An Overview of Signal Processing Engineering Education in China

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Abstract—**This Innovative Practice Full Paper presents a survey on how signal processing engineering education has been carried out in China. Although courses on signal processing vary from university to university in China, they mainly fall into four categories: courses on principle, method and technology, application, and implementation. Along with the theoretical teaching of these courses, increasing emphasis has been put on the practical part. Engineering education on signal processing has been put into practice over decades through the design and implementation of multi-level in-curriculum experiments, project-driven training, cross-disciplinary contest, and a whole-semester graduation project. Manifold tools and platforms have been adopted or established to enhance the diverse laboratory teaching of signal processing. These tools and platforms include hardware circuits, software tools, and hardware platforms based on embedded processors.**

Keywords—signal processing, engineering education, in-curriculum experiments, project-driven training, cross-disciplinary contest

I. INTRODUCTION

Engineering education has been an essential part of China's higher education over the years. It keeps yielding senior engineering and technology talents for China's social development and commercial construction. The past half-century witnessed a continuous improvement in the scale of engineering education, the structure of specialties and curricula, and education quality and efficiency [1]. Till the end of 2014, 1,139 universities have established up to 16,284 engineering specialties, which is outputting about 1.13 million undergraduates each year [2].

As one of the significant measures to ensure engineering education quality and efficiency, China Ministry of Education launched a construction program named "National-level Experimental Demonstration Center" in 2005. It aimed to accelerate the reform of laboratory teaching and the construction of laboratory infrastructure [3]. Universities with advantages in specific disciplines and specialties were encouraged to set up comprehensive experimental centers through the integration of dispersed laboratory teaching resources all over the campus. During the construction of a demonstration center for a specific discipline or specialty, first, the central idea of engineering education was re-examined and adjusted to form a student-oriented multi-level open practical teaching platform. Second, experimental tasks of a series of courses were designed from a system point of view. Through a close tie of basic teaching lab and senior research lab, some up-to-date achievements in the leading edge of specialty research were transformed into teaching resources. Moreover, undergraduates were encouraged to join a real research project for practical training. Finally, through online sharing and routine seminars, the demonstration centers exerted some radiation effect on other universities, which has facilitated the constructions of more effective lab centers.

Till 2015, when the "National-level Experimental Demonstration Center" program celebrated its 10th anniversary, 801 demonstration centers across 44 disciplines have been set up in 368 universities. Signal processing engineering education is integrated with one category of such demonstration centers called "Electrical and Electronic Experimental Center" (EEE Center), which holds more than 70 national-level centers now.

An EEE center consists of multiple labs such as the electrical lab, electronic lab, signal and system lab, automatic control lab, and some innovation labs open for students' research and development practice. Engineering education activities are carried out by these labs under a well-designed practice teaching system.

Taking Tsinghua University as an example, the practice teaching system is illustrated in Fig. 1.

The goal of the system is to improve students' hands-on skills and motivate their spirit of innovation to the greatest
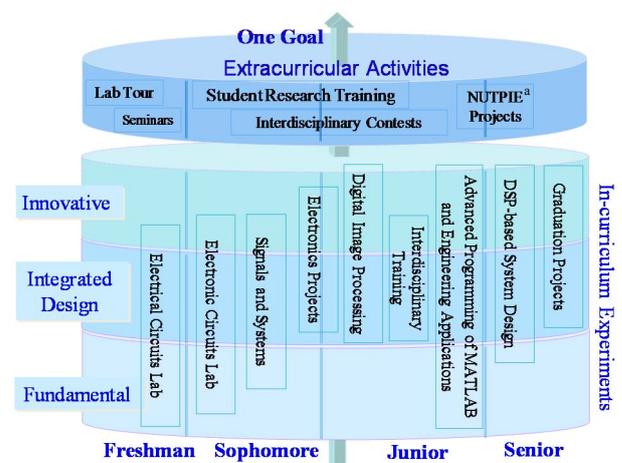
^a NUTPIE: National Undergraduate Training Program for Innovation and Entrepreneurship

Fig. 1. An example of the practical teaching system.

extent. To accomplish this, most of the activities are student-oriented, which mainly include in-curriculum experiments and extracurricular activities.

In-curriculum experiments are designed in three levels, stretching from basic to challenging. The fundamental experiments simply verify what students learn in theoretical courses. In integrated design experiments, students need to have comprehensive utilization of what they have learned from one or several courses, and work out solutions for individual tasks. In innovative experiments, the content of tasks or way to implement them are open, and students are motivated to come up with their idea and design. The ratio of the above three-level experiments varies for different courses.

While some experiments are parts of the theoretical courses, most of them are included in the independent lab courses. Different from the theoretical courses, lab courses are set up to enhance practical training. Among them, there are quite a few project-driven courses.

Besides, based on the support of the EEE center, undergraduates can join lots of extracurricular activities for engineering training. From 1996, many universities started similar programs to push junior undergraduates to research activities. Such programs are named, for example, SRT (Student Research Training) at Tsinghua University [4], SRTP (Student Research Training Program) at Zhejiang University [5], and PRP (Participation in Research Program) at Shanghai Jiaotong University [6]. Benefitted from these programs, students can receive early training in research and engineering. Furthermore, they can also put forward their innovative idea and apply for both instructional and financial support via this program. Besides, at the national level, from 2011, undergraduates can form teams to apply for the NUTPIE project [7]. There is also a national-level contest for innovation and startup.

As can be seen from Fig. 1, from the first year to senior, undergraduates are provided with ongoing engineering training with a different focus for a different stage. At the very beginning, lab tours and seminars are provided for the freshman to arouse their interests in exploration. During the last semester, each student is required to work on a graduation project as a reinforcement training.

Signal processing engineering education is fulfilled under the above framework. As a compulsory course group for undergraduates majored in information and electrical engineering, signal processing has been taught in pure theory before 1990. After then, with the rapid development of signal processing technology and its broader and broader application, more and more practice training content has been added into the teaching program.

In order to give an overview of signal processing engineering education in China, first, a literature review was carried out. Journal and conference articles on the teaching reform of signal processing education were reviewed. Second, syllabuses for both theoretical and experimental courses of signal processing were collected from tens of universities across China. Also, experimental items were examined into detail from the website of dozens of National-level Experimental Demonstration Center. Third, we visited several experimental centers to experience the tools and platforms used in signal processing teaching. Finally, we held several focus interviews with lecturers from different universities to find out how signal processing courses were taught.

The rest of the paper is organized as follows. Section II investigates and shows the design and development of signal processing curricula in China's universities. Engineering education content and methodology for signal processing are described with representative teaching practice in Section III. Tools and platforms used for signal processing practical teaching are classified with illustrations in Section IV. Finally, key points on the overview are summarized in Section V.

II. CURRICULUM DESIGN AND DEVELOPMENT

Signal processing is taught as the fundamental specialty courses in the undergraduate program of information and electrical engineering. Related specialties include electrical engineering, automation, computer science and technology, electronic engineering, microelectronics and engineering, aerospace engineering, nuclear engineering, and biomedical engineering.

Whereas courses on signal processing vary from university to university as well as specialty to specialty, they roughly fall into four categories: courses on principle, method and technology, application, and implementation.

A. Courses on Principle

"Signals and Systems" is a typical course designed to teach the principles of signal processing. In most of the universities, it is usually a compulsory 4-credit course taken by undergraduates of all the related specialties in their fourth semester.

In this course, the basic concept of signal and system, basic theory as well as primary analysis method in time-domain and transform-domain for continuous and discrete systems are taught.

B. Courses on Method and Technology

"Digital Signal Processing" is a general elective course following after "Signals and Systems."

In this course, the critical method and technology of digital signal processing are taught, which usually include the algorithm of discrete Fourier transform (DFT) and the design of various digital filters. While some universities set up this course as a 4-credit course for the fifth-semester undergraduates, some other universities customize a 2-credit course for undergraduates and leave more advanced methods and techniques taught later in a course for graduates. However, some universities just extract some classic content of this course and combine it into the principle course of "Signals and Systems."

In addition to "Digital Signal Processing," some other elective courses for signal processing are designed and developed for some specialties to deal with specific types of signals, which include "Statistical Signal Processing," "Stochastic Signal Processing," and "Real-time Signal Processing."

C. Courses on Application

Since the method and technology of digital signal processing are widely used in a variety of application areas, a group of courses are developed correspondently, as listed in Table I. Each course intends to deal with one category of signal, focusing on how to apply method and technology of signal processing in solving the problems of specific areas.

TABLE I. COURSES FOR DIFFERENT APPLICATIONS

Course	Signal	Sample Applications
Speech Signal Processing	Voice and speech	Speech recognition Automatic translation
Digital Image Processing	2-dimensional image	Fingerprint identification Satellite image processing Flaw detection
Digital Video Processing	Video	Digital TV[c] Computer vision
Communication Signal Processing	Electromagnetic wave signal	Mobile communication Radar
Biomedical Signal Processing	Cardiogram, brainwave, CT[a]/MRI[b] signal	Health monitoring Disease diagnosis

[a] CT: Computation Tomography
[b] MRI: Magnetic Resonance Imaging
[c] TV: Television

In these courses, characteristics of the targeted signal, practical algorithms for signal processing, and leading-edge applications are unfolded into detail. For example, in the course of "Digital Image Processing," the Wiener filtering method is taught for image restoration.

D. Courses on Implementation

In order to put a signal processing application into practice, we need a real system to both acquire the signal and implement the signal processing method. From the middle of the 1990s, some practical courses for signal processing have been set up, which include "Advanced Programming of MATLAB and Engineering Applications," "System Design Based on DSP", and "DSP Principle and Application".

For instance, "DSP Principle and Application" is one of the DSP practical courses developed by Qicong Peng, a professor with the University of Electronic Science and Technology of China, based on his research and development experience in DSP. In the early 1990s, Professor Peng attempted to take advantage of TI's (Texas Instruments) DSP in his real-time digital signal processing research project. Soon after, this successful engineering practice was transformed into teaching resources through the collaboration with the TI university program team [8]. A joint DSP lab with TI was set up in 1996, which facilitates the professors and students to keep up with modern industrial practice in DSP.

For some specialties, all the above 4-category courses are designed as a whole group [9] in their education programs. However, more commonly, due to the limited credit hours, content from several courses is combined and merged into one. For example, in the program for biomedical engineering specialty, some universities just integrate the essential contents of the course "Signals and Systems" and "Biomedical Signal Processing" into one course named "Biomedical Signals and Systems." Such teaching practice shows that combining theoretical teaching with a strong application background makes it easier for students to have a better understanding.

III. CONTENT AND METHODOLOGY

Engineering education contents for signal processing are taught by a variety of methods under the typical practical teaching system in China. In-curriculum experiments are developed in tight accordance with the above four categories of curricula. Also, some independent project-driven lab training courses link different categories of signal processing courses. Moreover, cross-disciplinary contests and graduation projects provide undergraduates with more comprehensive practical training.

A. In-curriculum Experiments

At present, with more and more emphasis put in engineering education, almost every course of signal processing is configured with some in-curriculum experiments at different training levels.

For example, several fundamental experiments are interspersed in the teaching of "Signals and Systems." By using MATLAB as a simulation tool, some of these experiments present an intuitive demonstration of the complex formula computation (e.g., convolution integral) and transform (e.g., Fourier transform) [10], which can help students have a more intuitive understanding on the abstract principle, concept, and theory.

"IIR (Infinite Impulse Response) filter" is another typical integrated design experiment in the teaching of "Digital Signal Processing." In Professor Wenjie Li's course teaching [10], an electrocardiogram signal with high-frequency noise is presented, and students are asked to design an appropriate IIR filter to eliminate the noise. What is more interesting, in Professor Li Li's class [11], every student recorded a music signal and used it as the signal source for all the experiments in the course. Students exercised the sample rate regulation, spectrum analysis, IIR filtering, and FIR (Finite Impulse Response) filtering on this signal and got the corresponding results. This design links up the knowledge fragments of digital signal processing and forms them a whole.

To enlarge students' view beyond what is taught within the class, some instructors assign an open course report for free and innovative exploration of theory and practice of signal processing. As written in one of the reports [12], a digital voice changer is designed and implemented by two undergraduates during their study of the course "Signals and Systems." Through this work, they have a profound understanding of autocorrelation calculation, and fast Fourier transforms, exercise self-learning and exploration of speech synthesis and reconstruction, and experience a real practice on MATLAB programming.

B. Project-driven Training

In-curriculum experiments help students learn signal processing and, at the same time, improve their hands-on skills. Moreover, project-driven training is mostly performed in practical teaching courses and extracurricular activities. Being involved in such projects, students could have an opportunity to comprehensively apply what they have learned from multiple courses and link the theory with practice.

For example, "Electronics Projects" is a comprehensive training course conducted in most of China's EEE centers in the summer term between junior and sophomore. It provides a concrete platform for students to build a complete signal processing system, which includes hardware circuits for signal acquisition, ADC (analog-to-digital converter), DAC (digital-to-analog converter), digital signal processing, and visualization of the result data. To design and implement such a system, students need to integrate what they have learned from previous courses on digital electronics, analog electronics, computer architectures, programming languages, and signal processing.

In some teaching practices [13], the application background of the project and performance indices for the target system is specified. While in some other classes, it is open for students to come up with their projects.

Attracted and propelled by the real problems encountered in the project, especially in the self-set project, undergraduates are willing for the quick learning of what has not been taught in previous courses. As written in one of the electronics project reports [14], two students successfully implemented a pulse measurement system and computed the pulse rate in their project. When they looked at the pulse waveform displayed on the oscilloscope, as shown in Fig. 2, they became very curious about how pulse waveform varies from one person to another and how it relates to the health status. This curiosity aroused their interest in further work on some signal processing algorithms. Based on the self-exploration, they worked out the algorithm to get a rough result of human blood pressure from the pulse signal.

C. Cross-disciplinary Contest

In real industrial practice, cross-disciplinary knowledge and skill are usually required.

Teaching practice also shows that when students are involved in a cross-disciplinary contest, they tend to engage with more passion. The desire to be the winner stimulates one's utmost potential and motivate one's best effort. While different teams work in parallel for the same contest, the advantages and disadvantages of each design can be seen. As a result, students can learn not only from their work but also from many others'.

In order to push undergraduate to be well-prepared for an after-graduation career, quite a few cross-disciplinary contests are set up. Among these contests, for example, the national collegiate Intelligent Model Car Competition (IMCC) is one of the largest.

IMCC was initiated by the China Ministry of Education and first held in 2006. Professor Qing Zhuo, who teaches "Signals and Systems" at Tsinghua University, is a leading member of the competition organizing committee.

Team members may come from a wide variety of disciplines such as mechanical engineering, automobile engineering, electrical engineering, and automation. They work together for more than nine months on the design, development, assembling, and debugging [15].

Signals from different sensors are processed to make an instant decision on the motion of a model car. Fig. 3 shows a spot scene of the model car competition. Since the car which finishes the race in the shortest time is the winner, both the stability of the hardware system and the signal processing algorithm matter a lot. Meanwhile, a minor fault may lead to a complete failure in the race.

Fig. 2. The pulse waveform displayed on the oscilloscope.

Fig. 3. A spot scene of IMCC.

Through a continuous practice over 14 years, the contest has been proved to be a useful engineering training platform for nationwide undergraduates.

D. Graduation Projects

In China, undergraduates spend a whole semester for graduation project training. Right before their graduation, during this last semester, every student need to work with a graduation project under the faculty's guidance, which gives them an enhanced practical training to be well-prepared for after-graduation research or industrial practice.

Graduation projects are carefully designed by the faculties. Some of them are subprojects extracted from the real research projects, some are joint projects with local or international companies, and a few others deal with self-developed tools or platforms used in the university's real teaching activities.

Over the past decades, with broader and more in-depth research and application of signal processing theory and technology, a large proportion of graduation projects for undergraduate programs of information and electrical engineering are in the area of signal processing. In some signal processing classes, it is the other way around that successful graduation projects are used as teaching material to stimulate students' interests in further study of signal processing related theory and applications.

Graduation project training plays an essential role in signal processing engineering education. Through a relatively long-period concentration on one project, undergraduates can gain practical training in design, research, and development. As can be seen from the following three examples, some of the students can obtain very outstanding achievement at the end of the one-semester graduation project.

1) Dynamic hand gesture recognition

Hand gesture recognition is an emerging human-machine interface and robotic control method. As an interdisciplinary area of pattern recognition, probability statistics, computer vision, and digital image processing, research of hand gesture recognition is challenging. Despite the already achieved results, many problems are still open to practical solutions.

Runpeng Cui, an undergraduate, majored in automation, addressed one of the problems of dynamic hand gesture recognition in complicated application background in his graduation project [16]. Under the guidance of his tutor, Cui had a survey on the current research by reading lots of documents in a short time. Motivated by the intense feeling of pride as standing in the leading edge of research, Cui significantly engaged himself in the algorithm design, implementation, verification, and improvement.

At first, a method based on Fréchet distance was designed and verified, which partially contributes to the application of an invention patent [17]. After then, in order to reduce the negative influence brought by the complicated application background, a dynamic time warping algorithm was redesigned, and experiments on both trajectory and posture were conducted for verification.

2) A fast algorithm for electromagnetic-based biomedical imaging

Signal processing has been extensively used in medical diagnoses such as X-ray imaging, CT, ultrasonic imaging, and nuclear MRI.

A new kind of electromagnetic-based biomedical imaging, which appeared about twenty years ago, can figure out not only the permittivity distribution but also the conductivity distribution of the object. However, owing to a massive amount of computation and memory cost, extensive utilization of electromagnetic-based biomedical imaging is limited.

In his graduation dissertation [18], Xueyang Wang introduced the work in algorithm and hardware optimization. Based on the latest progress in computational electromagnetics, an improved algorithm based on the CSI (Contrast Source Iteration) method was achieved. In the traditional CSI method, a considerable amount of basic linear algebra computation is needed for each process of single-step iteration. In order to improve the computation efficiency, a highly parallel computation platform was adapted to execute instructions in parallel. At the same time, data redundancy in the algorithm was eliminated to reduce memory costs.

Through parallel computation, the time-consuming algorithm was considerably accelerated. Experiments showed that the computation time had been reduced from several hours to several minutes.

Xueyang Wang gained a great sense of achievement from this significant improvement. After the training in his graduation project, he got familiar with the way of working out solutions for hardy problems and felt confident of being well-prepared for future research work.

3) FPGA-based integrated electronic lab platform

The development of an FPGA-based (Field Programmable Gate Array) integrated electronic lab platform is a project stimulated by the real requirement of lab teaching for both electronics and signal processing courses.

The DC (Direct Current) power, signal generator, and oscilloscope are frequently-used lab instruments while working with electronic and signal processing experiments. Undergraduates have to come to the teaching labs at pre-assigned lab sessions to use these instruments. In order that students could do hardware experiments outside the labs, a compact portable lab kit is demanded.

As two of the end-users of such kind of lab kit, Guangwei Tu and Yifan Wu felt excited to take this task as their graduation training project. With a sound understanding of the usage model of the lab kit, they fulfilled the design and implementation of the hardware and software under the guidance of their tutor[19,20].

It was owing to their work, the portable lab kit, as shown in Fig. 4, had been put into lab teaching practice since the fall semester of 2013. Through the interaction with a virtual instrument application installed in the laptop, the lab lit can be
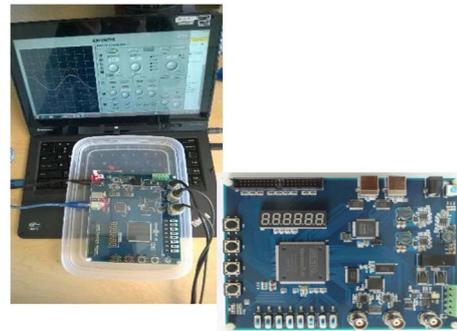

Fig. 4. An FPGA-based electronic lab kit.

used to output DC power, generate and measure signals, and verify signal processing algorithms via the onboard FPGA chip and peripherals.

Being involved in such kind of graduation project, Guangwei and Yifan became familiar with the hardware and software design and development of a typical signal processing system. Moreover, as the user and developer two in one, they experienced a whole process of practical training for product building, from user requirement statement to product test.

As can be seen from the above three examples, graduation projects can give undergraduates a substantial training. Moreover, in some universities, experts from enterprises are invited to evaluate students' graduation projects together with university professors. More than that, some enterprises would invest in graduation works directly if they have potential business value.

The past decade witnessed an increasing need for cross-disciplinary engineering talents of graduating students. Through the above hands-on teaching content and methodology, undergraduates can progressively have substantive training to get well prepared for employment after graduation.

IV. TOOLS AND PLATFORMS

In order to facilitate signal processing education, various tools and platforms have been established for lab teaching.

A. Hardware Circuit

Some fundamental experiments for signal processing are carried out based on the hardware circuit.

For example, the EEE center of Hangzhou Dianzi University set up ten experiments for "Signals and Systems." Among these experiments, four of them are done via a hardware circuit [21]. Taking one of the experiments called "Decomposition and Synthesis of Electrical Signals" for instance, instruments such as a signal generator, a DC power, and an oscilloscope as well as components such as a resistor, a capacitor, an inductor, and an operational amplifier, are used.

Hardware circuit applies to not only simple experiments for theory verification but also specific experiments on unique signals. For example, a very high-frequency signal or an extremely weak signal has to be done by a hardware circuit.

Some universities adopt a lab box containing a hardware circuit of signal processing for experiments. Fig. 5 shows a picture of a real lab box [22].

Fig. 5.   A lab box of signal processing hardware circuit.

B. MATLAB

As described in Section III, MATLAB is used as a simulation tool in the practical teaching of signal processing. More than that, MATLAB can also be used for system design.

With more and more frequent use of MATLAB, some universities developed a course named "Advanced Programming of MATLAB and Engineering Applications." This course follows after "Signals and Systems" and provides an overall introduction on how to use MATLAB as a simulation and design tool for signal processing.

As listed in Table II, some step-by-step experiments are well designed for this lab course [23]. Through these exercises for programming and integrated design, students become familiar with the main features of MATLAB and have some exercises for signal processing.

C. DSP-based Platform

A variety of embedded processors have been adopted to implement digital processing platforms for practical teaching, and the most popular one is DSP.

In [24], along with the course "DSP Principle and Application," in total, 13 experiments over three different levels are designed for students' training. Table III shows a list of experiments for the fundamental, application, and extending levels, respectively [24].

At first, DSP-based platforms were donated by enterprises such as TI. With the progress of practical teaching, many universities customized their DSP platforms. DSP chips were selected, and peripherals were built according to the real requirements of the experiments. Fig. 6 shows a real picture of a DSP platform used by Huazhong University of Science and Technology [25].

TABLE II.   EXPERIMENTS FOR MATLAB COURSE

Name	Content
MATLAB Programming I	Basic instructions, plotting
MATLAB Programming II	Simulink, advanced plotting
MATLAB Programming III	A graphic user interface, hybrid programming with C language
Synthesis of Music	Music signal generation
Synthesis of Speech	Speed and tone tuning
Image Processing	JPEG (Joint Photographic Experts Group) encoding, face recognition
Game	Matched filtering, user interface

TABLE III.   EXPERIMENTS FOR DSP COURSE

Level	Name	Content
Fundamental	CCS (Code Composer Studio) basics	CCS integrated development environment
	Debugging of a simple application program	Exercise of debugging tools
Application	DSP data access	Internal storage space allocation of TMS320VC5502 Instructions for storage space operation
	GPIO (General-purpose input/output) control	Onboard GPIO peripherals Use GPIO port to control LEDs (Light Emitting Diodes)
	Timer control	Configuration registers for timer The interruption processing flow of TMS320VC5502
	DMA (Direct Memory Access) read and write	Configuration of DMA interface DMA read and write
	UART (Universal Asynchronous Receiver/Transmitter) control	Configuration of UART registers Data communication via UART
	A/D (Analog to Digital) sampling	CODEC (Coder/ Decoder) chip TLV320AIC23B Operation of DAC7724
	FIR algorithm	FIR parameter design in MATLAB FIR implementation
	FFT (Fast Fourier Transformation) algorithm	Implementation of FFT Spectrum analysis
Extending	Voice echo	Simulation of voice echo
	Voice harmony	Simulation of voice echo
	Traffic signals	Simulation of traffic signals

Fig. 6.   University self-developed DSP platform.

By the use of a DSP platform, students can practice how to build a prototype of a signal processing system. Some universities also teach undergraduates how to tailor a DSP hardware system by themselves.

D. Pocket Lab Kit

In recent years, as the complement of in-lab practical teaching, more and more pocket tools and platforms have been adopted or developed for students. With these tools and platforms at hand, students can work with signal processing experiments anytime and anywhere. Such kind of portable lab kit can greatly facilitate signal processing engineering education.

In some universities, a compact board equipped with embedded processors and peripherals is delivered to each student, by which students can work on their projects freely during the course learning. Some labs design and develop their pocket lab kit, including signal generation and measurement modules, as well as an embedded processor with peripherals [19,20]. This portable lab kit was initially used in the electronic circuit lab course, which made it possible for students to experiment with circuits when they were out of the lab and did not have any access to the conventional waveform generator, oscilloscope, and digital logic analyzer. With the aid of the pocket lab kit, students can test and measure the hardware circuit for signal processing anytime and anywhere.

V. CONCLUSION

This paper gives a brief overview of signal processing engineering education in China. In general, signal processing education is no longer taught in pure theory. More and more emphasis has been put on the engineering training part. Methods of engineering training evolve from MATLAB-only software simulation to a fusion of software and hardware.

Based on a survey on the teaching reform in recent decades, first, it sketches a complete course plan for signal processing teaching. Educators can select corresponding courses from this plan to meet the different learning requirements of their students. Second, as engineering education plays an indispensable role in the teaching of signal processing, multi-level teaching content and methodology are discussed in detail. In addition to in-curriculum lab items, cross-disciplinary training should be emphasized by educators. Finally, tools and platforms for engineering education were summarized into four categories. Educators were encouraged to design and develop their teaching tools and platforms, which can work seamlessly with the course teaching.

For the curriculum design, almost all the universities set up a principle course of "Signals and Systems" for related specialties as a compulsory one. Besides, many other courses on signal processing methods and technology, application, and implementation have been developed. Among them, there are quite a few independent practical courses. Besides, with the rise and popularization of MOOCs (Massive Online Open Courses), several signal processing MOOCs have been established [26,27].

Content and methodology for signal processing engineering education are multi-dimensional. Based on the EEE center and the framework of the laboratory teaching system, multi-level in-curriculum experiments are designed. Project-driven training and cross-disciplinary contests extremely motivate students' engagement in engineering practice. Graduation project training plays a vital role in signal processing engineering education in China. Collaboration with enterprises become closer and more profound.

Through decades of engineering education, more and more tools and platforms for signal processing have been developed. Hardware circuits, MATLAB, and DSP-based platforms are three of the most frequently used tools and platforms in practical teaching. As a complement, pocket lab kit makes it possible for students to work with experiments and projects more freely.

Compared with the engineering education practice of signal processing in other countries, one significant difference is that, in most universities of China, it is carried out in a comprehensive experimental center under a uniform practice teaching system. Tools and resources are fully shared among various courses. Through some well-designed cross-disciplinary lab training, knowledge of signal processing is put into practice in the context of a real application system. The nationwide massive contest IMCC is another distinct feature. From 2006, this contest has engaged more than 200,000 undergraduates. After graduation, students who have excellent performance in the IMCC contest are welcomed by enterprises.

REFERENCES

[1] Yongxiang Lu. "Challenge and strategy of China's engineering education," Science and Technology Review, no. 1, pp.3-6,18, 1995.

[2] Research group of the "Made in China 2025" plan and the cultivation of engineering technology talents, "The 'Made in China 2025' plan and the cultivation of engineering technology talents," Researches in Higher Education of Engineering, no. 6, pp. 6-10,82, 2015.

[3] Xiaoning Zhang, "Present situation research of the national-level experimental demonstration center," Research and Exploration in Laboratory, vol. 28, no. 10, pp. 85-88,161, Oct. 2009.

[4] Ruofei Sun and Jing Ma, "SRT: an effective way to improve students' capability of research and innovation," Chinese University Science & Technology, no. 12, pp. 48-49, 2013.

[5] Min Ye, Zhiyuan Wei, Chengfu Lou, and Yiping Mao, "SRTP: a successful exploration of Zhejing University undergraduates teaching

reform," Researches in Higher Education of Engineering, no. 4, pp. 55-58, 2005.

[6] Sheping Tian, Hongliang Chen, and Huijie Qin, "Improving students' ability of innovation practice through participation in a research program," Research and Exploration in Laboratory, vol. 25, no. 11, pp. 1342-1344, November 2006.

[7] Yidong Liu, Liangyu Ren, and Liying Feng, "Some thoughts and understanding on implementing National Undergraduate Training Program for Innovation and Entrepreneurship," Journal of Inner Mongolia Normal University (Educational Science), vol. 27, no. 1, pp. 7-10, January 2014.

[8] Qicong Peng, Yubai Li, Qing Guan, Chao Xiang, and Zhengxiang Luo, "DSP education in UESTC," Proceedings of CCSP 2001, vol. 17, pp. 500-503, 2001.

[9] Yanfen Wang, Jianying Zhang, Xiaoguang Zhang, and Limei Cai, "Construction of experimental teaching system in the curriculum group of signal processing," Research and Exploration in Laboratory, vol. 32, no. 4, pp. 132-134, 139, April 2013.

[10] Wenjie Li and Xiaoming Zhang, "Construction of experiment teaching system for signal processing curriculum group in electrical subjects," China Modern Education Equipment, no. 217, pp. 106-109, May 2015.

[11] Li Li, Gang Chen, and Xuelian Tian, "Application of project-driven in the teaching of the course 'digital signal processing'," Research and Exploration in Laboratory, vol. 34, no. 12, pp. 168-171, December 2015.

[12] Xinran Lu and Yan Chen, "Design and implementation of a digital voice changer," Course report of Signals and Systems, Dept. of Automation, Tsinghua University, July 2015.

[13] Guoliang Du, Renjie Hu, Huichun Huang, and Lei Zheng, "Research and reform of project-based design of electronic circuit experiment," Journal of EEE, vol. 37, no. 3, pp. 98-100, June 2015.

[14] Wei Wang and Shaoshi Bang, "Digital blood pressure meter," Course report of Electronics Projects, Dept. of Automation, Tsinghua University, August 2012.

[15] Qing Zhuo, Jingchun Wang, Gongzhang Shen, "A ten years review of the National Student Intelligent Car Race", Collected Works of Decade Development of Collegiate Intelligent Car Racing in China, 2015.

[16] Runpeng Cui, "Recognition and retrievement of special hand gesture," Undergraduate thesis, Dept. of Automation, Tsinghua University, July 2013.

[17] Changshui Zhang, Guangdong Houand Runpeng Cui. "A dynamic hand gesture recognition method based on Fréchet distance," Invention Patent, CN103745228A, April 2014.

[18] Xueyang Wang, "Fast algorithm for electromagnetic based biomedical imaging," Undergraduate thesis, Dept. of Electronic Engineering, Tsinghua University, July 2013.

[19] Guangwei Tu, "An FPGA-based integrated electronic lab platform," Undergraduate thesis, Dept. of Automation, Tsinghua University, July 2012.

[20] Yifan Wu, "An FPGA-based integrated electronic lab platform," Undergraduate thesis, Dept. of Automation, Tsinghua University, July 2013.

[21] "Experiments for signals and systems," Hangzhou Dianzi University, China, [Online].Available:http://wljx.hdu.edu.cn/eol/jpk/course/layout/default/index.jsp?courseId=1480.

[22] "Signal processing lab box used by Jiangnan University, China," [Online]. Available:http://www.cc.jiangnan.edu.cn/eelab/pic.asp.

[23] Yuantao Gu, Teaching material for "Advanced Programming of MATLAB and Engineering Applications," Dept. of Electronic Engineering, Tsinghua University, 2015.

[24] "Lecture notes for DSP principle and application experiments," [Online]. Available:http://wenku.baidu.com/link?url=9XF5zRFbiKCz7IO8I3ed AeN6qo_nlVMBf3xYy-q5urN0QJXr8DTkhWhgtrAYEyhwqQJV3gserG49roaPu8xo9EKqeF54jDeqI9X_Y396rFe.

[25] "DSP lab teaching system by Huazhong University of Science and Technology," [Online]. Available:http://eelab.hust.edu.cn:8080/FRUITS/FRUIT7/201210/8241.html.

[26] Qing Zhuo, "Signals and Systems", [Online]. Available:https://www.xuetangx.com/courses/course-v1:TsinghuaX+40250144X+2016_T1/aboutQing Zhuo, "Signals and Systemsy", [Online].Available:http://eelab.hust.edu.cn:8080/FRUITS/FRUIT7/201210/8241.html.

[27] Linsong He, "Digital Signal Analysis: Theory and Practice," [Online]. Available:https://www.xuetangx.com/courses/course-v1:HUST+603+_/about.