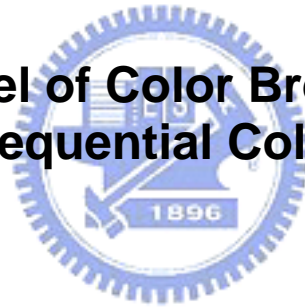


國立交通大學

電機學院光電顯示科技產業研發碩士班
碩士論文

色序法顯示器之色分離視覺模型

**A Visual Model of Color Break-Up for Design
Field-Sequential Color Displays**



研究生：閻淑萍

指導教授：謝漢萍 教授

中華民國九十六年一月

色序法顯示器之色分離視覺模型
**A Visual Model of Color Break-Up for Design
Field-Sequential Color Displays**

研究生：閻淑萍
指導教授：謝漢萍

Student: Shu-Ping Yan
Advisor: Dr. Han-Ping D. Shieh

國立交通大學
電機學院光電顯示科技產業研發碩士班



Submitted to College of Electrical and Computer Engineering
National Chiao Tung University
in Partial Fulfillment of the Requirements
for the Degree of Master
In
Display Institute
January 2007
HsinChu, Taiwan, Republic of China.

中華民國九十六年一月

色序法顯示器之色分離視覺模型

碩士研究生：閻淑萍

指導教授：謝漢萍

國立交通大學 電機學院



中文摘要

色序法其原理是利用三原色場在人眼視覺暫留的時間內所提供的光刺激累加來合成彩色的圖像，也就是說將彩色影像的三原色成分，分別呈現在三個不同的顯示時段，而得到色彩繽紛的彩色顯示效果。雖然它具有比目前其他的顯示技術俱有更好的顯色特性，卻存在著一個潛在的缺陷——色分離(CBU)，除了會降低顯示影像的品質外，長時間的觀看亦有可能造成眼睛的疲勞，是一個不可忽視的現象。

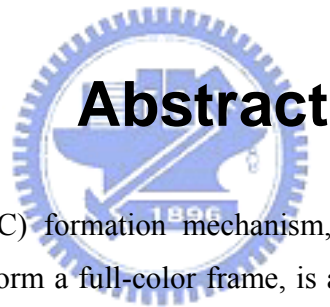
基於以上論述，研究主要將分為架構完整的改善機制，以現有的色序法液晶顯示器與投影技術為平台建立一個模型對 CBU 進行量化、評估與改善，最後利用色序法顯示器特性與 CBU 關聯為基礎將此模型應用在液晶顯示器上以提升影像品質。

A Visual Model of Color Break-Up for Design Field-Sequential Color Displays

Student: Shu-Ping Yan

Advisor: Dr. Han-Ping D. Shieh

National Chiao Tung University



Field-sequential color (FSC) formation mechanism, which displays multi-primary color fields in temporal sequence to form a full-color frame, is an effective way to generate full color images.

Color break-up (CBU), however, has appeared intrinsically in FSC-type displays to degrade visual quality, and thus been investigated in the past decades.

In this study, we first purposed “Color Break-Up Angle (CBUA)” to model the effect of entire image with CBU. Then, a psychophysical experiment was performed by using a convenient apparatus to derive the indistinguishable CBUA. Finally, the CBU suppression can be designed and verified for various sizes of FSC displays to improve image quality.

誌 謝

兩年的研究生生活與論文的完成，首先要感謝 謝漢萍教授，您不只提供了如此優良的學習環境，也給予我相當多的學習機會，讓我在專業技能、語言、或是做事方法各方面都具有相當的成長，在此誠心的謝謝您。

裕國學長，在此我也衷心地感謝你，謝老師是給予我學習機會的人，而你，才是真正讓我能感受到自己成長的人，你訓練我學習做研究的態度與方法，又傳授我許多專業方面的知識讓我能快速與正確的步上軌道，而今天我能有這麼一些小小的成就，這都要感謝你平時對我的要求以及訓練，我會謹記你曾對我說過的話，祈望在未來也能朝著正確的方向繼續努力與自我段煉。

我也很謝謝實驗室的學長姐們，方正學長、榮安學長、安琪學姊、企桓學長、均合學長以及仁宇學長等在我各方面的協助，以及華映的戴文智博士、吳世民經理與晏佐等人提供我實驗的平台以及技術上的支援，尤其要謝謝黃乙白老師在我這最後一學期的教導，因為您的協助與意見的提供，讓我整篇論文的架構能更趨完整，由衷的謝謝你們。

兩年的研究生生活當然不會只有無止境的學習與實驗，也很感謝其他的同學，俞文、明倫、佳峰、俊弘、健富、枝福、映頻、俊文、耀慶等，與實驗室的學姊、學弟妹們，琬琳、秀鳳、宛徵、勝昌、侑興等，有你們的陪伴讓我在這兩年的研究生生活過的很快樂，在此，尤其要謝謝健富，不論是我在學業或是生活方面遇到挫折或困難，你都帶給我支持下去的勇氣與力量，讓我能堅持到最後順利完成我的學位，謝謝你。

最後要感謝我的家人們，是你們在我背後默默的支持我讓我無後顧之憂，我才能如此順利與專心的完成我的研究，沒有你們的支持也不會有今天的我，在此表達我深深的感謝之意也將這篇論文獻給我最摯愛的家人。

Contents

摘要.....	iii
Abstract.....	iv
致謝.....	v
Table of contents.....	vi
List of Tables.....	viii
List of Figures.....	ix
Chapter 1 Introduction	1
1.1 Motivation and Objectives.....	1
1.2 Organization.....	4
Chapter 2 Principle	5
2.1 Introduction.....	5
2.2 Field sequential color LCD.....	5
2.3 Human Color Vision.....	8
2.3.1 Structure of Human Eye.....	8
2.3.2 Visual Signal Processing.....	11
2.3.3 Opponent-Color Theory.....	12
2.3.4 Spatial and Temporal Properties of Color Vision.....	13
2.4 Eye Movement.....	15
2.4.1 Saccade.....	16
2.4.2 Smooth Pursuit Movement.....	17
2.5 Mechanism of Color Break-Up.....	17
2.4.1 Stationary Image.....	17
2.4.2 Moving Image.....	19
2.6 CBU Qualitatively and Quantitatively Analysis Methods.....	19
2.6.1 Subjective Evaluation.....	19
2.6.2 Analysis Dynamic CBU by ΔE	19
2.6.3 Precise Recording.....	20
2.7 CBU Suppression Method.....	20

2.7.1 Field Rate Increasing.....	20
2.7.2 ACE Method.....	20
2.7.3 Multi-Primary Color Fields.....	21
2.8 Summary.....	22
Chapter 3 Physical Stimuli Analysis.....	23
3.1 Introduction.....	23
3.2 Modeling.....	24
3.3 Physical Stimuli Analysis.....	25
3.4 Measuring CBU.....	25
3.4.1 DLP Projection System.....	25
3.4.2 Digital Still Camera.....	28
3.4.3 Experiment Procedure.....	30
3.5 Simulation and Experiment Results.....	33
3.6 Summary.....	37
Chapter 4 Psychophysical Evaluation.....	38
4.1 Introduction.....	38
4.2 Psychophysical Evaluation.....	38
4.3 Experiment Result.....	41
4.4 Summary.....	47
Chapter 5 CBU Suppression.....	48
5.1 Introduction.....	48
5.2 Minimum Frame Rate Predicting.....	48
5.3 Image Compensation.....	49
5.4 Experiment Result.....	51
5.5 Summary.....	55
Chapter 6 Conclusion and Future Work.....	56
6.1 Conclusion.....	56
6.2 Future Work.....	57
Reference.....	58

List of Tables

Table 4-1	Characteristics for each subject.....	40
Table 4-2	The coefficients of the equation under two type displays.....	44
Table 4-3	The distinguishable CBUA of human eyes under these two displays.....	47
Table 5-1	The impairment category scale method sued for subjective evaluation.....	50
Table 5-2	Psychophysical evaluation in CBU.....	51



List of Figures

Fig. 1-1	Structure of color TFT LCD.....	1
Fig. 1-2	a) A stationary image in FSC display. b) Perceived one with CBU by moving eyes...3	3
Fig. 2-1	TFT-LCD with LED backlights Architecture.....	6
Fig. 2-2	Timing chart in the field sequential LCD with TFT addressing.....	7
Fig. 2-3	Schematic diagram of the human eye with key structures.....	9
Fig. 2-4	Schematic diagram of the wiring of the cells in the human retina.....	10
Fig. 2-5	Density of rod and cone photoreceptors as a function of location on the human retina.....	11
Fig. 2-6	Relative energy responses for the rod and cone photoreceptor.....	12
Fig. 2-7	Schematic illustration of the encoding of some signals into opponent-colors signals in the human visual system.....	13
Fig. 2-8	Spatial contrast sensitivity functions for luminance and chromatic contrast.....	14
Fig. 2-9	Temporal contrast sensitivity functions for luminance and chromatic contrast.....	15
Fig. 2-10	An example of saccade eye movement.....	16
Fig. 2-11	(a) Image in a field-sequential display and path of a saccade , (b) Observed color break-up during or just after the saccade.....	18
Fig. 2-12	(a) Moving image and motion direction, (b) Mechanism of CBU.....	18
Fig. 3-1	The experiment flow chart of the proposed model for establishes a visual evaluation index of CBU.....	24
Fig. 3-2	The schematic definition of CBUA.....	25
Fig. 3-3	One chip DLP projection system.....	26
Fig. 3-4	The structure of a single pixel of DMD and the relative light gray pixel.....	27
Fig. 3-5	Comparison the specification of DLP projection system with FSC LCD.....	28
Fig. 3-6	The color field array of color filters on the pixel array of an image sensor.....	29
Fig. 3-7	The window of controller signal soft of the DSC.....	30
Fig. 3-8	Schematics for the measurement system.....	31
Fig. 3-9	The measurement system under FSC LCD.	32
Fig. 3-10	The measurement system under DLP projection system.....	33
Fig. 3-11	Experimental results of measuring CBU between CBUA and the a) eye moving	

	velocity, b) viewing distance, and c) target width with FSC LCD.....	34
Fig. 3-12	Experimental results of measuring CBU between CBUA and the a) eye moving velocity, b) viewing distance, and c) target width with DLP projection system.....	36
Fig. 3-13	Experiment result captured by the horizontal moved camera and analyzed by MATLAB.....	37
Fig. 4-1	Schematic of the psychophysical experiment apparatus.....	39
Fig. 4-2	Threshold distance of psychophysical evaluation in seven observers under FSC LCD.....	42
Fig. 4-3	Threshold distance of psychophysical evaluation in four observers under DLP projection system.....	43
Fig. 4-4	The indistinguishable viewing distance of CBU with various, a) moving velocity, b) surrounding luminance, and c) target luminance in a 32" FSC LCD.....	46
Fig. 5-1	The schematic for clear explanation the compensation mechanism.....	49
Fig. 5-2	Evaluating the image quality of compensation in FSC LCD.....	53
Fig. 5-3	Evaluating the image quality of compensation in DLP projection system.....	54
Fig. 5-4	CBU suppression result captured in DLP projection system.....	54
Fig. 6-1	Experiment apparatus for measuring CBU on moving image by using CCD camera and rotational motorized stage.....	58