Case Study: An Universal Study Platform for Embedded Software Education

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Abstract — *Education of embedded software (ESW) design has been considered as one of the most important topics in electronic education. In this paper, the study of experience promoting education of embedded software design in Taiwan is presented. The case is a national program carried out by National Chip Implementation Center of Taiwan to help universities establish embedded software design environments and to encourage students to develop embedded software applications. We also describe the idea of a universal study platform extended from a centralized database used in the program. The universal study platform can be viewed as a unified window between students and vendors. Through the universal study platform, students can compare the features of different hardware platforms, share software design samples and experiences each other, get answers of problems queried on the platform, and learn or lab on-line. For demonstration, three domestic hardware platforms are introduced and applied by the universal study platform. Every proposed hardware platform has particular features and has various applications, so that students can learn different issues of embedded software design. With help of the universal study platform, students can effectively select the most suitable hardware platform corresponding to their requirements.*

Index Terms — *Embedded system, embedded software design, embedded software education.*

INTRODUCTION

Due to the rapid development of electronic technology and requirements of electronic markets, electronic products tend to become smaller, faster, and more popular. In Europe, nearly 50% of the 100 biggest companies have invested in embedded systems research [1]. This implies the increasing requirements of the talents of embedded systems. More and more educators put emphasize on this area [2]-[5] as well. However, the great diversity of electronic products and applications also lead to inconvenience in education of embedded systems because it is difficult to learn all software design skills from the same embedded hardware platform. Therefore, more and more embedded hardware platforms are developed and used in different courses for various applications, such as data sensing or video compression. When learning embedded software design, students usually encounter three difficulties. First, software resources are dispersive or unavailable on the Internet, so it is difficult for students to search for these resources. Second, the selection of embedded hardware platforms might not only confuse students but also educators. Third, time and locations for learning are confined. This might cause great inconvenience to students and thus restrict the growth of the number of ESW programmers. Considering the above problems, the case study of a national program that promotes embedded software education in Taiwan is presented in this article. This project is held by National Chip Implementation Center (CIC) [6], a national research and service center for IC design, aiming to cultivate IC design manpower. One of the outcomes of this program is establishing a centralized database of design samples and the Q&A set. Based on this achievement, we propose the ideas of the universal study platform, which provides a unified window between learners and vendors, open-sourced design samples, sharing of design ideas, query services, and online learning of embedded hardware platforms. Besides, the universal study platform also gives suggestions of the learning indices of every hardware platform. The learning indices are composed of some factors that can help users make comparisons and selections among different hardware platforms. Through the universal study platform, either a student or a teacher can get open-sourced design samples or other software resources of different hardware kits from our database, share their design experience and ideas, ask questions about the hardware kits and get answers from CIC, select a most suitable hardware platform corresponding to his requirements according to suggested learning levels, or even deliver a course on-line. Moreover, we also introduce three domestic embedded hardware platforms [7]-[9] applied to the universal study platform. These three platforms are mapped to different learning indices according to their features, respectively. This helps us demonstrate the practicability of the universal study platform. In addition to sharing design samples and experience, the ideas of online courses and virtual embedded hardware platforms will be also realized on the universal study platform in the future. Teachers can give courses on-line and share the teaching materials in our virtual classroom. All online courses will be evaluated by experts of CIC to guarantee the quality. Then students can learn embedded software design using online courses and virtual embedded hardware platforms to achieve the goal of learning anytime and anywhere.

This paper is organized as follows. In the first section, we give an overview of the CIC national program. Based on this program, the ideas of the universal study platform are proposed in the third section. To demonstrate the proposed platform, three domestic hardware platforms are introduced and applied in the forth section. Some discussions are also given in the same section. In the last section, we briefly summarize the contributions of this paper and describe the future works to be completed.

OVERVIEW OF THE CIC NATIONAL PROGRAM

For the past two decades, the semiconductor industry of Taiwan mainly focused on Original Equipment Manufacturer (OEM) and Original Design Manufacturer (ODM), so foundries usually fettered by some other countries and the global downturn. In recent years, the concept of knowledge economy has attracted more and more attention. This makes the semiconductor industry of Taiwan gradually enter the transformation phase. The importance of IC design techniques is thus becoming noticeable. To upgrade semiconductor industry of Taiwan, the most feasible way is to combine with the current advantages, *i.e.*, OEM and ODM. Therefore, foundries tend to develop SOC, SIP, and ESW design in recent years. Based on this reason, the Taiwan government spares no efforts to cultivate manpower of IC design. For promotion of ESW education, a national program was carried out by CIC and supported by National Science Council of Taiwan. The main targets of the program are (1) evaluating and deploying domestic embedded hardware platforms, (2) establishing embedded software/hardware developing environments, (3) constructing reference designs and a centralized database, (4) providing training courses and symposiums, and (5) holding ESW design contests. The details and achievements are described as follows:

- **Evaluating and deploying domestic embedded hardware platforms**: In education of ESW design, open-sourced embedded hardware platforms are very useful to students, but some resources of most current platforms are unavailable due to expensive license fees or confidential reasons. Therefore, CIC evaluated several domestic embedded hardware platforms and introduced some of these platforms to universities. Resources of these platforms are totally open-sourced, so that students can clearly understand the principle of embedded software/hardware architectures. Three domestic hardware platforms were finally selected, including Sunplus SPCE3200 [7], ANDES Leopard [8], and ITRI PAC PMP [9]. The selected platforms have been provided to universities to the number of about 100 every year. We will give a brief description of these three platforms in the forth section.
- **Establishing embedded software/hardware developing environments**: To let students have sufficient hardware and software resources to develop ESW applications, CIC assisted about 30 laboratories every year in establishing embedded software/hardware developing environments. The establishment includes providing necessary tool kits and solving installing problems.
- **Offering reference design and centralized database**: Besides establishing embedded software/hardware developing environments, a centralized database collecting resources together is also required. CIC created several reference designs and collected them in a centralized database. With open-sourced reference designs and the centralized database, students do not have to blindly spend much time searching for design samples, and transparent source codes further help students understand details of design concepts. An example of reference designs is digital photo frame. The codes of digital photo frames including GUI, image viewer, and audio player are totally open-sourced and ported on the embedded hardware platform.
- **Providing training courses and symposiums**: To promote ESW education, a series of ESW design courses were delivered in CIC. Unlike ESW courses in school, CIC courses put emphasis on laboratory and practical knowledge, such as “bootloader design” and “system-level design with platform architecture.” These courses were given in summer and winter vacations, so students could take the courses without delaying schoolwork. There are about 500 students taking these courses every year. In addition, CIC also held several symposiums to enhance communications among industry, school, and government.
- **Holding ESW design contests**: To encourage students to investigate and develop ESW applications, CIC holds ESW design contests every year. A professor can lead one team consisting of several students to participate in the contest. Entrants are allowed solving the problem given by the evaluation committee in limited time. The final prizewinners will be rewarded large bonuses and medals.

THE UNIVERSAL STUDY PLATFORM

In the national program, a centralized database is established for universities to provide design samples and answers of queries. In this paper, we further extend the idea to the structure of universal study platform, which is maintained by CIC and provides full-directional service to universities. The universal study platform can be viewed as a unified window among universities, vendors, and CIC, and it plays several important roles to help student learn ESW design:

- **An information center collecting dispersed resources together**: During learning ESW design, students usually face a problem: resources (*i.e.*, documents, samples, etc.) are unavailable or dispersed. This is because these resources are provided by different vendors or programmers, so students usually have to search for them through different manners, such as official website, attached CD of the hardware kits, forums, or classmates. The universal study platform collects these resources together, so that students can easily get required resources and information on the platform.
- **A rating system for hardware platforms**: Another key problem that might be encountered by students or educators is the selection of hardware platforms. The diversity of hardware platforms usually confuses students because every platform is designed by different vendors for various purposes. Here we give every hardware platform in the universal study platform several learning indices, representing both objective factors and subjective rating that benefit students to learn this hardware platform. These learning indices includes the general information of the hardware platform, degree of design transparency, number of design samples, core speed, ISA depth, ease of use of Board Support Package (BSP), user rating, and so on. With the suggested learning indices, it is more easily to decide which hardware platform can fulfill the user requirements.
- **A question center for responses of queries**: In school, a teacher teaches knowledge and solves problems of students. However, the teacher cannot answer questions all the time. Besides, many problems are also repeatedly raised. Therefore, the experts of CIC provide Q&A service to students, and collect common questions to a Q&A set on the proposed platform. Through the proposed platform, one can search for answers and raise problems anytime.
- **A forum sharing experience and feedback**: The proposed platform also provides a forum for students to share their study experience and report the problems or bugs. Therefore, students can still learn from each other through the forum even outside the classroom, and vendors can also get user responses as their reference to improve their products.
- **A virtual classroom for online learning**: Several online courses are planned to be open for users. Besides, virtual laboratory such as virtual platforms or remote laboratory will be provided in the virtual classroom as well. Therefore, students can learn both knowledge and practical design experience in the virtual classroom anytime and anywhere. In the future, every user can register on-line as a lecturer or student. A lecturer could give courses and recruit students. CIC will be responsible for the quality of every course.

The architecture of universal study platform is illustrated in Figure 1. Experts, hardware/software resources, and courses of CIC are the foundation of the platform. Based on these resources and knowledge, CIC categorizes them to the information center, question center, rating system, forum, and virtual classroom, and then organizes them the proposed platform. From the selection of hardware platforms, learning, laboratory, till sharing learning experience, the proposed platform provide a complete study environment to users. In the proposed platform, vendors play the role of content provider, providing hardware platforms, documents, and design samples to CIC. As for teachers and students, they are main users of the proposed platform. From the view of participants, the detailed descriptions of the proposed platform are described as follows:

- **Vendors**: Vendors are responsible for providing hardware platforms, documents, and design samples to CIC. They can also receive user experience and bug report from the universal study platform.
- **CIC**: CIC is in charge of maintenance and update of the universal study platform. At beginning, resources including documents, design samples, and the Q&A set are collected from vendors, users, and even the Internet. Besides, CIC also develop some design samples for the platform. Then these resources are allocated to information center and question center. At the same time, experts of CIC give suggested learning indices of every hardware platform, and provide query services to users. The training courses and virtual platforms by CIC are provided in the virtual classroom for online learning.
- **Students/teachers**: Teachers and students are main users of the proposed platform. Before learning of ESW design, users can get familiar with different hardware platforms through the rating system, and then select a suitable one according to their requirements. After selection, software resources such as documents and design samples can be found in the information center. In the virtual classroom, online courses will help users learn how to use the hardware platform. In addition, users can also share their design samples to others, such that the information center can be unlimitedly expanded. During development of ESW, users can also share their experience and discuss with each other in the forum. If there are unsolved questions, CIC is always ready to answer them in the question center. Furthermore, the virtual classroom will allow everyone giving courses and recruiting students on-line. Experts of CIC will preview the course materials to guarantee the course quality.

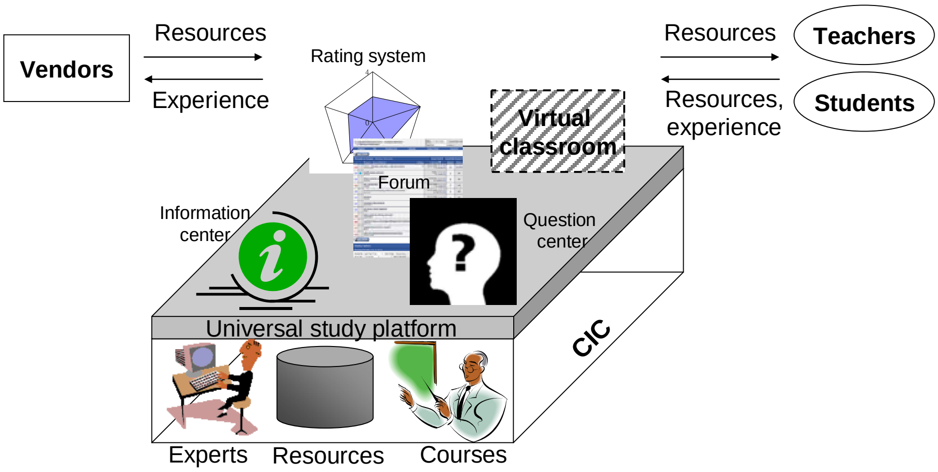


FIGURE 1
THE ARCHITECTURE OF THE UNIVERSAL STUDY PLATFORM

If the vendor is willing to provide hardware platforms to the universal study platform, CIC will start the above services after the hardware platforms are sent to CIC. In the first step, experts of CIC have to deeply understand all hardware kits provided to the universal study platform. Then according to specifications and user experience, the learning indices are added into the rating system. After that, design samples will be collected or created by CIC experts in the information center. Next, CIC lecturers will give related courses and uploads lectures and teaching materials to the virtual classroom. Meanwhile, an exclusive discussion board will be provided in the forum and question center, such that users can share experience and ask questions.

EXAMPLES: DOMESTIC HARDWARE PLATFORMS IN TAIWAN

For demonstration, we introduce three domestic hardware platforms in Taiwan for education of ESW design. These three hardware platforms will be applied in the rating system, and their learning indices will be illustrated in the later subsections.

Sunplus SPCE3200

SPCE3200 [7] is a highly integrated platform designed by Sunplus for multimedia applications. The platform is composed of a domestic 32-bit SoC (S+Core), 128MB SDRAM, 64Mb NOR Flash, 128Mb NAN Flash, QVGA 3.5" TFT LCD, and rich peripherals. The architecture of SPCE3200 is shown in Figure 2. From the figure, we can see that the SoC chip contains S+core CPU, Advanced High-Performance Bus (AHB) connecting with high-performance modules, and Advanced Peripheral Bus (APB) connecting with low-speed peripheral modules. High-performance modules include CMOS sensor interface (CSI), MPEG-4/JPEG encoding and decoding modules, LCD controller, TV signal encoding module, 2-channel 16-bit D/A converter, embedded 8KB RAM (LDM) and 32KB ROM, and memory interface controller. Low-speed peripheral modules include GPIO controller, SPI serial bus controller, SIO serial bus controller, I2C serial bus controller, I2S master/slave controller, UART controller, USB master/slave controller, Watchdog, SD controller, NAND flash controller, and 9-channel 12-bit A/D converter. A well-integrated development and debugging IDE environment as well as a ported eCOS system is offered with the platform, helpful for the Hardware-Dependent Software (HDS) and application developing. The core of SPCE3200 is S+Core7, a 32-bit and 7-stage pipeline RISC CPU, supporting 16/32-bit mixed instruction set and working at 27~162 MHz. Since many applications can be implemented by hardware, it saves execution time of software programs, and thus achieves low energy cost and high efficiency. Therefore, SPCE3200 is suitable for low-power devices or the controller of devices, such as handheld devices, small household appliances, sensors, or controllers of robots. With rich peripherals integrated, the applications of SPCE3200 are much wider than others.

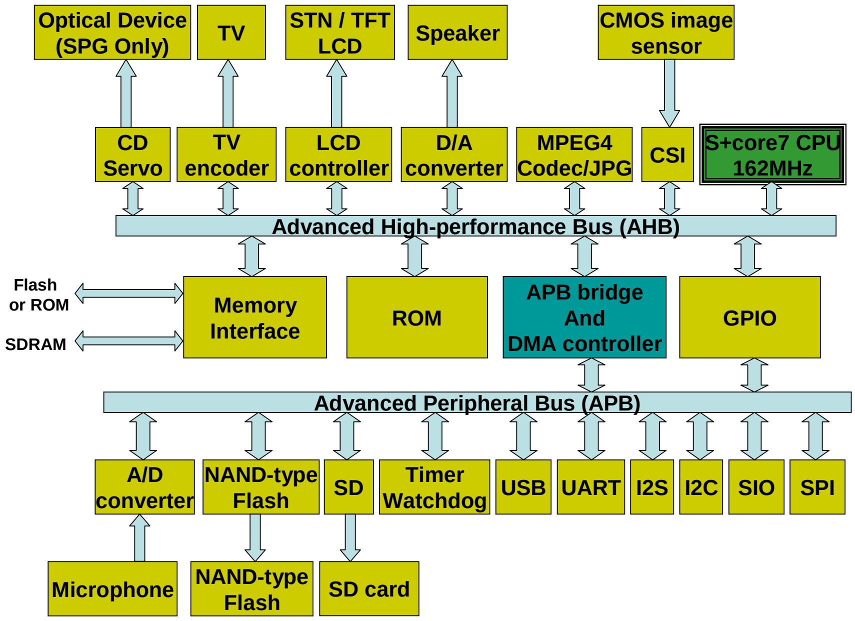


FIGURE 2
THE ARCHITECTURE OF SUNPLUS SPCE3200

ANDES Leopard

ANDES Leopard [8] consists of a 32-bit SoC, a SODIMM slot of SDRAM, 32MB Flash, QVGA 3.5” TFT LCD, Ethernet, UART, IIC, AC97, SD card, LED, LEDs, buttons, ICE port for on-line debug, and so on, as shown in Figure 3. Just like SPCE3200, there are AHB connecting with high-performance modules and APB connecting with low-speed peripheral modules. The core of ANDES Leopard is a 32-bit and 5-stage pipeline SoC, supporting 16/32-bit mixed instruction set. The maximum working frequency of the core can reach 500 MHz. Besides, the chip also contains controller of LCD, Flash, AHB, SDRAM, DMA, and so on. Besides, Leopard offers a well-integrated development and debugging IDE environment and a well-ported Linux kernel. Since Leopard has a well-ported Linux and a powerful CPU, it is suitable for developing general-purposed applications or applications that requires complex computations, such as Netbooks, mini-computers, or E-books.

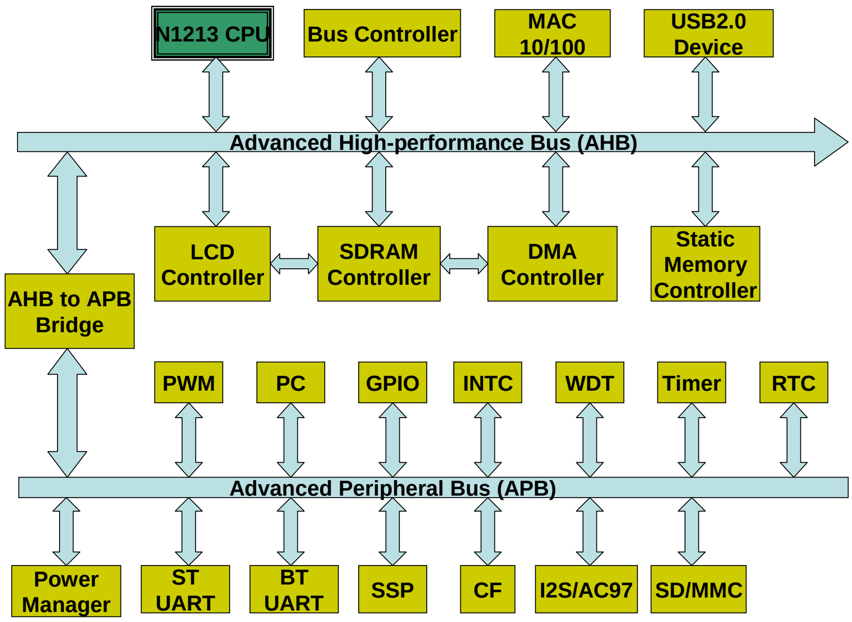


FIGURE 3

ITRI PAC-PMP

PAC (Parallel Architecture Core) is a high performance and low energy cost DSP developed by ITRI [9] (Industrial Technology Research Institute of Taiwan). PAC-PMP (Parallel Architecture Core Portable Multimedia Player) is a heterogeneous dual-core hardware platform designed mainly for multimedia and parallel applications. The structure of PAC-PMP is shown in Figure 4. PAC-PMP has a dual-core SoC, 128MB SDRAM, 32MB Flash, VGA TFT LCD, and several interfaces, such as UART, Ethernet, USB, IIC, UART, IrDA, LEDs, IIS, SD card, ICE port for on-line debug, and so on. The core of PAC-PMP adopts the heterogeneous dual-core structure, consisting of ARM926EJ-S and a domestic DSP with 5-way VLIW for multimedia applications. Besides dual-core architecture, the other feature of PAC-PMP is multimedia hardware codec, supporting H.264/AVC hardware accelerator (motion estimation and entropy coding) and multimedia DMA and SDRAM controller. In addition, the SoC also includes the newest Dynamic Voltage Frequency Scaling (DVFS) technique, which can dynamically adjust voltage frequency to efficiently reduce energy cost. Due to the sufficient hardware supports and powerful computational ability, PAC-PMP focuses on high-quality multimedia applications and parallel computing, such as recording video and answering the phone simultaneously. However, the high complexity of its structure also increases the threshold to learn this platform, so PAC-PMP is more suitable for advanced software designer. The applicable area includes PDAs, smart phones, high-definition DVRs, and so on.

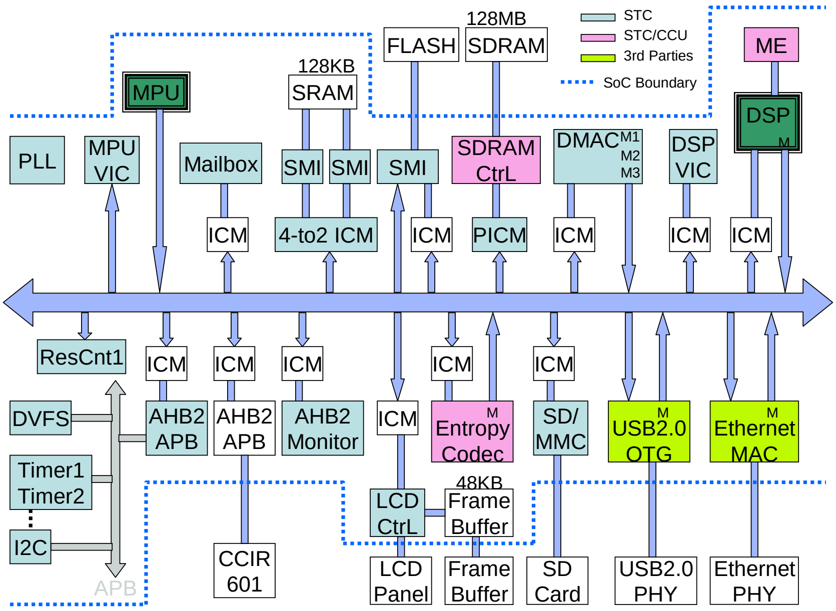


FIGURE 4
THE ARCHITECTURE OF ITRI PAC-PMP

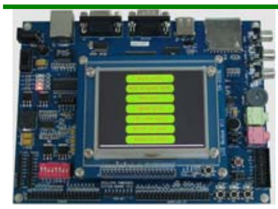
Analysis and Discussion

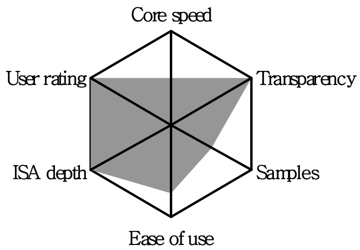
The above three hardware platforms are applied to the proposed rating system, and the learning indices are illustrated in Table 1, Table 2, and Table 3, respectively. Inside each table, the appearance of the platform is shown on the left top, the rating results can be seen on the right top, and the specification is described on the bottom. From the tables, the user can have a quick preview of each hardware platform, including its layout and features, and then make comparisons with others using the radar chart. Now we describe the detailed analysis in this subsection.

These three hardware platforms are designed for education, so their hardware/software functions are highly transparent. However, the transparency of PAC-PMP is slightly lower since some functions of ARM in PAC-PMP are close-sourced. On the other hand, the number of design samples of PAC-PMP is more than others because ARM is more popular than S+core of SPCE3200 and ANDEScore of Leopard. Besides, from “core speed” we can differentiate applicable areas of S+core and ANDEScore. S+core is a low-speed and low-power processor. With a large number of peripherals of SPCE3200, it is very suitable to be used for practices of device controlling and non-OS device drivers. In opposition to S+core, ANDEScore is a high-speed processer, where the clock rate can get up to 500MHz. Thus, complex programs or even a general-purposed OS can run on this core. We suggest Leopard be used to learn OS kernel programming and other general-purposed programming. Although ANDEScore can be used as a micro controlling unit as well, the huge energy consumption will become a critical issue.

PAC-PMP has different targets from the other two platforms because it is a dual-core platform. Obviously, the complexity to learn this platform is much higher due to the requirements of inter-processor communications (IPC) and DSP programming. This can be observed from "ease of use of BSP," which is also an important factor to know the difficulty to learn a hardware platform. Since the functions of PAC-PMP are more complex than others, it is unavoidable that its BSP is not as easy to use as the other two platforms. As a result, beginners are not suggested to learn this platform because of its high complexity, but it provides very good environments to learn parallel programming for advanced programmer.

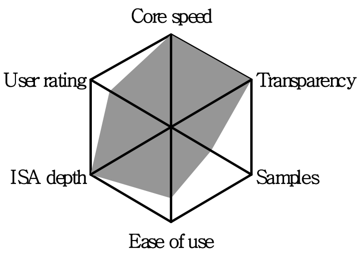
These three platforms are developed by domestic vendors of Taiwan. Even so, they still get high scores in "user rating." This reveals that these platforms are suitable for ESW education, so most users give high scores in this factor. From the above analyses, we suggest beginners select SPCE3200 or Leopard as the introductory study, while experts could select PAC-PMP for advanced study.





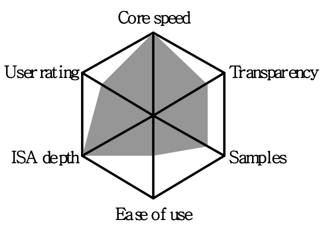
Processor	Sunplus S+core7
Memory	128Mb SDRAM, 64Mb NOR Flash, and 128Mb NAND Flash
Communication Interface	SPI, SIO, IIC, UART, USB, Ethernet, GPRS
Interaction Interface	Joystick, Touch panel, 3 buttons, and 3 LEDs
Multimedia Interface	TV Out, 3.5" TFT LCD, CMOS camera, IIS
Other Interface	SD card, SJTAG, GPS
Applicable area	Peripheral controlling, non-OS programming

TABLE 1
THE APPEARANCE, LEARNING INDICES, AND SPECIFICATION OF SUNPLUS SPCE3200



Processor	ANDES N1213
Memory	256MB SDRAM SO-DIMM, 32MB NOR Flash
Communication Interface	Ethernet, UART, IIC
Interaction Interface	Touch panel, buttons, LEDs
Multimedia Interface	LCD, AC97
Other Interface	SD card, AHB, X-Bus, MII
Applicable area	OS kernel programming, general-purposed programming

TABLE 2
THE APPEARANCE, LEARNING INDICES, AND SPECIFICATION OF ANDES LEOPARD



Processor	PAC DSP + ARM926EJ-S
Memory	128MB SDRAM, 32MB NOR Flash
Communication Interface	Ethernet, USB, IIC, UART, IrDA
Interaction Interface	touch panel, buttons, LEDs
Multimedia Interface	LCD, IIS,
Other Interface	SD card, AHB
Applicable area	DSP programming, multi-thread programming

TABLE 3
THE APPEARANCE, LEARNING INDICES, AND SPECIFICATION OF ITRI PAC-PMP

CONCLUSIONS

In this paper, we described the program of promoting ESW education in Taiwan. Based on this case study, the ideas of the universal study platform were proposed. This platform can help users learn ESW design anytime and anywhere. We also introduced three domestic hardware platforms used for ESW education in Taiwan. These hardware platforms are applied to demonstrate the performance of the universal study platform. In the future, we will first realize the incomplete parts of the proposed platform, such as the virtual classroom and the rating system. Besides, more user feedbacks are also required for demonstration.

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