Issue 8

Jan. 2015

APSIPA NEWSLETTER

Asia-Pacific Signal and Information Processing Association Newsletter

In this issue we celebrate the success of the recent 2014 APSIPA Annual Summit and Conference (APSIPA ASC 2014) event which was held in Siem Reap, Cambodia, from December 9-12, 2014. It was a success in all aspects and a big number of researchers including many students congregated in this gathering to exchange knowledge and build up research networks. The opening of this newsletter issue shades lights on some activities held in this conference. Thus, we take this opportunity to invite you all to participate in APSIPA conference in December 2015 which will be held in Hong Kong. The flyer of the conference is attached with this issue.

Three prominent keynote speakers have been invited to deliver landmarks in their research areas. Prof. P. P. Vaidyanathan from California Institute of Technology Pasadena, USA presented an interesting topic titled Ramanujan-sums and digital signal processing. He also complemented his speech by an abstract article about Ramanujan-sums, included in this newsletter issue. We encourage people to read this interesting article specially it paves the way to two extended papers in this topic published recently in IEEE Trans. on Signal Processing. The second keynote speaker was Prof. Helen Meng from Chinese University of Hong Kong and she presented a topic titled Development of Automatic Speech Recognition and Synthesis Technologies to Support Chinese Learners of English. Professor Meng demonstrated her group approach which depends on the theory of language transfer and involves a systematic phonological comparison between the primary language and secondary language to detect mispronunciations. The third speaker was Dr. Wei-Ying Ma from Microsoft Research Asia, China. His topic was

In this issue

#	**Topic**	**Speaker**
Tutorial 1	STRAIGHT Speech Analysis	Hideki Kawahara
Tutorial 2	Signal Processing Circuit for Pulse Transmission in Solar String	Ekachai Leelarasmee
Tutorial 3	MPEG: Evolving Standards for Video Coding	Yo-Sung Ho
Tutorial 4	Signal Enhancement in Consumer Products	Akihiko Sugiyama
Tutorial 5	Speaker Recognition – The Present and Future of Voice Biometrics	Eliathamby Ambikairajah and Waleed H. Abdulla
Tutorial 6	Recent advances in Subpixel rendering for image/video	Oscar Au
Tutorial 7	Vector Spaces for Cross-language NLP Applications	Rafael E. Banchs

titled Building a Scalable System and Algorithms for Machine Comprehension of Text. The essence of his talk was to show the current ability to learn big statistical models from large amounts of data and build comprehensive symbolic knowledge graphs from the Web.

The conference also started its activities by seven tutorials presented by leading researchers in their fields, detail of which is shown in the table above.
We encourage APSIPA community to register in our future conferences tutorials; especially they are free to attend. We also encourage them to suggest tutorials that have influence in the current research arena. ASIPA association message is to proliferate knowledge among research communities and this is why tutorials are free to attend.

Having said the rich contents of APSIPA annual conferences we encourage more participants to be involved in different activities so to achieve the goals APSIPA initiated for.

In this issue we also report on the important event IEEE SPS-APSIPA Winter School on Machine Intelligence and Signal Processing held on December 20-23, 2014. This event is the first joint activity between IEEE SPS and APSIPA which took place in New Delhi, India. It is an implementation of the Memorandum of Understanding (MoU) approved by the IEEE SPS and APSIPA in 2014 to support and sponsor joint activities.

Waleed Abdulla,
APSIPA Newsletter EiC

APSIPA ASC 2014 Report

The 2014 APSIPA Annual Summit and Conference (APSIPA ASC 2014) event was held in Siem Reap, Cambodia, from December 9-12, 2014. It was the sixth APSIPA annual conference, while the previous conferences were held in Japan (2009), Singapore (2010), China (2011), USA (2012) and Taiwan (2013). Although the venue was moved from Chiang Mai due to a political situation in Thailand, APSIPA ASC 2014 had a high record of 318 accepted papers from 380 submitted papers from 24 countries. The conference had high turnouts, which were over 350 attendees.

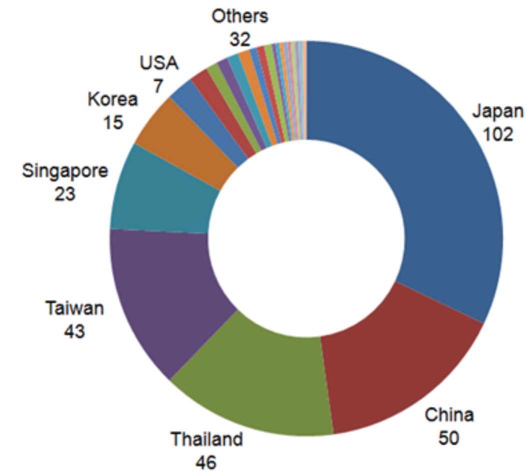


Fig. 1 Number of accepted papers by countries

Paper submission and presentation were organized in 6 separate tracks, Biomedical Signal Processing and Systems (BioSiPS) track, Signal Processing Systems: Design and Implementation (SPS) track, Image, Video, and Multimedia (IVM) track, Speech, Language, and Audio (SLA) track, Signal and Information Processing Theory and Methods (SIPTM) track and Wireless Communications and Networking (WCN) track, corresponding to the technical areas covered by 6 APSIPA technical committees.

The technical program included 7 tutorial sessions, 3 keynote speeches, 2 plenary overview sessions, 1 forum discussion session, together with 53 oral sessions and 7 poster sessions.

The social program included a welcome reception and a conference banquet. Siem Reap, city of Angkor Wat, is the capital city in northwestern of Cambodia, and a popular resort town as the gateway to Angkor temples region. Attendees had great experiences in the wonderful world heritage, colonial and Chinese-style architecture in the old French quarter, museums, traditional Apsara dance performances, silk

Fig. 2 Opening ceremony

Fig. 3 Keynote speeches

Fig. 4 The banquet

farms, fishing villages and a bird sanctuary near the Tonle Sap lake.

APSIPA ASC 2014 was a great success. The proceedings are all accessible online and can be downloaded at APSIPA website (http://apsipa.org/proceedings.htm). APSIPA ASC 2014 was also technical co-sponsored by the IEEE Signal Processing Society, and all accepted papers are accessible via IEEE Xplore as well as other Abstracting and Indexing (A&I) databases. We welcome your contributions to ASIPA ASC 2015, which will be held in Hong Kong, from December 16-19, 2015. Look forward to seeing old as well as new friends there.

APSIPA 2014 Conference Best Paper Awards

by Hsueh-Ming Hang

The Best Papers Awards in APSIPA 2014 Conference are well deserved by:

IVM Track: Single-sample-per-person-based Face Recognition using Fast Discriminative Multi-Manifold Analysis

Hsin-Hung Liu, Shih-Chung Hsu, and Chung-Lin Huang (*)

Department of Electrical Engineering, National Tsing-Hua University, Hsin-Chu, Taiwan

(*) Department of Applied Informatics and Multimedia, Asia University, Taichung, Taiwan

SLA Track: Modulation Spectrum-Based Post-Filter for GMM-Based Voice Conversion

Shinnosuke Takamichi, Tomoki Toda, Alan W Black (*), and Satoshi Nakamura,

Graduate School of Information Science, Nara Institute of Science and Technology (NAIST), Japan

(*) Language Technologies Institute, Carnegie Mellon University (CMU), U. S. A

SPS and BioSPS Tracks: Smoothing of Spatial Filter by Graph Fourier Transform for EEG Signals

Hiroshi Higashi, Toshihisa Tanaka (*), and Yuichi Tanaka (*)

Toyohashi University of Technology, Aichi, Japan.

(*) Tokyo University of Agriculture and Technology, Tokyo, Japan

WCN and SIPTM Tracks: Interference Suppression Schemes for Radio over Fiber Simultaneously Transmitted with 10 Gbps On-Off Keying

Yuya Kaneko, Takeshi Higashino, and Minoru Okada

Graduate School of Information Science, Nara Institute of Science and Technology, JAPAN

Snapshots from APSIPA 2014 Conference

Ramanujan-sums in signal processing

P. P. Vaidyanathan, *Fellow, IEEE*
Dept. of Electrical Engineering, 136-93
California Institute of Technology, Pasadena, CA 91125, USA
ppvnath@systems.caltech.edu

Based on a keynote talk given at the APSIPA ASC, December 2014, Siem Reap, Cambodia

A great deal has been written about the Indian mathematician Srinivasa Ramanujan. Born in 1887 in Erode, Tamil Nadu, India, Ramanujan grew up with modest education. In fact he never received formal advanced training in mathematics. Nevertheless, he developed his own mathematical ideas at a very young age and made profound contributions to number theory, infinite series, and mathematical analysis [4]. His genius was noticed by a few senior mathematicians in India, who suggested that he contact some of the famous western mathematicians and communicate to them his results. Among the once that Ramanujan wrote to, the only one who took his correspondence seriously was the legendary Cambridge mathematician G. H. Hardy. Hardy was very impressed by some of the results that Ramanujan had included in his first letter to him. While some of these results were known to the western world, many were new. Hardy subsequently made arrangements for Ramanujan to visit him and work with him. This collaboration continued for about five years during which Ramanujan published many profound papers in international journals. Unfortunately he had to return to India after this due to illness, and he passed away in 1920 at the young age of 32. But the work he did during his short life span was phenomenal. Indeed, the legacy of results left behind by Ramanujan has had a great influence on mathematics, and even today mathematicians are studying some of the results he wrote in his notebooks [2], [1]. Hardy, who was himself one of the greatest English mathematicians, had the highest regard for Ramanujan. You can read about it in Hardy's own words in his introduction to a book of collected papers by Ramanujan [4].

One of the papers which Ramanujan wrote in 1918 while at Cambridge introduces a summation now known as the Ramanujan-sum [13]. Given any positive integer q the Ramanujan sum $c_q(n)$ is defined by

$$c_q(n) = \sum_{\substack{1\le k\le q\\(k,q)=1}} e^{j2\pi kn/q} \tag{1}$$

where $(k,q)=1$ means that k and q are **coprime**, i.e., k and q have no common divisors other than unity. Thus we add complex sinusoids with frequencies

$$\omega_k = \frac{2\pi k}{q} \tag{2}$$

where k and q are coprime. These are referred to as coprime frequencies with respect to the DFT grid $2\pi k/q$. Clearly $c_q(n) = c_q(n+q)$, and the Ramanujan sum can be regarded as a periodic sequence whose q-point DFT $C_q[k]$ is zero when k is not coprime to q, and nonzero ($=q$) when k and q are coprime. The simple-looking summation (1) has beautiful properties, and profound applications in number theory. More recently there have been interesting applications in signal processing, as we shall briefly describe below. A more elaborate account can be found in [17] and [18].

Ramanujan showed that if we add the complex numbers $e^{2\pi kn/q}$ over coprime values of k as in Eq. (1), then the result $c_q(n)$ is always real, in fact, it is **integer** valued! For example,

$$\begin{aligned} &c_1(n)=1,\ c_2(n)=\{1,-1\},\ c_3(n)=\{2,-1,-1\},\\ &c_4(n)=\{2,0,-2,0\},\ c_5(n)=\{4,-1,-1,-1,-1\},\\ &c_6(n)=\{2,1,-1,-2,-1,1\},\ \cdots \end{aligned} \tag{3}$$

and so forth. Ramanujan's motivation in introducing this sum was to show that several standard arithmetic functions in the theory of numbers can be expressed as infinite linear combinations of the form

$$x(n) = \sum_{q=1}^{\infty} \alpha_q c_q(n). \tag{4}$$

Just to give a flavor for the type of problems that are interesting to number theorists, consider the sum-of-divisors function $\sigma(n)$ where n is a positive integer. This is defined as the sum of all **divisors** (factors) of n, including 1 and n. For example $\sigma(12) = 1+2+3+4+6+12 = 28$. Ramanujan showed [13] that $\sigma(n)$ can be expanded as an infinite series

$$\sigma(n) = \frac{n\pi^2}{6}\sum_{q=1}^{\infty}\frac{c_q(n)}{q^2}, \quad n\ge 1. \tag{5}$$

Many other amazing expansions for number-theoretic functions are developed in [13].

During the last decade it has been shown that the Ramanujan sum (1) has interesting applications in signal processing [9], [11], [12], [15]. For example applications in the representation of periodic signals [12], in time-frequency analysis [15], and in medicine [9] have been reported. To understand how these

This work is supported in parts by the ONR grant N00014-11-1-0676, and the Information Science and Technology (IST) initiative of the California Institute of Technology.

applications arise we have to understand some properties of Ramanujan-sums. First consider the terms

$$d_k(n) = e^{j2\pi kn/q} \tag{6}$$

in (1). Since $d_k(n) = d_k(n+q)$ it follows that this is periodic in n. For arbitrary k and q, the period can be either q or a divisor of q since there could be cancelations between k and q. But since k and q are restricted to be coprime in (1), the period is exactly q. (The period P of a signal $x(n)$ is the *smallest* positive integer such that $x(n) = x(n+P)$ for all n.) So each term in (1) has period q, although the terms have different frequencies given by (2). Now, if we add a bunch of signals with period q the result has period either q or a divisor of q. The beauty about the terms in (2) is that the period of the sum is exactly q and not smaller [17]. Thus, the Ramanujan sum $c_q(n)$ has period exactly equal to q.

In much of the early work, the infinite sum (4) was used as the theoretical basis and a closed form expression for α_q, developed in 1932 [3], was routinely used. Now, in signal processing applications it is convenient to consider finite duration signals $x(n), 0 \leq n \leq N-1$, and obtain finite expansions instead of (4):

$$x(n) = \sum_{q=1}^{N} a_q c_q(n) \tag{7}$$

Such an expansion represents a signal as a sum of periodic components with periods $1, 2, \ldots, N$. Compare this with the DFT representation

$$x(n) = \sum_{k=0}^{N-1} b_k e^{j2\pi kn/N} \tag{8}$$

For each k we can write $k/N = k_i/q_i$ where q_i is a divisor of N, and $(k_i, q_i) = 1$. Thus the N terms in (8) do not have N distinct periods but only K distinct periods where K is the number of divisors of N. So, this is one of the fundamental differences between the Ramanujan expansion (7) and the DFT expansion (8): the former contains terms with all periods $1 \leq q \leq N$ whereas the latter contains only periods that are divisors of N. The Ramanujan-sum has therefore been found to be useful to represent a signal as a sums of periodic components, with all periods allowed. This is useful to extract hidden integer periodicities in signals, especially periods that are small compared to the data size [11], [12], [9]. It is also useful to obtain a sparse representation of signals which are superpositions of a small number of periodic components.

A more elaborate theory of signal representations using Ramanujan-sums has recently been developed in [17], [18]. First it is shown that the 1932 formula for α_q [3] is not appropriate for finite expansions (7), which are more practical. Second it is shown that the finite expansion can be done directly, by using the fact that a certain matrix based on Ramanujan sums is guaranteed to be of full rank. It is also shown that the expansion (7) leaves much to be desired. Since each period is represented by a one-dimensional subspace (i.e., just one signal $c_q(n)$), it is easy to generate examples of periodic signals such that (7) does not lead to a sparse representation. To overcome this deficiency in the traditional Ramanujan sum representations, the so-called **Ramanujan subspace** is introduced in [17], and signal representations based on Ramanujan-subspaces are developed in [18]. The idea is briefly outlined below.

We know the Ramanujan sum $c_q(n)$ is periodic in n with period q. Consider all the cyclic shifts of this sequence, namely $c_q(n-l), 0 \leq l \leq q-1$. The space spanned by these q sequences is called the Ramanujan space $\mathcal{S}_q$ [17]. It can be shown that this space has dimension only $\phi(q)$ where $\phi(q)$ is the number of integers[1] in $1 \leq k \leq q$ coprime to q. Furthermore, it can be shown [17] that the space $\mathcal{S}_q$ can be spanned by the first $\phi(q)$ cyclic shifts, that is,

$$c_q(n), c_q(n-1), \ldots, c_q(n-\phi(q)+1) \tag{9}$$

Any nonzero signal in the space $\mathcal{S}_q$ has period exactly q (it cannot be a *proper* divisor of q). Next, it is shown in [18] that any signal $x(n), 0 \leq n \leq N-1$ can be represented as a sum of the form

$$x(n) = \sum_{q_k|N} x_{q_k}(n) \tag{10}$$

where the notation $q_k|N$ means that q_k are divisors of N, and where $x_{q_k}(n) \in \mathcal{S}_{q_k}$. In words, any $x(n)$ with duration N can be represented as a sum of K signals $x_{q_k}(n)$ where K is the number of divisors of N and the component $x_{q_k}(n)$ is a period-q_k signal belonging to the Ramanujan subspace $\mathcal{S}_{q_k}$. This therefore leads to a decomposition of a signal into periodic components where the periods q_k are divisors of N. The relation to the DFT representation is elaborated in [18].

Finally, any two periodic components $x_{q_1}(n)$ and $x_{q_2}(n)$ in the representation (10) are orthogonal in the interval $0 \leq n \leq N-1$. The orthogonal periodic components $x_{q_k}(n)$ are orthogonal projetions of $x(n)$ onto the Ramanujan subspaces $\mathcal{S}_{q_k}$. It can be shown [17] that these projections can be computed using essentially **integer projection** matrices. What this means is that the computation involves only a small number of additions and subtractions of the (possibly complex valued) samples in $x(n)$.

Since $x_{q_k}(n)$ belongs to $\mathcal{S}_{q_k}$ the expansion (10) is equivalent to the **double sum** representation

$$x(n) = \sum_{q_k|N} \sum_{l=0}^{\phi(q_k)-1} \beta_{kl} c_{q_k}(n-l) \tag{11}$$

It can be shown that $\sum_{q_k|N} \phi(q_k) = N$ so that there are exactly N terms in the summation (11). Thus

$$\{c_{q_k}(n-l)\} \tag{12}$$

forms a basis for $\mathbb{C}^N$, where $q_k|N$ and $0 \leq l \leq \phi(q_k)-1$. A number of examples are given in [18] to demonstrate the advantages of the new Ramanujan-space representation (11) over the traditional Ramanujan representation (7), and the traditional DFT representation.

But even the representation (11) has limited usefulness because it uses only components whose periods are divisors of N (like the DFT). In order to overcome this, an even newer

[1] $\phi(q)$ is called the Euler totient function [6].

representation based on the so-called **Ramanjuan frames** is developed in [16], by using a dictionary based approach. In this approach, we consider the $\phi(q)$ cyclically shifted Ramanujan sequences $c_q(n-l), 0 \leq l \leq \phi(q)-1$ for *all values of* q in $1 \leq q \leq N$ (i.e., we do not restrict q to be divisors of N). Thus, the representation takes the form

$$x(n) = \sum_{q=1}^{N} \sum_{l=0}^{\phi(q)-1} y_{ql} c_q(n-l), \quad 0 \leq n \leq N-1 \tag{13}$$

where N is the signal duration. The total number of terms in the right hand side is $\sum_{q=1}^{N} \phi(q) = O(N^2)$ which shows that the representation has lot of redundancy, that is, y_{ql} is not unique. But this is the beauty of the representation: we take advantage of the redundancy, and look for a solution which represents $x(n)$ as a sum of periodic components with as small periods as possible. (Note that smaller periods imply greater structure in the signal.) An optimization problem to this effect can be formulated, by using an appropriate norm of y_{kl} in the minimization process. This is reminiscent of a s**parsity constraint**, but there are important differences. The details can be found in [16]. Eqn. (13) can be written in matrix form as follows:

$$\mathbf{x} = \mathbf{A}\mathbf{y} \tag{14}$$

where $\mathbf{x} = [\,x(0) \quad x(1) \quad \ldots \quad x(N-1)\,]^T$ and $\mathbf{y}$ is a column vector containing the components y_{kl} in appropriate order. The **dictionary matrix A** has N rows and $\sum_{q=1}^{N} \phi(q) = O(N^2)$ columns so that it is a fat matrix. For example if $N=6$ then $\sum_{q=1}^{N} \phi(q) = 12$ so that $\mathbf{A}$ is 6×12. A unique solution $\mathbf{y}$ can still be obtained by imposing a side constraint as explained above.

Figure 1(a) shows an example of a signal $x(n)$, which is a superposition of three periodic signals, with periods $4, 7$, and 13. The three hidden periods cannot be seen from the figure. The sum has a period equal to the least common multiple of $4, 7$ and 13 which is 364. Since the signal duration is only 100, this larger periodicity cannot be seen. Figure 1(b) shows a plot of the DFT spectrum, from which it is hard to identify the hidden periods. But the Ramanujan dictionary based algorithm can readily identify the hidden periods, as shown in the Ramanujan spectrum of Fig. 1(c). There are clear peaks at $2, 4, 7$, and 13. The peak at 2 arises because of the 2nd harmonic of the period 4 component. Further examples can be found in [16], [18], and [19].

A number of interesting applications and new ideas arise out of the above representations. For example if we have a signal with time varying periodic components (i.e., periodicities localized in time) then how to generalize the above techniques for **time-period localization**? And how to extend these ideas for the case of multidimensional signals with nonseparable periodic patterns (as described by generalized lattices)? These, and other questions are currently under investigation.

The great English mathematician Hardy, in good humor, had once mentioned that profound, respectable mathematics cannot have any worthwhile applications in the real world [5]. In other words, if a mathematical theory of some sort finds an useful application, then that would be "ordinary" math. He went on to give examples, but we shall omit those here. Suffice it to say that history has proved Hardy wrong. In engineering sciences of the last century, we have repeatedly found many applications of deep, profound math. Examples include coding theory, cryptography, information theory, and many areas of signal processing. The inspiring article written by Maddox in the journal *Nature* [8] is worth mentioning here. The usefulness of Ramanujan's sum in signal processing is yet another example of the fact that highly respectable math can indeed have useful applications in engineering.

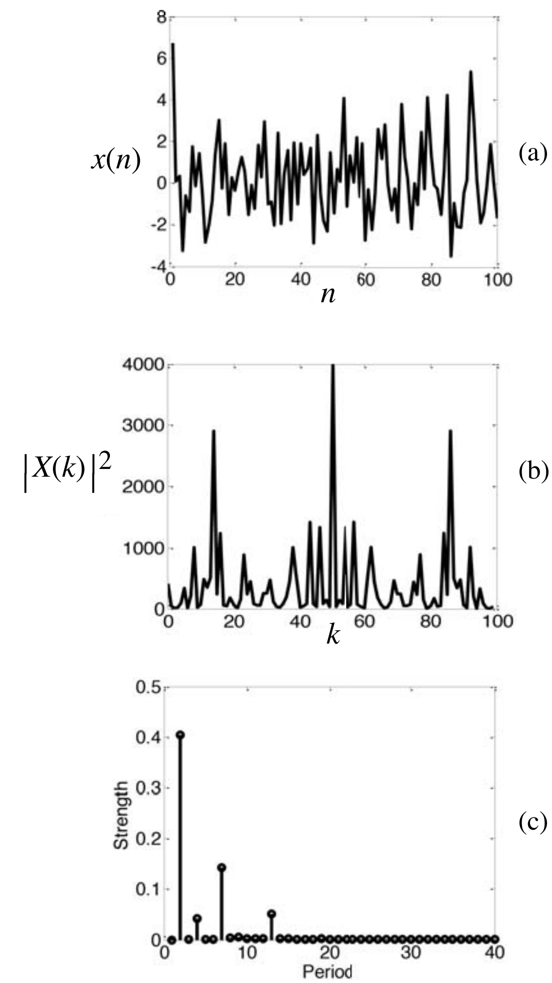
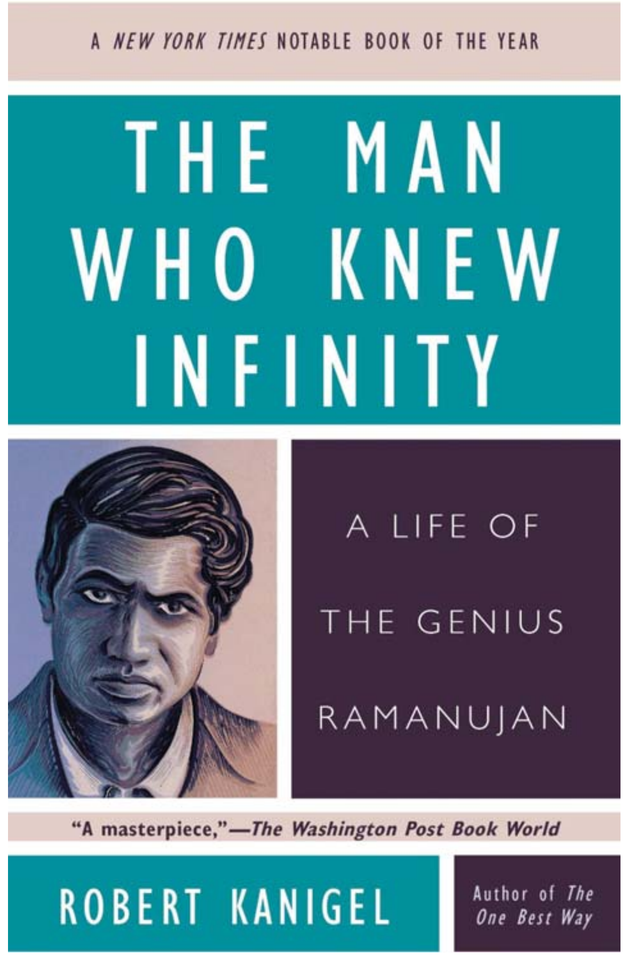


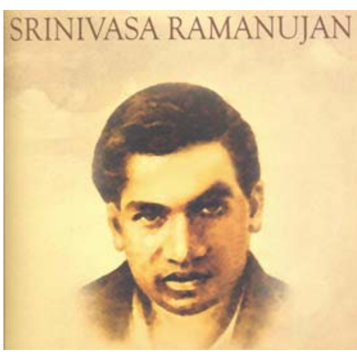
Fig. 1. (a) A signal which is a superposition of three periodic components with periods $4, 7$, and 13. (b) Fourier spectrum obtained from DFT, and (c) Periodicity spectrum obtained based on Ramanujan dictionary.

References

[1] G. E. Andrews and B. C. Berndt, , *Ramanujan's lost notebook,* Springer, N. Y., 2005.
[2] B. C. Berndt, , *Ramanujan's notebooks,* Springer-Verlag, Inc., N. Y., 1991.
[3] R. D. Carmichael, "Expansions of arithmetical functions in infinite series," Proc. of the London Mathematical Society, 1932.
[4] G. H. Hardy, P. V. Seshu Iyer, and B. M. Wilson, *Collected papers of Srinivasa Ramanujan,* Cambridge University Press, London, 1927.
[5] G. H. Hardy, *A mathematician's apology*, Cambridge University Press, Cambridge, 1940.

[6] G. H. Hardy and E. M. Wright *An introduction to the theory of numbers*, Oxford University Press, Inc., New York, 2008.
[7] R. Kanigel, *The man who knew infinity: A life of the genius Ramanujan*, Washington Square Press, Pocket Books, N. Y., 1991.
[8] J. Maddox, "Möbius and problems of inversion," Nature, vol. 344, no. 29, p. 377, March 1990.
[9] L. T. Mainardi, M. Bertinelli, and R. Sassi, "Analysis of T-wave alternans using the Ramanujan Transform," Computers in Cardiology, vol. 35 pp. 605-608, 2008.
[10] S.-C Pei and K.-W Chang, "Odd Ramanujan sums of complex roots of unity," IEEE Signal Processing Letters, vol. 14, pp. 20-23, Jan. 2007.
[11] M. Planat, "Ramanujan sums for signal processing of low frequency noise," IEEE Intl. Frequency Control Symposium and PDA exhibition, pp. 715–720, 2002.
[12] M. Planat, M. Minarovjech, and M. Saniga, "Ramanujan sums analysis of long-periodic sequenes and $1/f$ noise," EPL journal, vol. 85, pp. 40005: 1–5, 2009.
[13] S. Ramanujan, "On certain trigonometrical sums and their applications in the theory of numbers", Trans. of the Cambridge Philosophical Society, vol. XXII, no. 13, pp. 259-276, 1918.
[14] W. A. Sethares and T. W. Staley, "Periodicity transforms," IEEE Trans. on Signal Processing, vol. 47, pp. 2953–2964, Nov. 1999.
[15] L. Sugavaneswaran, S. Xie, K. Umapathy, and S. Krishnan, "Time-frequency analysis via Ramanujan sums," IEEE Signal Processing Letters, vol. 19, pp. 352-355, June 2012.
[16] S. Tenneti and P. P. Vaidyanathan, "Dictionary approaches for identifying periodicities in data," Proc. IEEE Asilomar Conf. on Signals, Systems, and Computers, Monterey, CA, Nov. 2014.
[17] P. P. Vaidyanathan, "Ramanujan sums in the context of signal processing: Part I: fundamentals," IEEE Trans. on Signal Proc., vol. 62, no. 16, pp. 4145–4157, Aug., 2014.
[18] P. P. Vaidyanathan, "Ramanujan sums in the context of signal processing: Part II: FIR representations and applications," IEEE Trans. on Signal Proc., vol. 62, no. 16, pp. 4158–4172, Aug., 2014.
[19] P. P. Vaidyanathan and Piya Pal, "The Farey dictionary for sparse representation of periodic signals," Proc. IEEE Int. Conf. on Acoust., Speech, and Sig. Proc., Florence, Italy, 2014.





Young Srinivasa

- Born in 1887
- Grew up in South India
- Recited Formulas for fun
- Had no formal education or training
- Received a scholarship to Kumbakonam Town High School

Dear Newsletter readers and promoters,

We would like to invite you to enrich APSIPA Newsletter by your expertise through submitting articles about your research or directions in research that could be interesting to the APSIPA members. We have been successful to introduce excellent articles in the previous issues of the newsletter that grasped the attention of many people. We would like to keep this momentum through your support. What we need is just one, two, or three full pages about your research. They could be abstracted from any of your published articles to steer the attention to your research.

Thanks for Your Support

APSIPA Newsletter EiC

RF Fingerprinting: Research Opportunities

Saeed Ur Rehman*, Kevin W. Sowerby$^{\tau}$, Shafiq Alam$^{\Upsilon}$
*Department of Computing, Unitec Institute of Technology, Auckland, New Zealand
$^{\tau}$Department of Electrical and Computer Engineering, The University of Auckland, New Zealand
$^{\Upsilon}$Department of Computer Science, The University of Auckland, New Zealand
Email: srehman@unitec.ac.nz, {kw.sowerby,sala038}@aucklanduni.ac.nz

***Abstract*—Radio Frequency (RF) fingerprinting aims to develop a unique identity for a wireless device that can be used in the same way a biological fingerprint operates, to improve the security and privacy of wireless communication. This is in contrast to the traditional bit-level algorithmic approaches to securing transmissions. In this letter, we introduce RF fingerprinting, and a comprehensive overview of research challenges and opportunities associated with its deployment in low-cost portable mobile devices.**

I. Introduction

Physical layer security is a new paradigm for securing the identity of wireless devices by extracting the unique features embedded in the electromagnetic waves emitted by transmitters, called RF fingerprinting. RF fingerprinting broadly refers to the process of identifying the source of a transmission based on features extracted from its RF signal. The features of a signal can be classified as:

a) Features specific to the channel, which describe the response of the wireless channel and its surrounding environment.
b) Features specific to the transmitter, which characterize the wireless transmitter through the unique radiometric features caused by the transmitter hardware.

RF fingerprinting based on features specific to a transmitter is also called radiometric identification [1]. Radiometric identification uses only features originating from the transmitter hardware and totally ignores features of the channel, such as channel response. However, the transmitted signal passes through a wireless channel, which might change some of its attributes. In this letter, RF fingerprinting refers to the process of identifying a specific transmitter from its received signal, and no differentiation is made between features specific to the channel and features specific to the transmitter.

Figure 1 is a generic rudimentary block diagram of a digital radio communications system, which shows the transformation of a baseband signal from its origin at the transmitter to its reception at the receiver. The grey-shaded components are typical sources of transmitter fingerprints. The imperfections include modulation errors at the modulator, phase noise at oscillators, spurious tones from mixers and Power Amplifiers (PA), non-linearity distortion at PAs, power ramp distortions (which are associated with the transients), and distortion of the equivalent filter in the path from the digital module to the antenna (including the analog Intermediate Frequency (IF) filters and RF filters). Although it may be possible to eliminate these hardware imperfections through more precise manufacturing and quality control, this would greatly increase the cost. In fact, most common technology standards, including IEEE 802.11, IEEE 802.15.4 and IEEE 802.22 , explicitly require various wireless devices to tolerate rather wide ranges of RF variations in received signals, in order to achieve seamless operation. Therefore, these transmitter-specific RF imperfections are likely to remain available for establishing the identity of a transmitter.

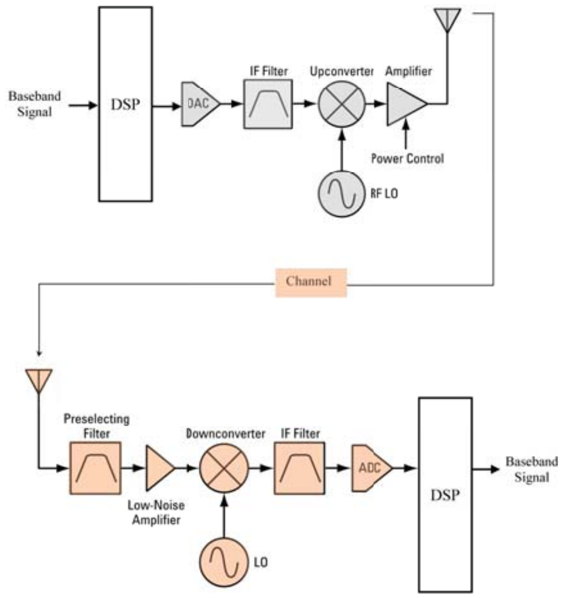


Figure 1. Radiometric block diagram showing different sources of impairments in overall digital communication system

The system-level diagram in Figure 1 displays the symmetry of the digital radio transmitter and receiver. To a degree, the receiver can be considered a reverse implementation of the transmitter. The front ends of commodity wireless receivers are built with inexpensive analog components, which have their own imperfections and, together with channel impairments, make it difficult to extract the unique features from the received signals. Furthermore, these imperfections vary between different receivers. Hence, despite the wealth of previous work, there is a demand for the practical deployment of RF fingerprinting using today's typical low-end receivers rather than performing experiments using high-end receivers in a laboratory environment.

A typical receiver consists of an analog front-end and a digital signal processing block . The analog front-end is generally non-ideal, which includes components such as a Low Noise Amplifier (LNA), an Oscillator, a Mixer, filters, capacitors, inductors and Analog to Digital Convertors. Additionally, the front-end is built on a Printed Circuit Board (PCB), where the components are mounted and connected via tracks [2]. Therefore, the design of the PCB and variations in its different parameters (e.g tracks width, layers, component placement) can introduce interference and distort the signal.

Distortion in most analog and RF circuit blocks arises either due to inherent randomness during the manufacturing phase [3, 4] or due to component non-linearities. Non-linearities cause unwanted effects including spectral regrowth and spreading, inter-symbol interference, and constellation warping [5]. The nonlinear properties change due to variation in temperature or device aging. For example, nonlinear phenomena that are often associated with LNA are the gain compression (or expansion) and the third order intermodulation product [6]. Mixers have non-ideal properties including self-mixing and in-phase/quadrature-phase (I/Q) imbalance. The nonlinear characteristics associated with oscillators include frequency offset and phase jitter. It is possible to compensate for frequency offset because it is slowly changing. The phase jitters have a strong effect in cases where the symbols are rather long, for example in OFDM systems.

Although many researchers have explored RF fingerprinting techniques, the feasibility of RF fingerprinting using today's typical portable mobile devices has not yet been successful. Researchers have not considered the limitations of the normal receiver which is built with low-cost components and has hardware imperfections embedded during the manufacturing phase. Our research work on a small number of devices has found that RF fingerprinting can be achieved with low-cost receivers for a specific transmitter-receiver pair, and that it is hard to reproduce an RF fingerprint from any other device that will deceive the RF fingerprinting system [7]. The dependency of RF fingerprinting on different parameters such as change in device temperature, components aging and wireless channel impairments are open research questions, which need to be addressed.

A. Open Research Challenges

Modeling the impairments of transceivers: Majority of the previous research into RF fingerprinting has experimentally evaluated the effect of impairments present in the front end of low-end devices. Our results reported in [7, 8] are based on the experimental testbed that consists of seven low-end transceivers, which were made of similar components. Performing experiments with a large number of receivers and transmitters would further validate our results. However, it is quite difficult to perform experiments on a large test bed owing to the cost of the equipment and the experimental time involved. Therefore, a novel theoretical framework is required, which should model the imperfections arising due to the modulator, oscillators, mixers and Power Amplifiers (PA), power ramp distortions, and distortion of the equivalent filter in the path from the digital module to the antenna and from various analog components in the transmission and reception chains. Developing a theoretical model of a transceiver, which could model the random impairments of different components at front end would be a major contribution. The theoretical model will enable the researchers to investigate the likelihood of two receivers forming the same fingerprint of a single transmitter in order to analyze the reliability and robustness of RF.

Effect of mobility and device aging: Majority of the RF fingerprinting experiments have deployed the transmitter and receiver at a fixed location during the measurements. Therefore, variations in channel characteristics were limited. Our preliminary simulation results show that channel impairments have limited effect on the performance of RF fingerprinting [9]. Measurements should be performed for a moveable transmitter and receiver, and data captured over many days to further investigate the effect of channel impairments. This would give an insight into any variation that can occur in an RF fingerprint over time.

Device aging would deteriorate the parameters of different RF components in front-end of transmitter and receiver. Furthermore variation in the temperature of the device and environment will also have some effects on an RF fingerprint. This would change the RF fingerprint of the transmitter over the time. To the best knowledge of the authors, there is no research article available to support this argument. Therefore, the effect of device aging and temperature variations is an open research issue and requires further investigation.

To compensate for changes in the RF fingerprint that could arise over time as transmitters' age, an unsupervised fast, reliable, and computationally less expensive incremental machine-learning algorithm should be developed. The unsupervised machine-learning algorithm should enable a wireless device to autonomously create an RF fingerprint and provide secrecy and privacy of the wireless device.

REFERENCES

[1] K. Ellis and N. Serinken, "Characteristics of radio transmitter fingerprints," *Radio Science*, vol. 36, no. 4, pp. 585–597, 2001.

[2] A. Kusiak and C. Kurasek, "Data mining of printed-circuit board defects," *Robotics and Automation, IEEE Transactions on*, vol. 17, no. 2, pp. 191–196, Apr 2001.

[3] F. Bulnes, R. Usamentiaga, D. Garcia, and J. Molleda, "An efficient method for defect detection during the manufacturing of web materials," *Journal of Intelligent Manufacturing*, pp. 1–15, 2014.

[4] S. Estreicher, T. Gibbons, M. Bebek *et al.*, "Phonons and defects in semiconductors and nanostructures: Phonon trapping, phonon scattering, and heat flow at heterojunctions," *Journal of Applied Physics*, vol. 115, no. 1, p. 012012, 2014.

[5] M. Kiviranta, A. Mammela, Y. Zhang, I. Moilanen, S. Boumard, T. Sarkkinen, and T. Jamsa, "Real-time simulation of impairments in the analog parts of the transmitter-receiver," in *Vehicular Technology Conference, 2005. VTC 2005-Spring. 2005 IEEE 61st*, vol. 2. IEEE, 2005, pp. 968–972.

[6] R. Baki, T. Tsang, and M. El-Gamal, "Distortion in rf cmos short-channel low-noise amplifiers," *Microwave Theory and Techniques, IEEE Transactions on*, vol. 54, no. 1, pp. 46–56, Jan 2006.

[7] S. U. Rehman, K. W. Sowerby, and C. Coghill, "Analysis of impersonation attacks on systems using rf fingerprinting and low-end receivers," *Journal of Computer and System Sciences*, vol. 80, no. 3, pp. 591–601, 2014.

[8] ——, "Radio-frequency fingerprinting for mitigating primary user emulation attack in low-end cognitive radios," *IET Communications*, vol. 8, no. 8, pp. 1274–1284, 2014.

[9] S. U. Rehman, K. W. Sowerby, S. Alam, and I. Ardekani, "Radio frequency fingerprinting and its challenges," in *Communications and Network Security (CNS), 2014 IEEE Conference on*. IEEE, 2014, pp. 496–497.

IEEE SPS-APSIPA Winter School on Machine Intelligence and Signal Processing, December 20-23, 2014

The past APSIPA President, Jay Kuo, and the President of IEEE Signal Processing Society (SPS), Alex Acero, discussed the possibility of building a partnership between APSIPA and the IEEE SPS in a breakfast meeting at ICASSP (Florence, Italy) in 2014 May. The idea was overwhelmingly welcomed and an initial draft of Memorandum of Understanding (MoU) was approved by the APSIPA Board of Governors in 2014 summer. Later on, this MoU was also approved by the Executive Committee of the IEEE SPS in 2014 September. Then, an official document was signed by both Presidents in 2014 October.

There are three main areas for partnership.

SPS will be the sole IEEE party to Technically Co-sponsor APSIPA's Annual Conference, APSIPA ASC. As a by-product of that co-sponsorship, APSIPA ASC proceedings should be eligible for inclusion in the IEEE Xplore® Digital Library. There may be fees to APSIPA for such hosting, and they may change during the duration of this agreement as IEEE policies change. Hence, the decision to include annual proceedings will be made each year by APSIPA. In any year, if APSIPA does decide to include APSIPA ASC papers in the IEEE Digital Library, it will only do so with SPS as its sole IEEE sponsor.

SPS hosts seasonal schools worldwide. Those held in the Asia-Pacific region may, if the organizers choose, have APSIPA as a 50-50 financial co-sponsor.

SPS maintains a list of Distinguished Lecturers. APSIPA may invite SPS Distinguished Lecturers to any of its events with the cost covered by APSIPA.

The first joint activity was the IEEE SPS-APSIPA Winter School on Machine Intelligence and Signal Processing that took place at New Delhi, India during December 20-23, 2014 The winter school was organized by the newly established Indraprastha Institute of Information Technology (IIIT), New Delhi and was attended by forty participants, majority of them coming from academia and some from industry as well. Prof. Mrityunjoy Chakraborty, member, BOG of APSIPA, was invited by the organizers to the winter school , who attended the event and delivered a lecture on APSIPA during

the inauguration. Since APSIPA membership from India so far is rather poor, Prof. Chakraborty made special efforts to reach out to the audience explaining the benefits of getting involved with APSIPA activities. The presentation by Prof. Chakraborty included a brief description of the genesis of APSIPA and its history of evolution, its current mission & vision, organizational structure etc, and followed it up by highlighting issues like membership including e.membership, APSIPA friend labs, ATSIP, APSIPA newsletter and APSIPA ASC. The participants were urged to join APSIPA as member/ e.member and in particular join the APSIPA friend labs. Benefits of publishing in ATSIP were explained in detail. The participants were also requested to submit papers to APSIPA ASC in future and attend the ASCs, with a view to hold the ASC in India in future. Many participants showed strong interests in APSIPA and it is thus hoped that in near future, participations in APSIPA activities from India may improve considerably. More information can be found on http://misp.iiitd.ac.in/

APSIPA Members Achievements

2014 UNSW Excellence in Senior Leadership Award

The Head of School of Electrical Engineering and Telecommunications, **Prof Eliathamby Ambikairajah,** has received **the 2014 UNSW Excellence in Senior Leadership award** from the Vice-Chancellor, in recognition of his tremendous leadership of the School over the last six years, and extensive contribution to the Faculty of Engineering and to the university.

Professor Ambikairajah took over as Head fo School in 2009 and has been instrumental in taking the School to new heights and setting a very strong trajectory. This is the first time this prestigous award has been given to an EE&T Head of School.

Congratulations to Professor Ambikairajah on this well-deserved award.

See more at:

http://www.engineering.unsw.edu.au/electrical-engineering/news/2014-unsw-excellence-in-senior-leadership-award

Head of School, Prof Eliathamby Ambikairajah (L) and Vice Chancellor, Prof Fred Hilmer (R)

7th APSIPA ASC 2015

ASIA-PACIFIC SIGNAL AND INFORMATION PROCESSING ASSOCIATION ANNUAL SUMMIT AND CONFERENCE 2015

DECEMBER 16-19, 2015
HONG KONG

apsipa2015.org

Honorary General Chair
Wan-Chi Siu, Hong Kong Polytechnic University

General Co-Chairs
Kenneth Lam, Hong Kong Polytechnic University
Oscar Au, Hong Kong Univ. of Science & Tech.
Helen Meng, Chinese University of Hong Kong

Technical Program Co-Chairs
Changchun Bao, Beijing Univ. of Technology
Akira Hirabayashi, Ritsumeikan University
Jiwu Huang, Shenzhen University
Gwo Giun Lee, National Cheng Kung University
Daniel Lun, Hong Kong Polytechnic University
Tomoaki Ohtsuki, Keio University
Tomasz M. Rutkowski, University of Tsukuba
Sumei Sun, I2R, A*STAR

Finance Chair
Chris Chan, Hong Kong Polytechnic University

Secretary
Bonnie Law, Hong Kong Polytechnic University

Forum Co-Chairs
Wai-Kuen Cham, Chinese Univ. of Hong Kong
Homer Chen, National Taiwan University
King N. Ngan, Chinese University of Hong Kong
Ming-Ting Sun, University of Washington

Panel Session Co-Chairs
Shing-Chow Chan, University of Hong Kong
Dominic K.C. Ho, University of Missouri
Yo-Sung Ho, Gwangju Inst. of Science & Tech.
Yoshikazu Miyanaga, Hokkaido University

Special Session Co-Chairs
Mrityunjoy Chakraborty, India Inst. of Technology
Yui-Lam Chan, Hong Kong Polytechnic University
Lap-Pui Chau, Nanyang Technological University
Hsueh-Ming Hang, National Chiao-Tung University
Hitoshi Kiya, Tokyo Metropolitan University

Tutorial Co-Chairs
Waleed Abdulla, University of Auckland
Woon-Seng Gan, Nanyang Technological Univ.
Wing-Kuen Ling, Guangdong Univ. of Tech.
Lee Tan, Chinese University of Hong Kong

Registration Co-Chairs
Man-Wai Mak, Hong Kong Polytechnic University
Lai-Man Po, City University of Hong Kong

Publication Chair
Zheru Chi, Hong Kong Polytechnic University

Publicity Co-Chairs
Kiyoharu Aizawa, University of Tokyo
Yui-Lam Chan, Hong Kong Polytechnic Univ.
Hing Cheung So, City University of Hong Kong
Mark Liao, IIS, Academia Sinica
Thomas Fang Zheng, Tsinghua University

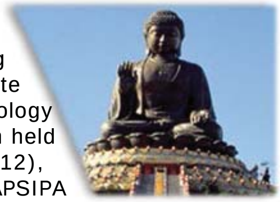
Local Arrangement Co-Chairs
Edward Cheung, Hong Kong Polytechnic Univ.
Frank Leung, Hong Kong Polytechnic University

Advisory Committee

Chairs:
Sadaoki Furui, Toyota Technological Institute at Chicago
Wen Gao, Peking University
C.-C. Jay Kuo, University of Southern California
Haizhou Li, Inst. for Infocomm Research, A*STAR
Ray Liu, University of Maryland

Members:
Thierry Blu, Chinese University of Hong Kong
Shih-Fu Chang, Columbia University
Liang-Gee Chen, National Taiwan University
Li Deng, Microsoft Research
Takeshi Ikenaga, Waseda University
Kebin Jia, Beijing Univ. of Technology
Anthony Kuh, University of Hawaii
Antonio Ortega, University of Southern California
Soo-Chang Pei, National Taiwan University
Susanto Rahardja, National Univ. of Singapore
Yodchanan Wongsawat, Mahidol University
Chung-Hsien Wu, National Cheng Kung Univ.

CALL FOR PAPERS



APSIPA ASC 2015 will be the seventh annual conference organized by the Asia-Pacific Signal and Information Processing Association (APSIPA). Founded in 2009, APSIPA aims to promote research and education in signal processing, information technology and communications. Annual conferences have previously been held in Japan (2009), Singapore (2010), China (2011), the USA (2012), Taiwan (2013), and Cambodia (2014). The field of interest of APSIPA concerns all aspects of signal and information including processing, recognition, classification, communications, networking, computing, system design, security, implementation, and technology with applications to scientific, engineering and social areas. **Accepted papers in regular sessions and special sessions will be published in APSIPA ASC 2015 proceedings which will be submitted for inclusion into IEEE Xplorer as well as other Abstracting and Indexing (A&I) databases.**

The technical program includes the following tracks, but are not limited to:

1. Biomedical Signal Processing and Systems (BioSiPS)
Biomedical Signal and Information: Theory and Methods, Medical Information and Telecare Systems, Neural Systems and Applications, Bio-inspired Signal Processing and System, Biomedical Circuits and Systems.

2. Signal Processing Systems: Design and Implementation (SPS)
Nanoelectronics and Gigascale Systems, VLSI Systems and Applications, Embedded Systems, 3D Video Processing and Coding, High Efficiency Video Coding.

3. Image, Video and Multimedia (IVM)
Image/Video Processing, Coding and Analysis, Image/Video Storage, Retrieval and Authentication, Computer Vision and Graphics, Multimedia Systems and Applications.

4. Speech, Language and Audio (SLA)
Audio Processing, Speech Information Processing: Recognition, Synthesis, Understanding and Translation, Natural Language Processing: Language Modeling, Natural Language Generation/Understanding, Machine Translation.

5. Signal and Information Processing Theory and Methods (SIPTM)
Modern Signal Processing Theory and Method, Detection and Parameter Estimation, Array Processing and Multi-channels, Signal and Information Processing in Applications.

6. Wireless Communications and Networking (WCN)
Information and Network Security, Wireless Communications and Networking, Standards and Emerging Technology, RF and Antennas.

PAPER SUBMISSION

Prospective authors are invited to submit either full papers, up to 10 pages in length, or short papers up to 4 pages in length, where full papers will be for the single-track oral presentation and short papers will be mostly for poster presentation.

IMPORTANT DATES

Submission of Proposals for Special Session, Forum, Panel & Tutorial Sessions:	May 8, 2015
Submission of Full and Short Papers:	June 8, 2015
Submission of Papers in Special Sessions:	June 8, 2015
Notification of Papers Acceptance:	September 1, 2015
Submission of Camera-Ready Papers:	October 1, 2015
Author Registration Deadline:	October 1, 2015
Tutorial Session Date:	December 16, 2015
Summit and Conference Dates:	December 17-19, 2015

Organizer/Sponsor: The Hong Kong Polytechnic University

Sponsor: Asia-Pacific Signal and Information Association (APSIPA)

Technical Co-Sponsor: IEEE Signal processing Society
IEEE Hong Kong Chapter of Signal Processing

Email: secretary@apsipa2015.org

APSIPA Who's Who

President: Haizhou Li, Institute for Infocomm Research, A*STAR, Singapore

President-Elect: Wan-Chi Siu, The Hong Kong Polytechnic University, Hong Kong

Past President: C.-C. Jay Kuo, University of Southern California, USA

VP - Conferences: Susanto Rahardja, National University of Singapore, Singapore

VP - Industrial Relations and Development: Haohong Wang, TCL Research America, USA

VP - Institutional Relations and Education Program:

Yo-Sung Ho, Gwangju Institute of Science and Technology, Korea

VP - Member Relations and Development: Kenneth Lam, The Hong Kong Polytechnic University, Hong Kong

VP - Publications: Tatsuya Kawahara, Kyoto University, Japan

VP - Technical Activities: Oscar C. Au, Hong Kong University of Science and technology, Hong Kong

Members-at-Large:

Waleed H. Abdulla, The University of Auckland, New Zealand

Kiyoharu Aizawa, The University of Tokyo, Japan

Mrityunjoy Chakraborty, Indian Institute of Technology, India

Kosin Chamnongthai, King Mongkut's University of Technology Thonburi, Thailand

Homer Chen, National Taiwan University, Taiwan

Woon-Seng Gan, Nanyang Technological University, Singapore

Wen Gao, Peking University, China

Hsueh-Ming Hang, National Chiao-Tung University, Taiwan

Anthony Kuh, University of Hawaii at Manoa, USA

K.J. Ray Liu, University of Maryland, USA

Tomoaki Ohtsuki, Keio University, Japan

Ming-Ting Sun, University of Washington, USA

Headquarters

Address:

Asia Pacific Signal and Information Processing Association,
Centre for Signal Processing,
Department of Electronic and Information Engineering,
The Hong Kong Polytechnic University,
Hung Hom, Kowloon, Hong Kong.

Officers:

Director: Wan-Chi Siu, email: enwcsiu@polyu.edu.hk
Manager: Kin-Man Lam, Kenneth,
email: enkmlam@polyu.edu.hk
Secretary: Ngai-Fong Law, Bonnie,
email: ennflaw@polyu.edu.hk
Treasurer: Yuk-Hee Chan, Chris,
email: enyhchan@polyu.edu.hk

Are you an APSIPA member?
If not, then register online at
http://www.apsipa.org