34th Annual International Conference of the IEEE EMBS
San Diego, California USA, 28 August - 1 September, 2012

CIC Signal Processing Embedded System
A Modulizable Platform for Multi-Domain Signal Processing

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***Abstract*— IT (Information Technology) industry is well developed in IC (Integrated Circuit) design, SoC (System-on-a-Chip), embedded, and etc. in Taiwan. Most of the commonly-used platforms are not configurable or modulizable at the moment. The biomedical academia in Taiwan is eager for a flexible biomedical signal sensing platform. This paper presents a novel multi-domain nano-sensor signal processing embedded system. The platform can be tailored for different demands of biomedical signal sensing.**

I. Introduction

CIC (National Chip Implementation Center) is a non-profit organization and aiming to provide IC design environment, chip fabrication/measurement services, and system design services to the industry and academia in Taiwan.

The development needs and design service demands in system integration of biomedical electronic system are growing rapidly recently in Taiwan. Small laboratories in Taiwan's universities usually have budget problems to purchase expensive commercial biomedical instruments. Whereas due to lacking of manpower and budget, most of the Taiwanese biomedical related research institutes are not able to develop specific SiP (System in Package) platform on their own. Some studies paid a lot of efforts on low-cost biomedical instruments [1]. CIC started a project in order to assist Taiwanese biomedical academia in July 2010. The project aims to establish biomedical electronics design environments and technology, and introduce state-of-the-art instruments for academia.

The initial phase of the project is targeted to establish an affordable, customizable and modulizable platform which can be utilized for ECG (Electrocardiogram), digital stethoscope, PO (Pulse Oximeter), pH meter, EC (Electrical Conductivity) meter, etc. According to different types of signals, users can switch sensors and modules to fit the characteristics of the signals.

The multi-domain nano-sensor signal processing embedded system shows great success in the initial phase of CIC's project. The system is designed to be a customizable and modulizable biomedical embedded platform, which comprises a BSA (Biomedical Signal Acquisition) module, an ADC (Analog-to-Digital Converter) module, a PA (Pre-Amplifier) module, and a compact embedded system running Android OS. The LCD touch panel on the top of the system is able to display captured signals and show further analytical data in real-time. The BSA module is exchangeable and can be designed to meet the sensing requirements of any type of biomedical signals.

After the completion of the system, we tried to minimize and add more features on the platform. The ADC and PA modules are re-designed into smaller sizes. The compact embedded system on the top was replaced by TI's MSP430 platform with a Panasonic PAN1315EMK Bluetooth module. The completed Bluetooth version platform offers wireless connectivity and better mobility. Users can use a tablet computer to receive the data transmitted from the platform, and further analyze the data on the tablet computer real-time or post-process the data on desktops.

The CIC multi-domain nano-sensor signal processing embedded system is adopted in several universities; we are still receiving feedbacks from the laboratories using the platform. The next phase of CIC's project would try to further minimized and integrate the whole system into a tiny SiP platform.

II. Multi-Domain Nano-Sensor Signal Processing Embedded System

A. Biomedical Signal Acquisition Module

The module as shown in Figure 1 can connect with front-end biosensor and transmit sensed signals to pre-amplifier module.

B. Pre-Amplifier Module

The module as shown in Figure 2 can amplify low magnitude signals. The module is helpful when measuring specific signals with small changes. The module can be dismissed or replaced according to the properties of the signals. Splitting of the modules enables the platform to measure different types of signals in different scales. The technical details of the pre-amplifier module are shown in Table I.

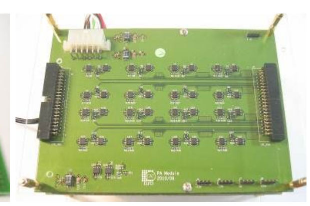

Figure 1 & 2 – Biomedical Acquisition Module & Pre-Amplifier Module

TABLE I. Technical Specification of Pre-Amplifier Module

Channels	Measuring Range	Resolution
16	1k ~ 5M Ω	0.01k Ω

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C. Analog-to-Digital Converter Module

The ADC module as shown in Figure 3 contains a 24-bit analog-to-digital converter [2], able to convert 16 channels of signals by scanning. There is an FPGA (Field-Programmable Gate Array) chip equipped on the module used for hardware acceleration, real-time analysis, and massive signal processing. The module supports various communication protocols such as UART, SPI, and I^2C for connecting a variety of devices and interfaces. The technical details of the ADC module are shown in Table II.

Figure 3 – Analog-to-Digital Converter Module

TABLE II. TECHNICAL SPECIFICATION OF ADC MODULE

Sampling Input	Sampling Output	Resolution
23.7k Samples/Second	> 1.6k Samples/Second	24-bit

Based on TI ADS1258-EP and Measurement

To approach smoother measured data curves and eliminate measuring deviations, we send the mean value of a set of 128 samples from each channel into next stage. The calculate acceleration can be achieved by taking first 24 bits from the 31-bit buffer ($2^{24} \times 128 = 2^{31}$) for instant sum value. The operation can be completed in only one clock cycle with FPGA chip, while the operation may need two or more clock cycles when performing on general MCUs (Micro Controller Units). According to our measurement, the module is able to transmit and receive more than one hundred sets of 16-channel data per second.

D. Human Interface Module

The human interface module on the top of the platform comprises a 7-inch LCD touch panel, an embedded system featuring 667 MHz ARM1176JZF-S CPU and 128 MB SDRAM. Since CIC is a non-profit organization, we have to take licensing issues with industry as well as academia, and the future prospects of a novel technology for introducing into consideration. Thus Google Android is chosen as the OS for our platform due to its openness and its rapid growth of developers.

The development of the module can be divided into two categories:

- System Libraries: GPIO (General Purpose Input/Output) Device Driver and JNI (Jave Native Interface)
- Android Application and Utilities: SigView and SigView Wizard

The GPIO driver is used for data exchanging with the ADC module. Since general Android applications are coding in pure Java, we need to set JNI in order to enable data exchanging between Android applications and device drivers coding in C, C++, or assembly [3]. The architecture concept diagram is shown in Figure 4 [4].

The Android app “SigView” is designed for plotting signals. SigView is able to display data from 16 channels and up to three different charts in single screen simultaneously. Users can choose to show the original signal plot or analytical result plot. The display of each channel is customizable and there are more flexible settings which help users to build their own plot styles. The signals received by SigView can be saved into removable micro SD cards in binary format for further use. Currently only the mean values processed by FPGA chip are saved into SD cards due to performance issues. We believe the performance issues could be resolved with next generation tablets for storing raw data from the ADC module. Users can also save screenshots anytime for reference.

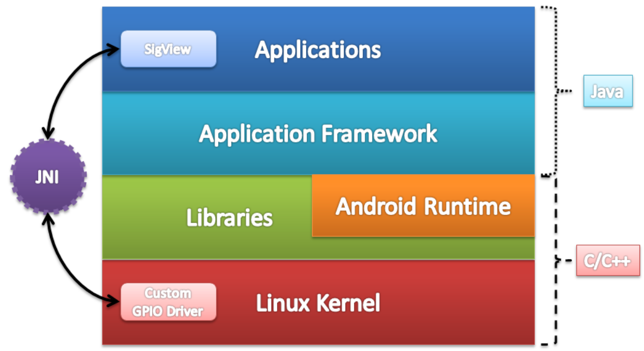

Figure 4 – Android Architecture Concept Diagram

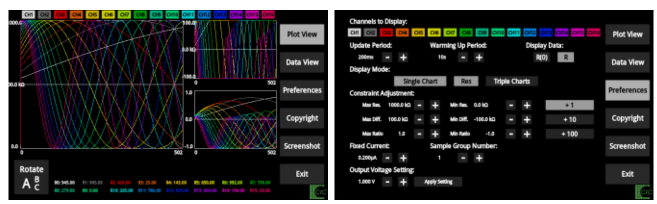

Figure 5 & 6 – SigView in Multiple Charts View & Preferences Menu

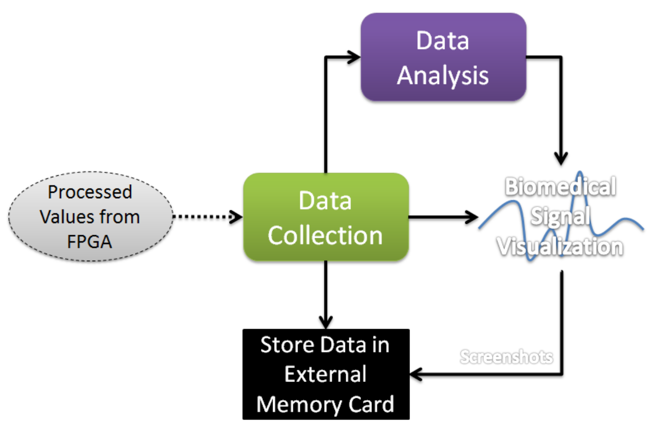

Figure 7 – SigView Concept Operation Flow Diagram

Currently SigView is designed to show signals in line charts, which are applicable to most cases of signal displaying. The display style can be programmed to generate different chart types. The 3D chart functions are planned to be implemented in the near future. Developers can utilize the

APIs (Application Programming Interfaces) to build their own Android Apps.

The SigView Wizard is a desktop application used for emulating SigView on PCs and helps users to convert saved SigView binary files into most commonly used formats for further data analyses.

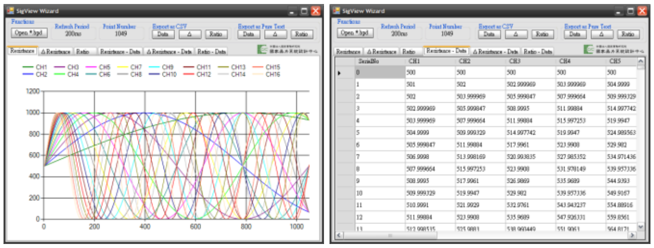

Figure 8 & 9 – SigView Wizard in Chart View & Data View

E. *The Completed Platform*

The architecture concept diagram of the platform is shown in Figure 10. Initially, BSA module senses signals and transmits analog data to PA module. The PA module amplifies analog signals and then transmits amplified data to ADC module. The ADC module converts analog data into digital data, and further transmits the mean values of each channel after summing and calculating. Once users execute SigView app on the embedded system running Google Android OS, SigView starts to collect mean values of each channel transmitted from the ADC module, and then shows corresponding charts on the LCD touch panel. The operation concept flow diagram is shown in Figure 11.

The photo of the completed platform is shown in Figure 12. Figure 13 shows an application utilizing the platform in a laboratory of National Chiao Tung University.

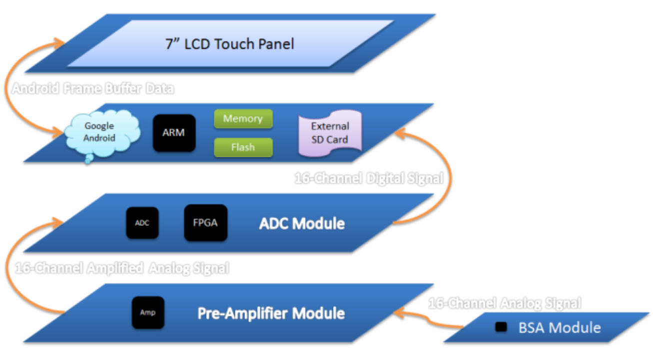

Figure 10 – Platform Architecture Concept Diagram

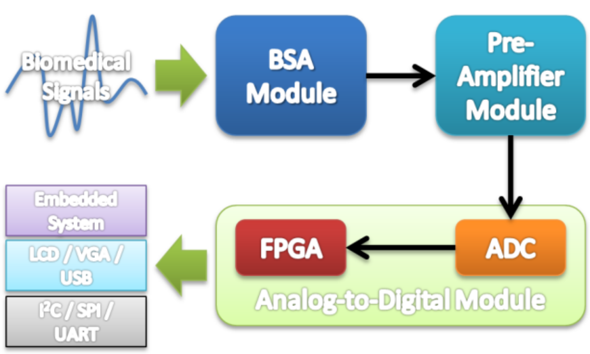

Figure 11 – The Concept Operation Flow of the Platform

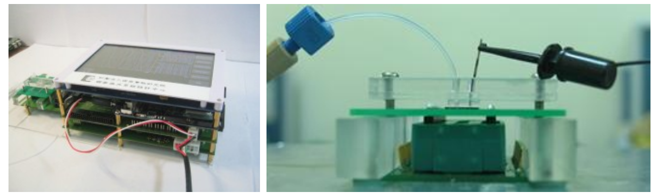

Figure 12 & 13 – The Completed Platform & Application in NCTU

III. Wireless Multi-Domain Nano-Sensor Signal Processing Embedded System

To make our nano-sensor embedded system being more value-added, we decided to develop a wireless version of the platform. The embedded system on the top was replaced by TI MSP430 experimenter board [5] with Panasonic PAN1315EMK Bluetooth evaluation module kit [6].

A. *TI MSP430 Experimenter Board with Panasonic PAN1315EMK Evaluation Module Kit*

The experimenter board and the Bluetooth module kit are shown in Figure 14. The board turns into a Bluetooth data transceiver. Users can use tablet PCs to connect with the platform, and view the measuring results on the tablet PCs directly.

Besides the top module, we redesigned the PA module and the ADC module into smaller sizes. A new tiny DAC (Digital-to-Analog Converter) module [7] is equipped to supply power and adjust power output on the BSA module. Users can control the power settings remotely via the Bluetooth link as well. The DAC module is shown in Figure 15. The technical details of the DAC module are shown in Table III.

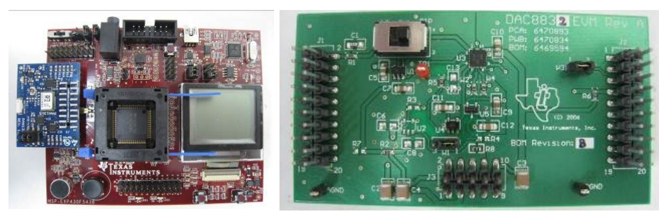

Figure 14 & 15 – TI Experimenter Board with Panasonic Bluetooth Module & DAC Module

TABLE III. Technical Specification of DAC Module

Operation Rage	Accuracy	Resolution
2.7 ~ 5.5 V	1 LSB INL	16-bit

Based on TI DAC8832 Evaluation Module

B. *The Completed Wireless Platform*

We chose a tablet PC running Google Android OS as the remote terminal for the wireless platform, thus the original SigView app can be ported onto the tablet PCs easily. The SigView Bluetooth version integrated Bluetooth connection control and remote power adjustment functions into the original SigView app. The SigView app became more powerful and able to offer a variety of connectivities to users. The wireless platform architecture concept diagram is shown in Figure 16, and the completed platform is shown in Figure 17. An application utilizing the platform with SiNW-FET sensor in National Chiao Tung University is shown in Figure 18.

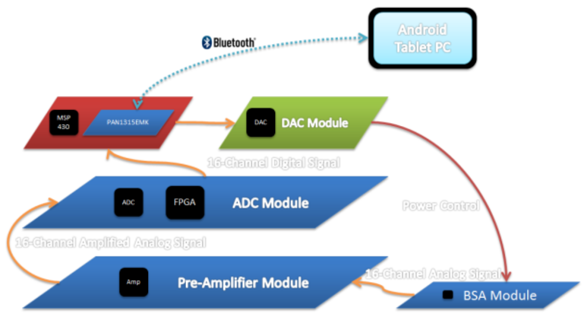

Figure 16 – Wireless Platform Architecture Concept Diagram

Figure 17 – The Completed Wireless Platform & Application

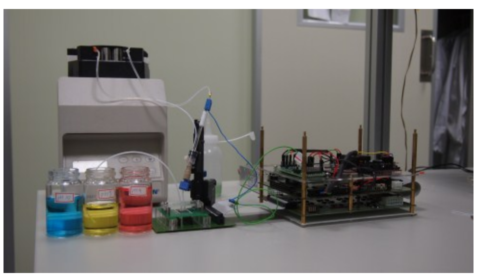

Figure 18 – A SiNW-FET Biomedical Signal Sensing Application in NCTU

IV. Conclusion

This article shows two multi-domain nano-sensor signal processing embedded systems developed by CIC. Both the two systems have compact sizes, flexible connectivities, and reasonable costs of materials. The wireless version utilizes tablet PCs for instant data presenting and remote sensing, provides a modern way for biomedical signal measuring.

CIC multi-domain nano-sensor signal processing embedded systems showed great success and proved the feasibility of our idea. We did much effort on reducing the total size of the platform, though the size is not small enough to be "wearable". The future phases of the CIC's project will focus on platform minimization and the flexibility of sensor choices, thus the results may further benefit the biomedical academia in Taiwan and elsewhere.

V. Future Works

We are currently running a project named MorSensor – Modulized Wireless Sensor Fusion System. The project is aimed to develop a tiny integrated embedded sensor system which can attach various types of sensor. Combination of different types of sensors would reach a better performance than possible with a single sensor. We will have a new power system for MorSensor platform as well. The two multi-domain nano-sensor signal processing embedded systems are still relying on wired power supplies, while MorSensor platform will have multiple power sources including batteries and wireless power charging. The proposed SiP platform is expected to have a more powerful ARM processor and Wi-Fi connectivity for running latest version of Android.

We are currently running the first phase of the new project. The concept architecture diagram of MorSensor platform is shown in Figure 19. The proposed specifications of the platform are shown in Table IV. The platform is highly customizable that users may choose necessary layers only according to their needs. A tiny platform (The total size is smaller than a tennis ball.) with multiple boards with connectors is developing for simulating the proposed SiP. After the function verifications were passed on the board version platform, we will start to convert the verified platform into SiP version. The proposed platform could be expected to be utilized in telemedicine due to its small size and ease of use. The tablets provide a variety of telecommunication methods and user-friendly interfaces, thus even non expert users can hand on without any problem.

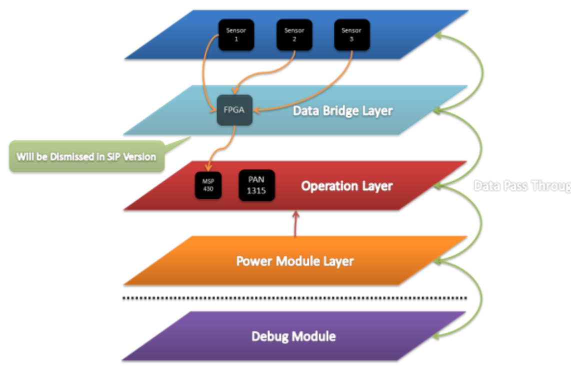

Figure 19 – MorSensor Architecture Concept Diagram

TABLE IV. TECHNICAL SPECIFICATION OF MORSENSOR VERIFICATION BOARD MODULE

Board Dimension	**Board Height**	**Stacking Height**
3.5 cm x 3.5 cm	< 1.0 cm	2.5 cm ~ 4.0 cm

References

[1] Myers, F.B.; Henrikson, R.H.; Liyi Xu; Lee, L.P.; , "A point-of-care instrument for rapid multiplexed pathogen genotyping," Engineering in Medicine and Biology Society, EMBC, 2011 Annual International Conference of the IEEE, pp. 3668-3671, Aug. 30 2011-Sept. 3 2011

[2] Texas Instruments Incorporated, "16-Channel, 24-Bit, Analog-to-Digital Converter (Rev. D)," ADS1258-EP Enhanced Product 16-Channel, 24-Bit Analog-to-Digital Converter, http://focus.ti.com/docs/prod/folders/print/ads1258-ep.html

[3] Google Inc., "JNI Tips," Android Developers, http://developer.android.com/guide/practices/design/jni.html

[4] Google Inc., "Android Architecture," Android Developers, http://developer.android.com/guide/basics/what-is-android.html

[5] Texas Instruments Incorporated, MSP430 Bluetooth Platform, http://processors.wiki.ti.com/index.php/MSP430_Bluetooth_Platform

[6] Panasonic Corporation of North America, PAN1315 from Panasonic, http://www.panasonic.com/industrial/electronic-components/rf-modules/bluetooth/pan1315.aspx

[7] Texas Instruments Incorporated, DAC8832 Evaluation Module, http://www.ti.com/tool/dac8832evm