Subsystem: This section covers the memory subsystem. It not only introduces hierarchical structure, storage media, and address mapping technology of various memory types but also explains memory design and address mapping technology used in the open-source hummingbird processor platform. In addition, it involves guiding students in modifying the memory size and conducting simulation comparisons.

6) Input/Output System Design: This section discusses input/output system design. It introduces I/O organization, commonly used interfaces, and interface transmission methods. Students are guided in the design of low-speed interfaces like GPIO, SPI, UART, and I2C on the open-source hummingbird processor platform, enhancing their ability to integrate sensors or RF transceiver modules required for the Internet of Things.

7) Ocean Internet of Things: This section provides a brief introduction to the concept and key technologies of the Internet of Things. It covers sensors, wireless sensor network technology, and IoT communication and network technology. Students are guided in integrating temperature and humidity sensors with ultrasonic sensors to collect and analyze relevant data in marine scenes.

The theoretical teaching section aims to provide students with a comprehensive understanding of the research background, technological development context, research significance and value, and research methods related to the course technology. It also aims for students to master the basic knowledge and theoretical calculations related to SoC and RISC-V. Additionally, students are encouraged to apply theoretical knowledge in specific scenarios, such as ocean Internet of Things scenarios, to establish a strong theoretical foundation for subsequent experimental operations.

3.2 Experimental Teaching

This course innovatively abandons the monotonous experimental teaching model of the past and instead designs an experimental teaching model that integrates software and hardware. This model is based on school-enterprise joint training and offers targeted and closely aligned practical teaching that complements the theoretical teaching. The experimental teaching includes six specific parts:

1) RSIC-V gnu-toolchain Learning: This part covers the content of the gnu toolchain and the usage of commonly used tools such as gcc, g++, as, readelf, objdump, etc. It guides students in installing and learning to use the RISC-V gnu toolchain.

2) Comprehensive Experiment on Open-Source Hummingbird Processor Platform: This part focuses on guiding students in conducting FPGA comprehensive experiments. It teaches students how to generate bitstream files and download them to FPGA development boards.

3) RISC-V Processor IP Design Experiment: In this part, students combine enterprise RISC-V processor IPs to develop and design independently, cultivating their ability for independent design.

4) Open-Source Hummingbird Processor Platform AMBA Bus Experiment: This part uses the GPIO controller as an example to guide students in understanding the data exchange between AMBA bus and IP.

5) Open-Source Hummingbird Processor Platform Memory Design: Students are guided to learn about the memory subsystem, address allocation, and modification of memory size. They design simulation experiments to improve their practical skills.

6) Open-Source Hummingbird Processor Platform Input and Output System: In this part, students learn about GPIO design, SPI, and other I/O interfaces. They also simulate and design IIC interface modules and connect external temperature and humidity sensors with wireless transmission modules.

Upon completion of the experimental learning, students will have acquired a certain level of professional design ability and experimental foundation. They will participate in the experimental assessment, which requires them to comprehensively design an Internet of Things system based on the open-source hummingbird processor platform. They will use the FPGA platform and open-source hummingbird processor platform to connect external sensors and wireless transmission modules and develop relevant supporting software. Ultimately, they will achieve ocean scene data collection and analysis.

The course experiment is primarily based on the RISC-V development board, which is depicted in Figure 2. The main control chip of the RISC-V development board possesses high integration, strong scalability, and high sensitivity, combining the key advantages of the Xilinx XC7A200T-2 FPGA chip and the GD32VF103 MCU chip. Simultaneously, it integrates the system's timing constraints, port management, water quality parameter data collection, caching, communication functions, control functions, and other capabilities. Furthermore, it is compatible with multiple sensors, facilitating experimentation from multiple perspectives.

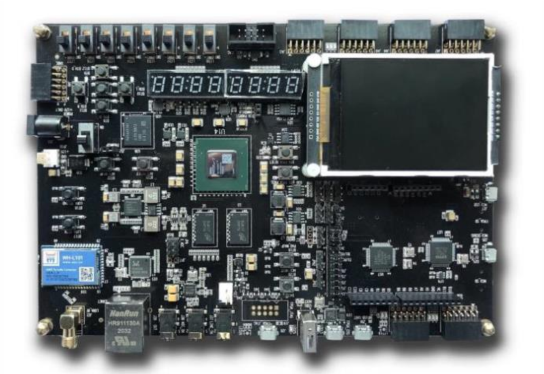

Fig. 2. RISC-V Development Board.

The software aspect of the experiment employed the Nuclei Studio IDE for development, utilizing Verilog as the primary programming language. The code is succinct and pedagogically friendly, making it an excellent fit for student learning and usage. The UART low-speed interface design for students to learn open-source hummingbird processor platformis illustrated in the Figure 3, and it is clear that the code is very suitable for students to use. Additionally, the accompanying software operating platform offers utmost flexibility, with a serial port debugging function that can be adjusted based on specific project and learning requirements, such as baud rate and data bits. This feature enables students to engage in independent development and research.

```
#include <stdio.h>
#include <time.h>
#include <stdlib.h>
#include "hbird_sdk_soc.h"


void uart1_init()
{
  gpio_iof_config(GPIOB,IOF_UART_MASK);
  uart_init(UART1,115200);
  uart_config_stopbit(UART1,UART_STOP_BIT_1);
  uart_disable_paritybit(UART1);
  uart_enable_rx_th_int(UART1);
  uart_enable_tx_empt_int(UART1);
  uart_set_rx_th(UART1,0);
}

int main(void)
{
 srand(__get_rv_cycle()  | __get_rv_instret() | __RV_CSR_READ(CSR_MCYCLE));
 uart1_init();

while ((UART1->LSR & 0x1)==0);
while ((UART1->LSR & 0x1)==1)
{

printf("d=%d\r\n",uart_read(UART1));
int i;
for(i=0;i<8;i++)
    {printf("%x\r\n",uart_read(UART1));
    int f=uart_read(UART1);
    if((f>5)&&(f<20))
        {  printf("i=%x\r\n",uart_read(UART1));
        }
    }

}
return 0;
}
```

Fig. 3. Code Examples.

3.3 Real Case

According to practical teaching feedback, 74% of students achieved an A grade, 22% achieved a B grade, and the remaining students received a C grade. It is worth noting that all students successfully passed the exam, and the majority have demonstrated mastery of theoretical concepts and the ability to apply them in practical design tasks. Notably, there has been approximately a 30% increase in the number of students achieving A grades compared to previous teaching models. This improvement suggests that the implemented teaching reform has not only enhanced students' capacity to grasp theoretical knowledge but also their ability to independently design and engage in hands-on activities. Overall, this educational reform has yielded significant outcomes.

4 Conclusion

The rapid advancements in fields like SoC chip design, ASIC design, and IoT applications pose significant challenges to the present curriculum and teaching system. Within the traditional teaching system, issues including inadequate teaching resources, a dearth of practical platforms, and a disconnect between theoretical knowledge and industry demands exist, severely limiting the enhancement of students' engineering practical abilities and innovative ideas. Consequently, the knowledge acquired by students in school fails to be applied effectively in practical work post-graduation. As a result, the curriculum and teaching system in related fields can no longer achieve a seamless connection between universities and enterprises. Addressing these aforementioned concerns, Zhejiang Ocean University's School of Information Engineering has proposed a teaching reform plan for the SoC design and smart ocean applications course, which is based on the open-source hummingbird processor platform. The plan emphasizes keywords such as "SoC," "ASIC," and "Internet of Things applications".

The teaching reform plan devised for this course enhances the theoretical knowledge within the conventional teaching system and introduces adjustments to the experimental teaching approach. Moreover, it strives to underscore the significance of practical teaching. By amalgamating theoretical knowledge with industry demands, this plan aims to foster students' hands-on abilities in areas such as chips, integrated circuits, and applications related to the Internet of Things. Consequently, it enhances their innovation potential and practical skills in related domains, enabling them to better adapt to future technological requisites. Simultaneously, the research findings, curriculum, and teaching reform plan presented within this article can serve as valuable references and sources of inspiration for related universities and enterprises. We hope to attract more educational institutions and industries to prioritize these fields, hence promoting curriculum and teaching reform, in turn facilitating the development of proficient and contemporary talents.

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