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Graduate Institute of Communication Engineering Newsletter

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In this issue

Technology Developed in GICE

Novel Evolutionary Algorithms for Fast Synthesis of Microwave and Millimeter Wave Integrated Circuits

from Electromagnetics Group

Optimization of matching networks is a necessary step to design a high performance microwave circuits. Unfortunately, the problem to synthesize an optimal matching network for a given circuit specification can be reduced to the NP-complete problems [1]. Therefore, enumeration is still the only way to ensure the global optimality so far. However, the design of microwave circuits usually has real-time constraints, and thus it is desired to have an algorithm to fast find a reasonable solution or possibly the global optimum instead of enumeration.

If the time for the design of matching networks can be reduced to only a few seconds, the work efficiency of design engineers can be enhanced significantly. Since the computing capability of modern computer is powerful and the parallel computations are well developed, it is worth putting more effort on computer-aid design (CAD) and electronic design automation (EDA). Therefore, a robust algorithm is presented in this article, which can fast and accurately synthesize the optimum matching network, which is not presented in the current commercial circuit-simulation software. With the help of the proposed algorithm, the time for the design of matching networks can be reduced to only a few seconds.

The matching network design can be reduced to the nonlinear least-square problem. The operating frequency is the independent variable, while the electric parameters of each circuit component are the adjustable variables, and the dependent variable is the frequency response of the network. Finding the nonlinear least-square error solution is equivalent to achieve the desirable frequency response. FIg.1 illustrates the flow of matching network synthesis. Given an sampling data of target frequency response of $\Gamma(f)$, the

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GICE Honors

Prof. Tzong-Lin Wu
The Outstanding Research Innovation Award of National Taiwan University

Prof. Homer H. Chen
IPPR Technical Innovation and Industrial Application Award

★ ***Hung-Chuan Chen***
2013 IEEE EMC Society President's Memorial Award
(Advisor: Professor Tzong-Lin Wu)

★ ***Dong-Chan Tsai***
IPPR Technical Innovation and Industrial Application Award
(Advisor: Professor Homer H. Chen)

★ ***Jui-Chih Kao***
EuMC Young Engineer Prize
(Advisor: Professor Huei Wang)

Message from the Director

Tzong-Lin Wu

Professor & GICE Director

Dear Colleagues and Friends,

Timing has entered the autumn, NTU campus along with the cool breeze and fallen leaves looks like a fantastic painting. The comfortable climate here may stimulate more research innovation and achievement from students and professors in GICE. One of successful events held In this quarter is "2013 brainstorming workshop on wireless 5G", which is organized by Prof. Char-Dir Chung and attracts more than 240 audiences with intensive interaction between industries and academia.

Hopefully, you enjoy the reading of GICE Newsletter.

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first step is to transform terminated impedance (Z_T) to the $\Gamma_{in}(f)$, followed by calculating the square error between transformed response and target response. The synthesis algorithm should find the nonlinear least-square solution under pre-defined constraints, such as the order of network (*N*), limits of transmission-line electrical lengths (*EL*) and characteristic impedances (Z_0).

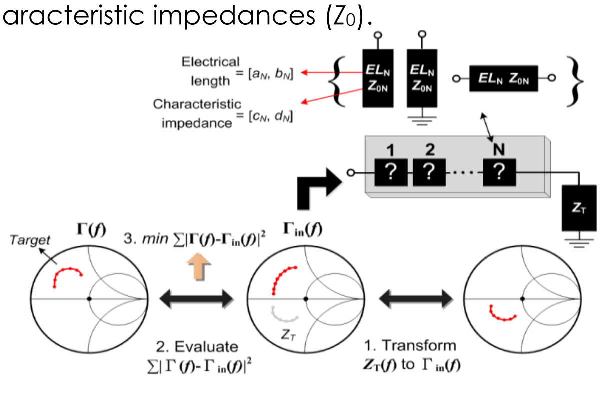

Fig. 1 Flow charts of matching network synthesis. Each unknown block (symbol '?') is one of the distributed components. The [ai, bi] and [ci, di] denote the range of EL and Z_0 which belong to component i respectively.

Our proposed algorithm for circuit synthesis is based on the real-coded expended compact genetic algorithm (rECGA) [2] and evolutionary strategy (ES) [3] with special niching method, which combines advantages of linkage learning from genetic algorithm (GA) and exploration ability from ES for robust global optimizations. The least-square solution of matching is transformed to the chromosome with the highest fitness. Fig. 2 illustrates the flow chart of the proposed algorithm. Due to the specific design of the proposed algorithm for matching network synthesis [4], the possibility of immature convergence is reduced and the optimum matching network can be found rapidly. Besides, the proposed algorithm can simultaneously find many sub-optimal circuits with different topology, which makes the design flexible in choosing the desired circuit architecture.

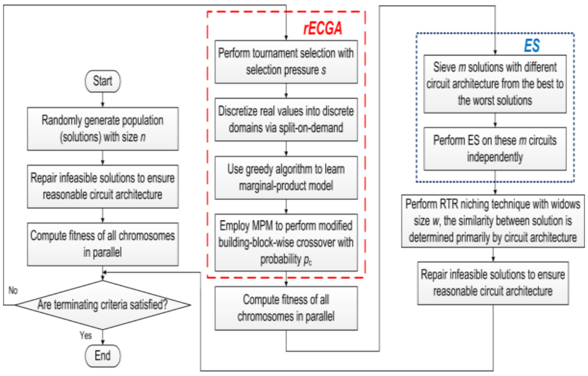

Fig. 2 Flow chart of the proposed circuit synthesis algorithm. The procedures of rECGA and ES are the cores of this algorithm. In a simple word, rECGA takes charge of global search of solutions and ES is responsible for fast local search.

In order to validate the proposed algorithm, several experiments have been performed and analyzed. Without loss of generality, one of the experiments is performing conjugate matching syntheses on two commercial packaged transistors; they are NE-42484 and ATF-58143 respectively [5]. Fig. 3 illustrates the synthesis problem of NE-42484, and the specification for ATF-58143 is the same.

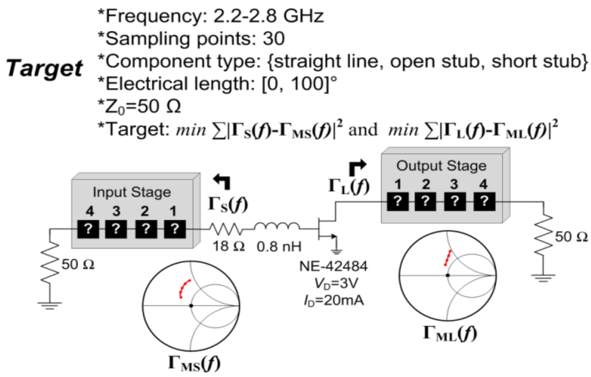

Fig. 3 The example for performance measurement of our proposed algorithm. The synthesis target is to employ 4th-order network to synthesize broadband simultaneous-conjugate-matching from 2.2 to 2.8 GHz. The gate of the transistor is connected with small resistor to ensure the existence of simultaneous-conjugate-matching condition, and the effective series inductance (ESL) is also considered.

We employ our proposed algorithm and the latest published work in microwave [6] (asymptotically equal to simple GA) to synthesize these optimal matching networks and perform statistic for comparison. The criterion of finding the optimal

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solution is that the final population contains at least one solution, in which circuit architecture is the same as the optimal solution and fitness is larger than 95 % that in optimal circuit. Fig. 4 shows the frequency response of $\Gamma_{MS}(f)$ and $\Gamma_{ML}(f)$ of stabilized NE-42484 in the Smith chart, and the correspondent optimal circuits and responses validated by enumeration are also illustrated.

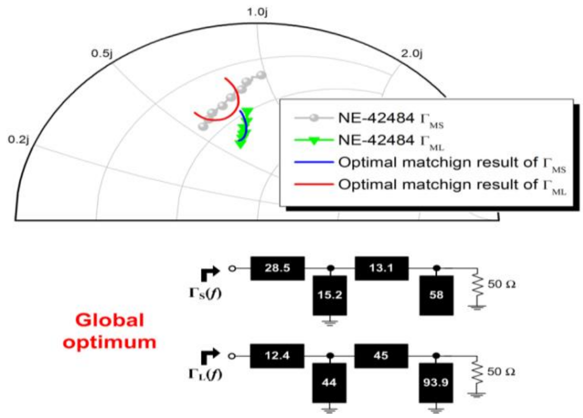


Fig. 4 The curves of $\Gamma_{MS}(f)$ and $\Gamma_{ML}(f)$ of stabilized NE-42484 transistor, and the correspondent frequency response (solid line without symbol) and circuit topology of optimal matching network are also illustrated.

Fig. 5 shows the optimal matching result with ideal passive components, and the in-band region is highlighted in the figure. The matched small signal gain almost fit to the maximum available gain (MAG) of the stabilized device due to optimized matching.

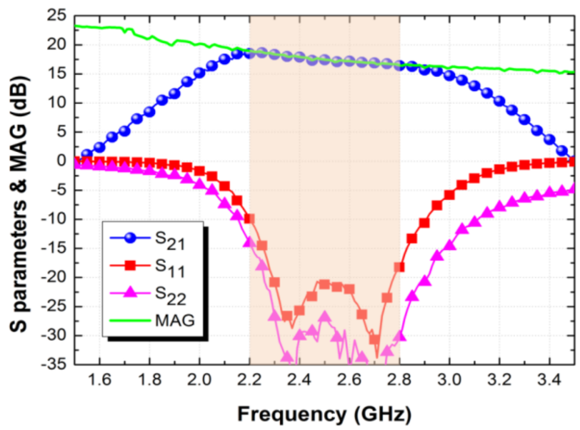
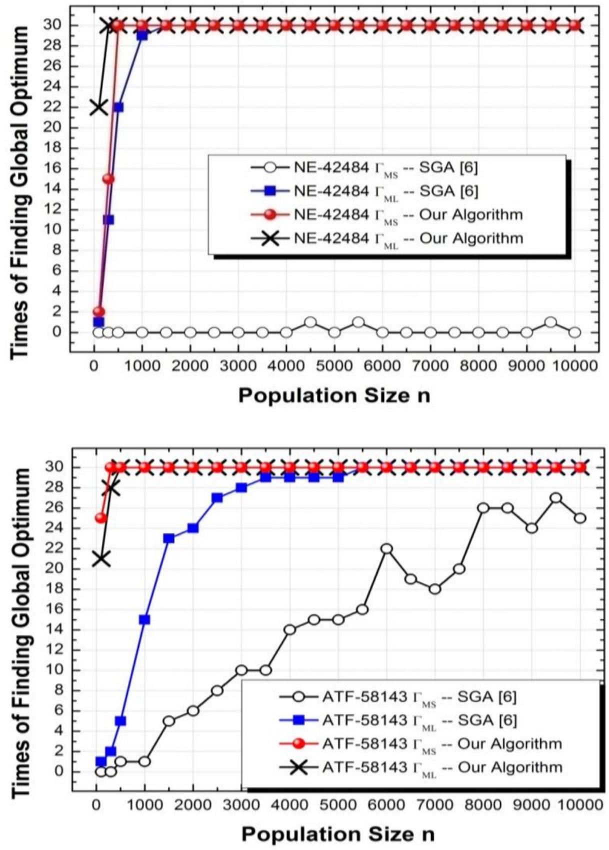


Fig. 5 The S-parameters of matched NE-42484, which is matched with global optima of $\Gamma_{MS}(f)$ and $\Gamma_{ML}(f)$. It is obvious that the $|S_{21}|$dB is almost the same of MAG in 2.2-2.8 GHz (highlight) due to optimized matching.

Fig. 6 shows the statistic results of conjugate matching synthesis of NE-42484 and ATF-58143. Each experiment executes 30 independent runs. The x-axis represents population size n from 100 to 10000 (n = 100, 300, 500, 1000, ⋯, 9500, 10000) with totally 100n function evaluations, and the y-axis denotes times of finding the global optimum for conjugate matching. It can be observed that the proposed algorithm outperforms previously published work, since our algorithm can fast and accurately find global optimum with a few computation efforts. The program executing time of our algorithm is 20 seconds with n = 500, function evaluations 100n and using a 2.13 GHz processor; it can be reduced further more by adopting parallel computation. Therefore, the proposed algorithm indeed can fast synthesize the optimal matching.



(a)

(b)

Fig. 6 (a) The times of finding global optimum in matching $\Gamma_{MS}(f)$ and $\Gamma_{ML}(f)$ of transistor NE-42484. (b) Statistic for transistor ATF-58143. The function evaluations of algorithms are 100n. Since the [6] is not robust algorithm, which usually takeover by other local optima; while our algorithm can find global optimum with 100% statistic probability when n is larger than 500.

An integral circuit fabricated in 0.1-μm GaAs pHEMT process with 2-mil substrate is designed and implemented for demonstration. This circuit synthesized by our algorithm is a full-Ka band (26-40 GHz) medium power amplifier. The matching network designs of amplifier can be decomposed into three parts as shown in Fig. 7 and it can be solved sequentially from the output stage to the input. The correspondent synthesized results are also shown in the figure. The first step is to synthesize the output network such as broadband load-pull matching; followed by transforming the input impedance of second stage to the output impedance of driver-stage like $\Gamma_{ML}(f)$ or load-pull response; finally, transform input impedance of driver-stage to the system impedance 50 Ω. Since

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the coupling effect should be taken into account, several physical parameters are slightly adjusted with the help of commercial full-wave EM software (Sonnet). The chip photograph is shown in Fig. 8 with a compact chip size of 1×1.5 mm².

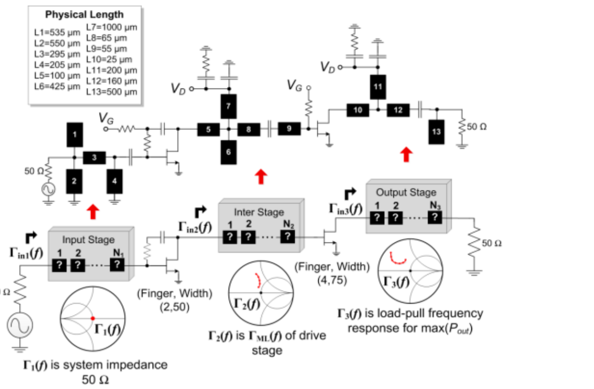


Fig. 7 The decomposition of synthesis 2-stage single-ended medium power amplifier. It can be solved sequentially from output stage to circuit input. The RC feedback is inserted in driver-stage is used to improve the input return loss, and both driver and output stage are treated as black-box in optimization.

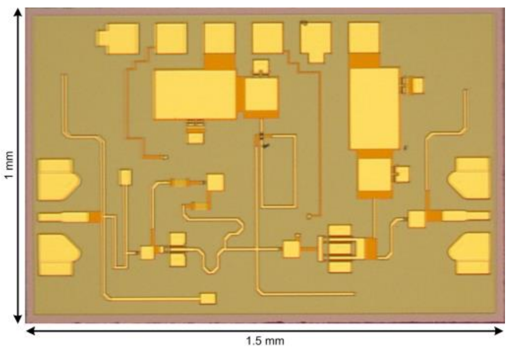
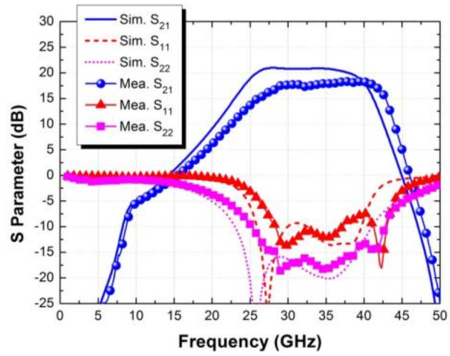
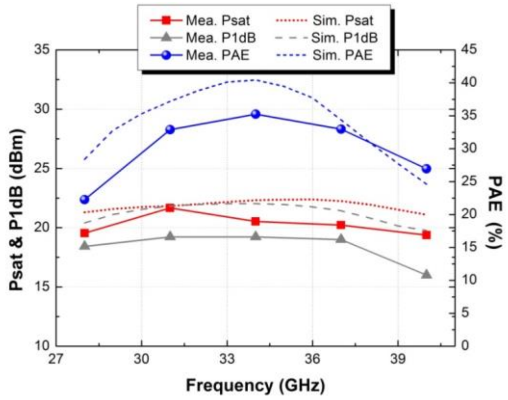


Fig. 8 Chip photograph with a compact chip size 1×1.5 mm2.

Due to the synthesized matching network, the circuit performs the good broadband responses. Fig. 9 shows the *S*-parameters of simulation and measurement results and the large signal results, the gain, return loss, output power and efficiency are desirable. The measured output power P_{sat}(@peak PAE) is 19-22 dBm with 22-35% higher peak PAE. This experiment illustrates a simple design methodology of medium power amplifier under real-time constraint by circuit synthesis algorithm, and this synthesis can be extended to the architecture with transistors combining for a higher output power.



(a)



(b)

Fig. 9 (a) Measurement and simulation results of S-parameter from 1 GHz to 50 GHz. Both the in-band gain and return loss are desirable due to good synthesized matching. (b) Frequency response of large signal. The P_{sat} is 22 dBm with 33% peak PAE at 31 GHz.

This article has presented a novel circuit synthesis algorithm combining advantage of rECGA and ES with special niching method. In order to validate the proposed algorithm, several experiments have been conducted, and the statistic results show that our algorithm outperforms the previously published work. A broadband MMIC amplifier is also implemented to demonstrate the proposed algorithm. Our algorithm indeed can synthesize desired matching network for circuit designs rapidly and accurately.

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Technology

Music Information Retrieval with the Acoustic Emotion Gaussians Model

from Communication and Signal Processing Group

Music Information Retrieval (MIR) is a multidisciplinary research field of developing automatic information system that is able to understand and perceive music pieces. This technology has emerged in recent years as a promising content-centric solution to manage the ever increasing amount of music information available digitally. As the most appealing function of music lies in its power to convey emotions and to evoke them in listeners, modeling the association between music and emotion for music emotion recognition (MER) has long been considered as the core technology to facilitate music organization, indexing, and retrieval.

MER is challenging because emotion perception is subjective. There is typically no single, deterministic ground truth for a song, and we instead have to learn emotions from multiple listeners. This subjectivity issue suggests the need to personalize an emotion-based MIR system.

Another issue of MER is the conceptualization of emotion. The categorical approach to MER that describes emotion as discrete tags involves the non-trivial selection of the number and the type of emotion terms being used for the system, which is not an easy decision considering the usability of the system and the predictability of the tags. To avoid this issue, the valence-activation (VA) model [1], which corresponds to the two most important emotion factors proposed by psychologists, has been widely adopted in MIR. This dimensional approach to emotion conceptualization provides straightforward visualization means for music browsing, retrieval, and variation tracking. Mr. Emo (Figure 1) [2], which was developed by students from our institute, demonstrates a pioneer VA-oriented music search interface.

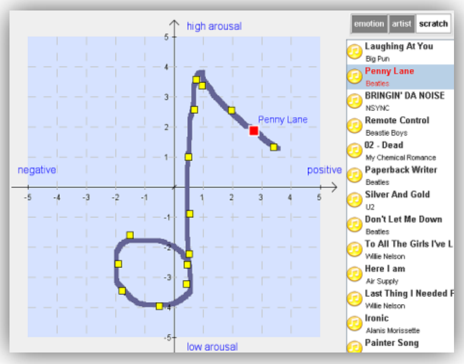

Fig. 1. Screenshot of the Mr. Emo music search system. The horizontal axis represents valence (positive or negative affective states), whereas the vertical axis represents arousal (or activation; energy and stimulation level).(Source:[2])

Early MER systems [2] assumed that the perceived regression-based methods to model between VA space and musical features (represented by a vector). Recent years have witnessed a growing number of attempts that models a song's emotion by a probabilistic distribution in the VA space to better account for the subjective nature of emotion perception [3], [4]. From Figure 2, we can observe that the overall emotion for a clip can be described by a 2-D Gaussian distribution (depicted by a red cross and blue ellipse). Even though some efforts have been made in the literature to model the Gaussian parameters using regression algorithms, few attempts if any have been made to develop a principled probabilistic approach.

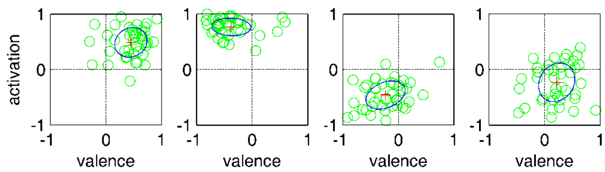

Fig. 2. Subjects' annotations on four music clips, where each green circle corresponds to an annotation given by a subject for a song. Each block contains the annotations given by 40 subjects for a specific music clip.

In this article, we introduce the *acoustic emotion Gaussians* (AEG) model [5] that involves the generative process of VA emotion distributions from audio signals, as Figure 3 shows. Suppose there are K acoustic descriptors $\{A_k\}_{k=1}^{K}$ that describes diverse kinds of acoustic features, e.g., timbre, tempo, and tonality, and each A_k can generate a relevance score based on the acoustic features of a music clip. Then, we assume that each A_k can be associated with a bivariate Gaussian G_k in the VA space, and $\{G_k\}_{k=1}^{K}$ forms a *VA Gaussian mixture model* (GMM). The weight for each G_k, denoted as θ_k, is governed by the *acoustic posterior probability* of a clip over each A_k. Accordingly, given a set of training annotations and their corresponding clips in the form of $\{\theta_k\}_{k=1}^{K}$, we can learn the mean and covariance of each Gaussian component using the EM algorithm. This is a procedure similar to the conventional GMM learning one, except that the prior weights are fixed in our case. Please refer to [5] for details.

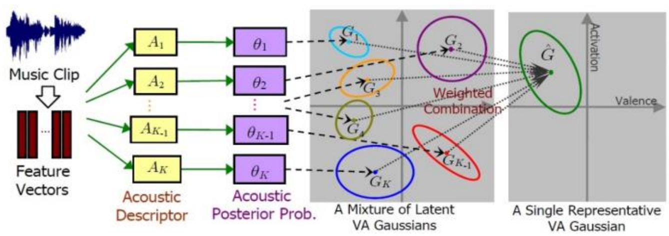

Fig. 3. Illustration of the generative process of AEG.

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AEG-based MER follows the flow depicted in Figure 3. Based on $\{\theta_k\}_{k=1}^{K}$ of a test clip, we obtain the weighted VA GMM, $\sum_k \theta_k G_k$, which is able to generate various VA GMMs. For example, if a clip's acoustic features can be completely described by a single $A_{k'}$, where $\theta_{k'} = 1$ and $\theta_k = 0, \forall k \neq k'$, its emotion distribution would exactly follow $G_{k'}$. One can combine $\sum_k \theta_k G_k$ into a single VA Gaussian for simplicity, as shown in the rightmost of Figure 3.

By interconnecting the acoustic descriptors and VA GMM, we can map a clip into the VA space as well as a VA point back to the acoustic posterior probability, leading to two methods [5] (termed Prediction and Fold-in, respectively) for an emotion-based music retrieval system outlined in Figure 4. Moreover, AEG has the following additional strengths:

- Sound statistical foundation.
- Transparency and interpretability of model learning and semantic mapping.
- Low complexity involved in the computation of MER.
- Flexibility to personalize a background VA GMM with personal annotations via the maximum a posteriori (MAP) method [6].

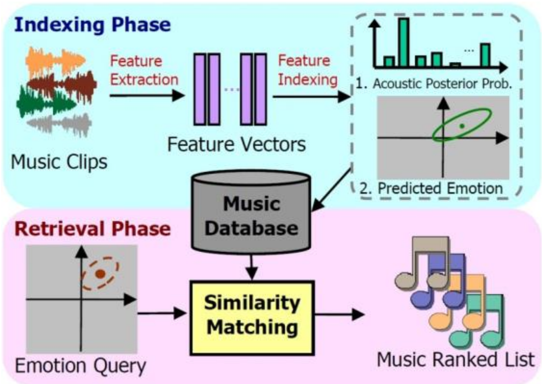

Fig. 4. Diagram of the emotion-based music retrieval system.

In what follows, we illustrate the learning process of AEG and present its performance of MER using the MER60 dataset [6], which contains 60 30-second music clips. Each of the 60 clips has been annotated by 40 subjects for valence and activation values. We use several well-known frame-based acoustic features, which can be extracted by MIRToolbox [7], and simply train a frame-level acoustic GMM to represent the set of acoustic descriptors.

Figure 5 presents the VA GMMs learned with $K = 32$ at different iterations of EM. We observe that the VA Gaussians gradually separate from one another as the learning progresses, and each ellipse gets increasingly smaller until convergence. In the end, the Gaussians cover different areas in the VA space, making it possible to approximate all kinds of VA distributions with different acoustic posterior weights. Regarding the evaluation of MER, we perform leave-one-out train-test experiments. Our result indicates that AEG can outperform support vector regression (SVR) in terms of KL-divergence between the predicted VA Gaussian and the ground truth one (1.193 vs. 2.052, the smaller the better).

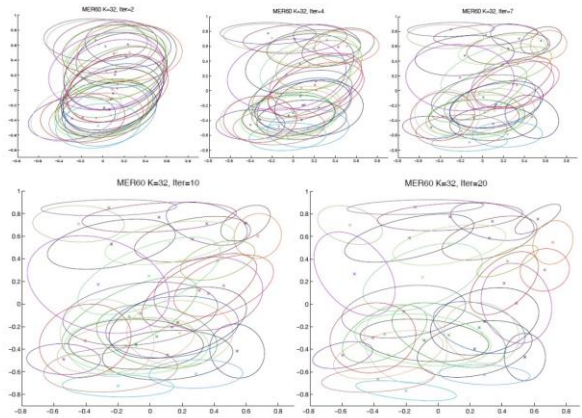

Fig. 5. The learned VA GMMs.

To conclude this article, we argue that AEG not only stands out as a principled probabilistic framework for music emotion research, but also unifies the computation processes for MER and emotion-based music retrieval. The experimental result demonstrates that AEG can effectively model the subjectivity nature of emotion perception. As AEG is a generic framework, we believe it can be easily extended to other multimedia data such as image and video as well.

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The Graduate Institute of Communication Engineering of National Taiwan University

Communications technology is a rapidly growing field changing the face of society everywhere in the world. High-quality information and communication systems are becoming prime requirements for economic success as well as the foundation for further social development. As being the top school in Taiwan, The Graduate Institute of Communication Engineering (GICE) of National Taiwan University has been a unique department which is well known for the best practice and new developments in the teaching of electromagnetics and communication and signal processing.

GICE comprises the "Electromagnetics Group" and the "Communication and Signal Processing Group," both providing the MSc and PhD degree. Through the intensely training in research activities, we prepare our future educators, researchers and engineers with fundamental knowledge, creativity, and problem solving skills to face the future challenges.

At GICE, we believe that the successful professional is one who sees connections between theories and practical applications. We offer not only advanced and up-to-date training but also close collaboration with international and Taiwanese industry. It fosters students' insights into current trends and provides ample opportunities of practical experiences.

We have 15 IEEE fellows among 44 faculty members, leading other institutions in Asia and also being comparable with top universities in the world. Many GICE members have long-term research collaboration with worldwide-topcompanies such as IBM, Intel, Acer, ASUS, HTC, Garmin, Mediatek, and TSMC. GICE students have abundant job opportunities and play critical roles in the Taiwanese ICT industry.

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Activities

2013 Second Brainstorm Workshop on Wireless 5G

The 2013 Second Brainstorm Workshop on Wireless 5G was organized and chaired by Prof. Char-Dir Chung (Graduate Institute of Communication Engineering, National Taiwan University), and held at the Barry Lam Hall of the College of EECS, National Taiwan University, Taipei, Taiwan, ROC, on Saturday, September 28 (Teachers' Day), 2013. The workshop was composed of five panels, one distinguished lunch speech, and one wrap-up session. There were thirty panelists and one distinguished speaker addressing the most recent directions and development on Wireless 5G, as well as the potential technologies on multiple-access transmission, network architecture, and cross-layer structure which may be candidates for wireless 5G standardization. The group of panelists and distinguished speakers consisted of academic and industrial experts from Taiwan (16 persons), mainland China (11 persons), Hong Kong (2 persons), Singapore (1 person), and United States (1 person). The panelists and the distinguished speakers are affiliated with the top-grade organizations, including National Taiwan University, National Tsing-Hua University, National Chiao-Tung University, National Sun-Yat-San University, Peking University, Tsing-Hua University at Beijing, Southeast University, University of Electronic Science and Technology of China at Chengdu, Xidian University, Beijing University of Posts and Telecommunications, Huazhong University of Science and Technology, Hong Kong University of Science and Technology, Hong Kong Polytechnic University, Singapore University of Technology and Design, Industrial Technology Research Institute, Institute for Information Industry, China Mobile, DaTang, and China Telecom. Besides, more than 240 local audiences from academy, research institutes, industry, and government joined the workshop. The Workshop provided an opportunity for these local audiences to meet and interact on various subjects in the development, direction and potential technological trends on wireless 5G. In the emerging era of wireless 5G, this workshop created a successful academic platform for the in-depth exploration on wireless 5G technologies, and thereby placed a footprint on the global 5G development roadmap.

Panel Discussion

Activities

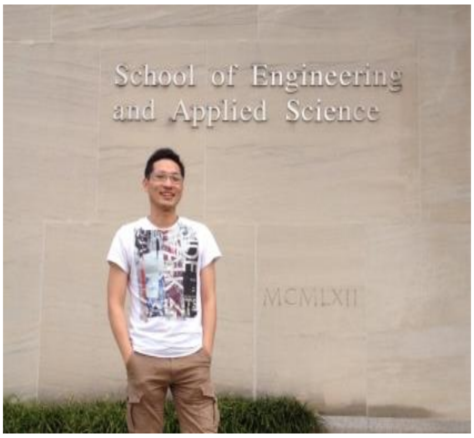
2013 EM Education Initiaitive: Summer Program

This summer program is participated mainly by juniors, seniors and graduate students majoring in Electrical Engineering. This quarterly event is held together by Taiwan Electromagnetic Industry-Academia Consortium (TEMIAC), IEEE Microwave Theory and Techniques Society Taipei Chapter and Ting-Shiun Telecommunication Development and Education Foundation. Experts from industries and academia are invited and there are approximately one hundred people to attend this summer program. The main issue discussed in this program is about the various applications in electromagnetism, the basic theory of transmission lines, Smith chart's theory, instruments and measurement methods, electromagnetic simulation, RF system modern antenna design, wireless broadband technology and industry trends, monolithic microwave / millimeter wave integrated circuits and related applications profile, high-speed circuit EMC and signal integrity design, microwave filters and passive circuit, and so on. This summer program aims to enhance the basic electromagnetic education in our country. From sharing the state of art, we hope to cultivate excellent talent by this summer program.

Corner of Student News

by Tzu-Yu Chuang

Every moment in Princeton is a splendid journey across my life. Dipping in the community where Einstein, Shannon, Feynman had spent their life, it is not hard to be charmed by the unsophisticated atmosphere here, with a campus full of Collegiate Gothic architectures. People studying in Princeton are like wizards in Hogwarts, while they build up the world with most advanced sciences and delicate research.



I am working as a Visiting Student Research Collaborator with Professor H. Vincent Poor and Professor Mung Chiang in Princeton University. Our joint work is focusing on the statistical data processing on social complex networks. Most of my time, I work as a graduate student as others in the campus, like taking courses in the Friend Center, having meals in the Dining Hall, exercising in the Dillon Gym, and, even hanging out at bars. However, involving in the community of Princeton University offers me great opportunities to cooperate with topmost researchers. There are seminars and grouping meetings of profound subjects hold every week, and, occasionally, an inviting talk delivered by guest scholars from every corner of the world. The research step in Princeton is tense but the life is really fulfilling.

If I am going to say something special about my like in Princeton, I would like to mention two activities I involved this summer. I joined the badminton tournament of schools in Ivy League hold in Columbia University, which is an exciting experience to fight for Princeton to against other schools. Besides, I also planned a trip to learn riding superbikes in New Jersey Motorsports Park. It was really an amazing class not only because it is a class of how to ride superbike fast on the track but also a class of right concept and attitude of how to operate and control the superbike properly. The life in Princeton teaches me a very important thing: it is me to choose colors of my life. For me, they are badminton and superbike, besides the research. I spent most of my leisure time on them, and that is what I expected what my life would be. Even though it is kind of homesick sometimes, but, life will not be lonely. I am really happy to have a page in Princeton in my pursuing of PhD degree.

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