行政院國家科學委員會專題研究計畫成果報告

下一代彩色影像壓縮技術之設計與研發

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主持人：蔡銘箴　　國立交通大學資訊管理研究所
電子信箱: mjtsai@cc.nctu.edu.tw

一、中文摘要

網際網路的蓬勃發展已使得資料的傳輸，從單純的文字檔案擴展到影像，聲音甚至動畫等的多媒體檔案，基於經濟及實用性的考量，為了在有限的頻寬下能同時容納更多使用者傳遞的訊息，適當的資料壓縮是必須的。在其他應用科學領域中，醫學影像、無線通訊、遙測、及地質學資料等都有對影像資料壓縮技術的需求，以便利其重要資料的處理。在實際網路傳遞的及時資料中，影像資料佔據了相當可觀的頻寬，如何有效地減少其所需的頻寬，並且保持影像的品質，對許多學術領域而言，是一個相當值得研究的課題。

關鍵詞： 彩色影像壓縮， 小波轉換， 數位餘弦轉換， 量化， 編碼，網際網路

Abstract

The fast development and utilization of the Internet has extended the pure text data communication into the multimedia era (image, audio, and even video data). Due to the consideration of economy and efficiency, proper data compression is necessary in order to allow more users' messages within limited bandwidth. The same demand of compression algorithms are also needed in the data processing of medical imagery, wireless communication, remote sensing, seismic images ...etc. Among the real time information, image data occupy a conceivable amount of bandwidth. How to effectively reduce the required bandwidth and maintain the fidelity of the image quality is a very important research topic for wide scientific applications.

Keywords: color image compression, wavelet transform, discrete cosine transform, quantization, entropy coding, Internet。

二、緣由與目的

緣由－資料壓縮，基本上可分為兩大類型，一是Lossless無失真的壓縮[1]，另一則是Lossy失真的壓縮。對一般的使用者而言， Lossless的壓縮適用於文字資料的處理或重要資料的保存，原因是這些被壓縮的資訊必須能夠具有被還原(reversable)的特性，以備日後存取之用，是故，不容有稍許的誤差，造成驗證的困擾。然而，對於影像處理而言，Lossless的壓縮方式，經過不斷的試驗及分析，對許多natural image的影像而言，最多只能達到2~3:1的理論壓縮比，對於平常傳輸的頻寬限制，往往需要壓縮的能力，高於此一比值，譬如10:1或100:1，因此，另一種型態的壓縮-Lossy失真的壓縮方式，便應運而生，以期能提高壓縮比，而又能維持低失真率（容許處理過的影像，與原始的

影像，有稍許的不同，基於人體視覺系統的研究，人類視覺的觀察力，能夠容忍許些微的差距，這樣的需求，是可以滿足的）。因此，Lossy 失真壓縮的應用，符合使用者的需求，對舒解網路頻寬的限制及其他類似的應用要求，有莫大的助益。

現今最被使用的影像壓縮技術，是以 Discrete Cosine Transform（DCT）為主的 JPEG 國際標準（Joint Photographic Experts Group）[2]。JPEG 的處理方式是把整張影像分割成以 block（8x8）方塊為主的壓縮方式，這樣的處理架構，對於軟體或硬體應用，有增加處理效能的優點。然而，它最主要的缺點是在高壓縮比時，被還原的影像，嚴重的失真，顯而易見的 block artifact 最為人所詬病。若以低頻寬傳輸為需求的無線通訊為例，JPEG 的處理方式常造成模糊的方塊圖像，影像的內容往往無法辨認。除此之外，醫學影像（medical imaging）[3] 對高畫質、低失真度的處理，最為要求，Remote Sensing 遙測，Seismic 地質學影像也都亟需影像壓縮的技術，以利資料的傳輸及儲存。所以新一代的影像傳輸標準的制訂，以滿足眾多行業的需求，是目前國際間學術界和工業界相當努力的課題。

查諸文獻，以 Wavelet Transform（小波轉換）[4,5,6,7] 為主體的影像壓縮方式是目前最被看好的下一代影像壓縮技術的主流。它的優點是以整張影像來做處理，從而去除了 block artifact 產生的機會，而它類似 filter bank 的結構，使得它基頻的係數，在低頻寬傳輸時，可以有效地描述影像中的物體，使得它的效能遠勝過其他方法。而它的另一特性是可以提供以 content based data structure [8,9,10,11,12] 以利編碼技術的安排，以簡潔的資料結構，表達所需傳送的資訊，使以最少的頻寬需求，保持有效的最高畫面品質。

所以，以 JPEG 為主的影像壓縮標準，已經逐漸不能滿足現今頻寬與影像品質的要求，對低複雜度，高壓縮比，高畫質的的壓縮技術，以供下一代彩色影像壓縮標準的參考，是目前迫切需要的。

目的－ 本計畫的研究目標，著重於彩色影像壓縮技術的探討與發展，我們提出由小波轉換(wavelet transform)為架構的彩色影像壓縮的原理。由於 Wavelet Transform 對整張影像作處理，並不分割至小塊(block)，所以不會產生 block artifacts 的瑕疵。在低頻寬傳輸時，wavelet 基頻的係數，可以有效地描述影像中的物體，使得它的效能遠勝過其他方法。系統化的研究步驟包括了分析 wavelet filter [13] 的 transform 轉換特性，色層 color channel 的相互關係 intercorrelation，運用 intersubband 或是 intrasubband 係數作模型參數的轉換[14]，entropy 編碼[15]的效率分析。一些常用的影像也被選擇列入可供廣泛參考的影像資料庫，並在低頻寬傳輸時當作試驗的樣本；同時，奠基於 human visual system 人體視覺系統的 visual test 也作了進一步的視覺比較。同時，我們亦密切注意國際標準組織對影像壓縮標準制定的發展[16]，使此一研究，有相當具體的成果，並提供在相關領域中尋找具發展潛力研究題材的機會。

三、結果與討論

本研究計劃已獲得相當豐富的研究成果，累積至今，已有兩篇國際會議論文的發表。第一篇是發表於 1998 年三月二十九日至四月一日於美國鹽湖城雪鳥市，由 IEEE 所主辦的 Data Compression Conference（DCC98），論文題目為"Color Image Compression by STACK-RUN-END

Coding"，論文內容請見附件一。

第二篇則是發表於 1998 年五月十五日至十八日 International Conference of Acoustic，Speech，and Signal Processing (ICASSP98)在美國華盛頓州的西雅圖市，同樣也是由 IEEE 所主辦，論文題目為"STACK-RUN-END Compression for Low Bit Rate Color Image Communication"，論文內容請見附件二。本次論文發表，獲得國科會的機票及大會註冊費的補助，論文發表心得報告請見附件三。

四、計劃成果自評

本研究計劃研究成果，獲得國際學術界的肯定，且成果相當豐碩及充實；預期在相關領域及關鍵科技上，可以有效地應用，對提昇我國產業及科技水準有相當大的貢獻。

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附件 一:

Color Image Compression by STACK-RUN-END Coding *

Min-Jen Tsai
National Chiao Tung University
Institute of Information Management
1001 Ta-Hsueh Road, Hsin-Chu, 300, Taiwan, R.O.C.
E-mail: mjtsai@cc.nctu.edu.tw

ABSTRACT

We present a new wavelet based image coding algorithm for color image compression in this paper. The key renovation of this algorithm is based on a new context oriented information conversion for data compression. A small number of symbol set was then designed to convert the information from the wavelet transform domain into a compact data structure for each subband. Unlike zerotree coding or its variations which utilize the intersubband relationship into its own data representation where hierarchical or parents-children dependency is performed, our work is a low complexity intrasubband based coding method which only addresses the information within the subband or combines the information across the subbands.

The scheme works first by color space conversion, followed by uniform scalar quantization. A concise data structure which categorizes the quantized coefficients into (stack, run, end) data format is performed, where raster scanning order for individual subband is the most often used sequence but predefined scanning order will also work. This algorithm uses a small symbol set to convert these three different type data into a compact bit stream. Two different context lists in each subband are specified from the symbol stream and alternatively compressed by adaptive arithmetic coder with high efficiency. The bit stream maintained the progressive transmission property since it is organized at the subband order.

Compared with the standard Stack-Run Coding [1], our method generalized the symbol representation and the extension of the symbol alphabets . The termination symbols which carry the zero value information towards the end of the subband or across the subbands till the end of the image help to speed up the decoding processes. Our experiment results shows that our approach is very competitive to the refinement of zerotree type schemes. Compared with the zerotree refined schemes [2] by the thorough tests through a huge number of testing color images, this algorithm results in competitive PSNR values and perceptually high quality images at the same compression ratio for color image compression. From perceptual viewing test, high detail fidelity maintenance of the color image is achieved by our techniques.

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附件 二：

STACK-RUN-END COMPRESSION FOR LOW BIT RATE COLOR IMAGE COMMUNICATION *

Min-Jen Tsai

National Chiao Tung University
Institute of Information Management
1001 Ta-Hsueh Road, Hsin-Chu, 300, Taiwan, R.O.C.
E-mail: mjtsai@cc.nctu.edu.tw

ABSTRACT

A new wavelet image coding algorithm was designed for color image compression in this paper. This algorithm utilizes multi-ary symbol set to represent the meaningful coefficients in the wavelet transform domain which are necessary for the image reconstruction in the respective color channel. The scheme works first by color space conversion, followed by raster scanning the individual subband for data conversion to symbol representation. Adaptive arithmetic coder is then used to compress the symbols with high efficiency. Unlike zerotree coding or its variations which are essentially the intersubband coding approach with the complexity in addressing the location relationship across the subbands, this work is a low complexity intrasubband based coding method with context specification within the subband, and termination symbol across subbands. Compared with the zerotree refined schemes, this algorithm results in competitive PSNR values and perceptually high quality images at the same compression ratio for color image compression.

1. INTRODUCTION

Color image compression is an important technique to reduce the communication bandwidth consumption in Internet or wireless multimedia transmission and the applications for storage and archiving purposes. The most common used JPEG [1] is the current standard which is based on the block discrete cosine transform. The block artifacts are significant at highly compressed reconstructed images. Wavelet transform [2][3] based image compression algorithms [4][5][6] have achieved good compression performance and been expected to be the core technique for the next generation image communication standard [7]. Among all the approaches, Dr. Shapiro's zerotree [4] data structure has been widely used and extended to different variations and refinements. In essence, they are intersubband based approaches where intersubband relationship has been explored from the ancestor and children dependency. Contrast to the zerotree approach, our new algorithm is an intrasubband scheme where only information within the subband is needed. The algorithm is conceptually simple without addressing the relationship across the subbands and easily to implement because of the small number of symbol set. Beyond its simplicity, its performance is significantly better than JPEG standard and very competitive with the zerotree refinements.

This paper is organized as follows. In Section 2, we explain the Stack-Run-End compression in detail. In Section 3, we summarize the experiment results and outline its characteristics. Finally, we conclude our renovation with summary.

2. STACK-RUN-END COMPRESSION

The hierarchical decomposition structure of the wavelet transform and uniform scalar quantization in each subband is basically performed before the application of the proposed algorithm. However, this algorithm could be applied to different wavelet decomposition format with different quantization procedures as well. Based on the observation that the quantized transform coefficients are either zero values or nonzero values (called significants) with positive or negative sign, efficient grouping scheme and representation for those meaningful information are necessary in the data conversion procedure for image compression techniques. Our approach is different from JPEG's run grouping and similar to the more advanced approach "Stack-Run Coding" [8][9]. The refinement of Stack-Run-End (SRE) coding in this color image compression extends the original stack-run symbol set by the consideration of grouping zero value coefficients into the termination symbol representation, especially near the end of the subband. If no significant coefficients locate at the high frequency subbands, an end-of-image symbol should be used to terminate the computation and transmission.

To make a concise introduction of our algorithm, an example in Figure 1 illustrates the (stack,run) conversion approach. From Figure 1, only three nonzero transform coefficients with integer values exist after the uniform quantization. The nonzero coefficients are called "stack" and the zero values between the stacks are grouped as "run" value. For the zero values towards the end of the subband could be simply represented by an "end-of-subband" symbol. Several consecutive "end-of-subband" symbols towards the end of the image

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could be simplified by an "end-of-image" symbol for the encoding.

The symbol alphabet in our context for the "stack" value are denoted as the following:

"+": the binary value 1 with the sign value "+", always used in the stack's MSB.

"-": the binary value 1 with the sign value "-", always used in the stack's MSB.

"1": the binary value 1 of the significant coefficient.

"0": the binary value 0 of the significant coefficient.

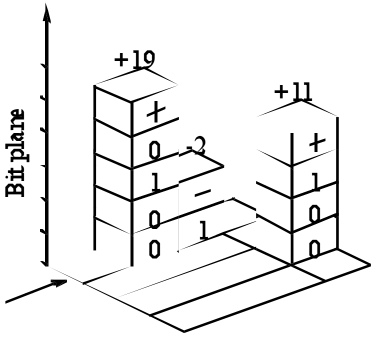


Figure 1. Illustration of the transform coefficients from the perspective view. The raster scanning follows the arrow direction. The values of the significants are +19, -2 and +11. The run values are 1, 0 and 8 with one termination symbol "EOB".

Two symbols "+"and "-"are used to represent the "run" value. The exception for the run value located at the end of the subband is used by the termination symbol "EOB". Several consecutive EOBs towards the end of the image will be represented by another termination symbol "EOI". They are summarized as the following:

"+": the binary value 1 of the run value.

"-": the binary value 0 of the run value.

"EOB": the symbol for those zero values which are between the last nonzero significant coefficient and the end of the subband.

"EOI": the symbol for those zero values which are between the last nonzero significant coefficient and the end of the image.

In Figure 1, the significant coefficients +19, -2, +11 are labeled on the stacks by the above symbols. Given the requirement to distinguish the various contexts, the binary representations of the quantized coefficients are added a binary value 1 which is actually worked as the indication for the quantization compensation during the reconstruction to reduce the quantization error. So, the significants +19, -2, +11 are represented as 20, 3, 12 with the sign information on the top of the stacks. For example, +19 could be labeled as 00101 (from LSB to MSB order) in the binary representation. With the positive sign information at the MSB , the total representation for +19 is "0010+". The representation for the negative value is the same for "-2" as labeled "1-".

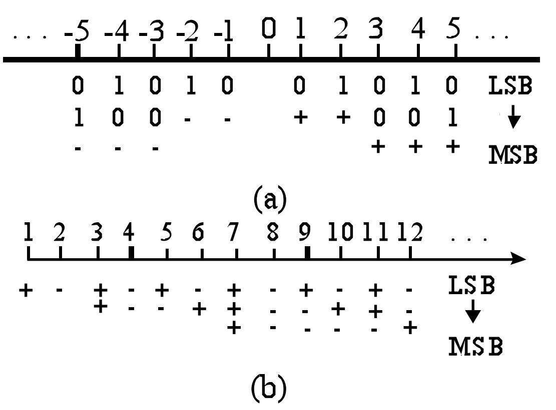


Figure 2. Mapping rule for (a) stack (b) run values

Those zero values in the Figure 1 will be grouped as run values or special termination symbols. The mapping relationships for the stack and run value are illustrated in Figure 2. We have noticed that the run values are always positive integers. To avoid the confusion in context representation, the MSB "+" of the run binary representation would be redundant except for the value equivalent to 2^k-1 where k is an integer. This is a very important observation to further facilitate the compression efficiency and reduce the number of the symbol representation.

From the initial scanning point, there is a zero value before "+19", the run value is 1. Since there is no zero value between "+19" and "-2", the run value 0 is not encoded. Another run value "8" exists between the "-2" and "+11". After the significant value "+11", four zero values are left till the end of the scanning. If this is the end of the subband, an EOB symbol is used which is regardless of the run value. If the situation is no further significant values towards the end of the image, an EOI symbol is used. Assuming this is the end of the subband, the whole symbol stream could be represented as "+0010+1----001+EOB". At this point, we already successfully convert the meaningful information in the subband into a more concise data representation.

Since the information created from above example is either stack ,run or the termination symbols, it has been examined that directly applying one entropy coding scheme for the whole symbol stream could not efficiently compress those symbols. To utilize the information created from different types of data with different symbol distributions, a partition of the symbol stream for the best entropy coding is necessary. The "location list" and "stack list" are generated after the partition according to the following rules:

- Stack list is the list of stack symbols ordered sequentially from LSB to MSB. However, the LSB of the stack is not included.

- Location list is the list of the run values with the LSB of the adjacent stacks and the termination symbols EOB and EOI.

According to the above rules, the symbol stream of the example in Figure 1 will be easily separated from "+0010+1----001+EOB" into the stack list with the stream "010+-01+" and the location list with the stream "+01---0EOB"respectively. After this separation, a more compact stack and run values are closely related within the similar context list. Since the symbol is well defined and uniquely distinguishable with the prior information about the image size and the decomposition structure at both encoder and decoder, there is no confusion about the information presentation.

A zeroth order adaptive arithmetic coder [10] is applied to further compress those two lists for each subband. The coder's counter of the symbol appearance is always reset whenever a new location or stack list occurs. The coder itself is very simple and the adaptability is very fast given the small setting of the maximum frequency for the symbol appearance. It also considers the local variation of the probability distribution to adjust the frequency order. Alternately encoding the stack list and location list for the stack-run-end compression, a subband based embedded stream could be created for the progressive transmission and display.

3. DISCUSSION

A huge amount of color image data have been tested under this new stack-run-end compression approach. In this image set which contains over 100 color images ranging from 64x64 to 736x576, we adopt the advice from [11] to exclude some over-used images like lena and pepper. We try to extend the fields and include more new images with wide varieties which are suitable for Internet communication and wireless transmission or other similar purpose uses. Since the images come from different available resources, we expect they can cover wide area of applications for color image compression evaluation.

Even the judgment of compression performance is not mainly based on the numerical metrics like the peak signal noise ratio (PSNR), those numbers are by far the most common used and the easiest way for evaluation comparison. In our experiments, current standard JPEG and the refinement of zerotree scheme from Said & Pearlman [6] (S&P) are also compared. To make the fair comparison, both SRE and S&P use the 9-tap/7-tap filter [12] in the wavelet transform and perform the hierarchical decomposition. Given the testing environment is the personal computer with Pentium MMX233 under Window NT 4.0, BMP image format with R, G, B channels is the most popular format for PC applications. From statistics, the R, G, B color channels have high correlation relationship. To decorrelate the interrelation, the whole computation has been performed under the YUV color domain to increase the efficiency. After the compression, the reconstructed images are stored in the BMP image format for display and evaluation. The overall color PSNR performance of various target compression ratio at low bit rate from over 100 color images are summarized and tabulated at Table 1.

Algorithm and bit rate	0.25bpp (96:1)	0.5bpp (48:1)	0.75bpp (36:1)	1.0bpp (24:1)
SRE	24.63dB	27.46dB	29.70dB	31.61dB
S&P	24.81dB	27.72dB	29.90dB	31.88dB
JPEG	23.36dB	26.18dB	27.76dB	29.01dB

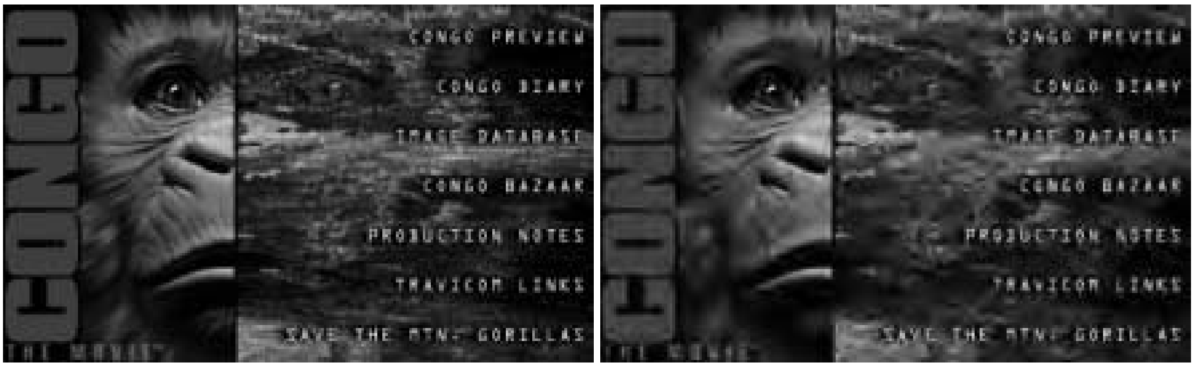
Table 1: Compression results from SRE, S&P and JPEG methods at the bit rate 0.25, 0.5, 0.75 and 1.0 bpp with the compression ratio at 96:1, 48:1, 36:1 and 24:1 respectively. The average of color PSNR from R, G, B channels are calculated over 100 color images.

In Table 1, the average color PSNR are calculated for each target bit rate for each tested image. For each compression technique, we get the final PSNR value by summing all the color PSNR numbers and then divided by the number of the images. Even those numbers are the overall results which do not tell the compression performance for each individual image, they still disclose the characteristics of the compression techniques in the numerical sense. We notice that SRE and S&P are far superior to JPEG method from the color PSNR metric. The PSNR difference between SR and S&P is between a few tenth of a dB variation which is negligible.

In addition to PSNR metric evaluation, we also requested 2 experienced technicians to visually compare the reconstructed images and give the perceptual quality score for those three methods at high compression ratio. The conclusion is that JPEG produces significant block artifacts which is the apparent noise from the reconstructed images. SRE and S&P have much better image fidelity maintenance and both algorithms are very comparable. The interesting behaviors from the SRE and S&P reconstructed images are that SRE has the better capability to maintain the details of the object and S&P seems to keep the color distribution better.

From Table 1, it can not distinguish the individual image compression result under different algorithm. We demonstrate an example in Figure 3 to illustrate the point from the perceptual observation. From the pictures at Figure 3, the reconstructed image from JPEG has obvious block artifacts and color distortion. SRE and S&P have blurred textures but still maintain the object structure. If we emphasize the text information from the reconstructed images, it is very encouraging that SRE has much stronger edge details than S&P and JPEG. This observation agrees with the conclusion from the visual test.

There is also a common critique to refer the complexity issue during the algorithm development. Since the SRE



(1) Original image

(2) Stack-Run-End processed image, color PSNR = 23.11dB

(3) S&P processed image, color PSNR = 23.03dB

(4) JPEG processed image, color PSNR = 21.50dB

Figure 3. Demonstration of the original 24 bit congo image and the reconstructed images by SRE, S&P and JPEG Methods at the compression ratio 96:1 which is equivalent to 0.25 bits per pixel (bpp). (1) is the original congo image. (2),(3),(4) are reconstructed image by SRE, S&P and JPEG method respectively. Color PSNR values for all three techniques are also included in (2), (3) and (4).

codes are not optimized yet, it is still too early to jump to the conclusion about the complexity comparison. In addition, there are many other consideration about the issues in CPU, memory or compiler during the realization. From our preliminary analysis, SRE compression has the similar complexity to the S&P method. Both methods are on the same scale of the speed with the potential for improvement, which are about 2~3 times slower than the JPEG method at the current version.

The advantage of the termination symbol design for color image coding in SRE compression is important at least two ways. The first one is that Y channel constructs the most of color content information than U, V channels. EOB and EOI symbols will be more often used for U, V channels which can benefit the reduction of the number of symbols in conversion. The other one is to speed up the reconstruction procedure for the receiver which can spare the minimum waiting time at the decoder.

4. CONCLUSION

In this paper, we introduce a new algorithm: Stack-Run-End compression for color image coding. The technique is an intrasubband wavelet based approach which is different from the zerotree type based schemes. The algorithm uses multi-ary alphabet symbol set to convert the meaningful information of the wavelet transform coefficients into a concise data structure. Two type of context lists for each subband are alternatively compressed by the zeroth order adaptive arithmetic coder with high efficiency. The bit stream has the progressive transmission property since it is organized at the subband order. Our experiment results shows that our approach is very competitive to the refinement of zerotree type schemes. From perceptual viewing test, high detail fidelity maintenance of the color image is achieved by our techniques.

5. REFERENCES

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附件 三:

IEEE 1998 年音響學、語音和訊號處理國際會議（ICASSP 98）會議報告

蔡銘箴 助理教授

國立交通大學資訊管理研究所

I.會議經過

IEEE 1998 年音響學、語音和訊號處理國際會議（ICASSP 98）於今年(民國 87 年）5 月 11 日至 15 日在美國華盛頓州西雅圖市 Convention Center 舉行。共有來自全球逾三十多個國家千餘位專家、學者、產業界代表與會。

此次會議正值 IEEE 訊號處理學會五十週年慶，主辦單位策劃的會議內容與型式和往年略有不同，十一日有六個 Tutorial Sessions :

- Speech and Audio Compression : Techniques and Applications
- Simulation-Based Computational Methods for Statistical Signal Processing
- Low-power Multimedia DSP Systems
- MPEG-4
- Wavelets: what can they do for you?
- Conversational Systems :the Development of Spoken Dialogue Interfaces

十二日則有大會為五十週年慶所舉辦的專題報告。主講者有 Texas Instruments 的 Thomas J. Engibous, Analog devices 的 David D. French, GM 的 Fred Shlapak, MIT-Lincoln Lab 的 Bernard Gold, MIT 的 Alan Oppenheim 及 AT&T Larry Rabiner，十二日下午至十五日下午共有高達 106 個 sessions 及產業界的 Exhibition。內容相當豐富及精彩。

我個人的論文於五月十二日下午發表。

II.與會心得

參加此次會議有下列四點感想:

1. 由參與國家及人數眾多顯示世界各先進國家都投入了無數人力與物力在訊號處理上之研究與發展。
2. 研討會包含訊號處理之領域非常的廣泛，除了理論發展外，硬體與軟體的結合應用亦日趨廣泛，顯示訊號處理有許多值得研究的題裁和方向。
3. 國內在此研討會發表論文逾十多篇，顯示在訊號處理的研究上，國內有良好的基礎及發展潛力，然美、日其他先進國家，在此項目上發展更是龐大，吾人不可自滿而怠惰。
4. Microsoft Research 招待與會大眾至其總部參觀，展現他們結合實務與理論應用的研發成果，其企圖心及潛力，不容忽視。

III. 建議

下列三點是我的建議:

1. 國內應更積極參與國際性大型論文研討會，並增加差旅補助的金額及名額，以提高國內研究者的參與興趣，從而減縮國內與國外研究的差距。
2. 國內應舉辦國際性研討會 並邀請國內外廠商參與，以促進產學合作為目標。
3. 結合產、官、學界，共同討論如何提升及應用國內研究與發展的能力。

IV．攜回資料名稱與內容

參與此次會議，帶回 Conference Guide 及 Conference Proceedings 的 CD-ROM。

V. 其他

參與此次會議，結識不少本國及其他國家的專家、學者及產業界代表，相信對往後之資料收集、心得交換，將有相當大的助益。