台灣二〇〇二年國際科學展覽會

科　　別：工程學

作品名稱：倍位元灰度影像產生器

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一、中英文作品摘要

[摘要]：倍位元灰度影像產生器

本研究設計一新型的影像投射系統，可將影像顯示的灰度位元加倍，例如，顯示面板只需用 4 位元，即可顯示 8 位元的影像；亦能充分利用光路光源，增加光源使用率。此系統使用兩片相同灰度位元的顯示面板，此兩面板所顯示的影像經過灰度的重新處理，且各經由不同光源強度比值的光路合成後，其灰度分佈將可增爲原來的平方倍。經模擬與實驗顯示，此種系統很輕易就能獲得預期目標。無論使用穿透式或反射式皆可應用於目前單片液晶面板之投影系統中；未來可望利用網板來表現灰度，應用於紅外線景物投射系統中，作爲紅外線影像式尋標器靜態模擬時所需的高強度動態範圍與高解析度之影像產生器。

[Abstract]: Double-bit gray-level image generator

In this study, a novel image generator utilized in a projecting system has been proposed; it can double the bits of gray-level for image display and enhance the efficiency of illumination of lamp in the optical path. With this system, a 4-bit display panel can achieve an 8-bit image display. Two display panels with same gray-level bits is adopted, images on them will be processed, and then go through different path with a proper intensity ratio. The gray level distribution of image displayed which the two images combined afterward, will be the square of that of original one. The results of simulations and experiments have approved to meet the requirements. No matter transmitting or reflective types can be applied to current projecting systems with single LCD panel. It is expected that a halftone-gray-level pattern will be suitable for this system to form an infrared scene projector, and to act as an image generator with high dynamic range and resolution for static simulation of infrared imaging seeker.

二、內文

(一)、前言

1. 研究動機

近年來，人類生活已不自覺的進入 3C 的領域中，電視、電腦已是日常的必需品，因此作爲人機視覺介面的顯示器，其性能就相當的重要。偶然間，在電器量販店中看到大型的液晶背投電視，雖然深受其大型螢幕所震撼，但慢慢觀察後，卻發覺其對比與灰度不足，導致視覺效果大打折扣，遂進行思考研究其改良之道。

液晶面板灰度的產生是利用液晶分子施加電壓後產生扭曲後與偏光板的合成作用[1,2]，目前靠面板中電路的驅動方式，從過去的 6 位元提昇到 8 位元，不過也增加了電路的複雜度與成本[3]。

市售的液晶投影機通常使用三片穿透式液晶面板，分別控制原始影像的 R、G、B 三色信號分量，光源利用濾光鏡亦分成三色各穿透一個面板，再經合光稜鏡將三色合成，最後利用光學鏡組投射到屏幕上。但是由於使用三片面板，加上 LCD 穿透率的影響，光機系統複雜且光源利用率低。

本研究即構思一種新型的影像產生器，同時解決上述對比與灰度不足，以及光源利用效率的問題。

2、研究目的

a. 設計一影像投射機構，經由此機構可將影像顯示的灰度位元加倍，例如，顯示面板只需用 4 位元，即可顯示 8 位元的影像。除了可降低顯示面板的電路複雜度，亦能提高灰度，增加色彩顯示數目。
b. 此影像投射機構能充分利用光路光源，增加光源使用率，不僅降低所需光源的強度，亦能提高影像顯示的對比。
c. 將此種能巨幅提昇灰度的影像產生機構，推廣應用在需要高強度動態範圍的影像測試上，例如，紅外線影像飛彈進行動態模擬時所需的紅外線影像產生器。

（二）、研究方法或過程

1.、研究構想

相較於一般的顯示器，對於投影系統而言，提高影像灰度的方法可以較多樣化，因爲不僅可由內部的顯示面板著手，亦可從外部的投射機構加以思考改良。另外，爲了提高光源的使用效率，液晶面板的使用片數愈少愈好，因此目前的三片式系統並不理想。單片式的反射型液晶覆矽(LCoS)面板似乎是最佳的選擇，但是其對比較差，且除非使用離軸不對稱式的光機設計，否則會浪費另一軸的部分光源；另一可行的方法則是再多使用一片面板，將此部份光源加以利用。

經過上述的綜合考慮，本研究提出下列構想：

1) 使用兩片面板影像疊加的方法，提高影像的灰度顯示數目，
2) 其中一片面板的光源恰好可使用另一軸的光源。

欲完成此構想，必須進一步思考影像合成的法則。對於一個完美的影像而言，每一個像素的亮度與灰度的關係應該成正比，且形成一條連續直線。如下圖所示，

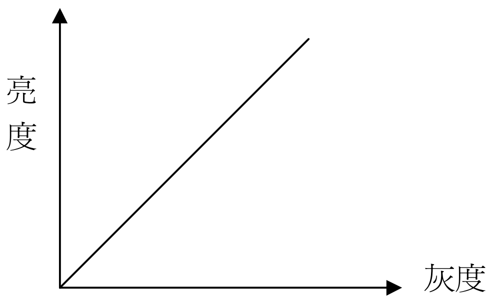


圖 1. 理想的灰度與亮度關係

但是經過數位影像處理後，像素的灰度數目有一定的限制，通常是使用八位元的灰度來表現一個像素的各種亮度，亦即從最暗到最亮只有 256 種灰度值，使得亮度的顯示並不連續。爲簡化說明起見，我們以四位元的灰度爲例，其所能表現的亮度有 16 種，如圖 2 所示，

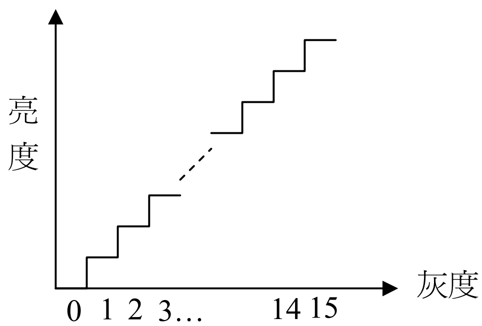


圖 2. 四位元灰度與亮度關係

利用灰度疊加的方式，圖 2 的四位元灰度可以使用兩個二位元灰度來進行合成，只是這兩個二位元灰度所對應的亮度必須不同，其比值爲 4:1，如下圖所示，

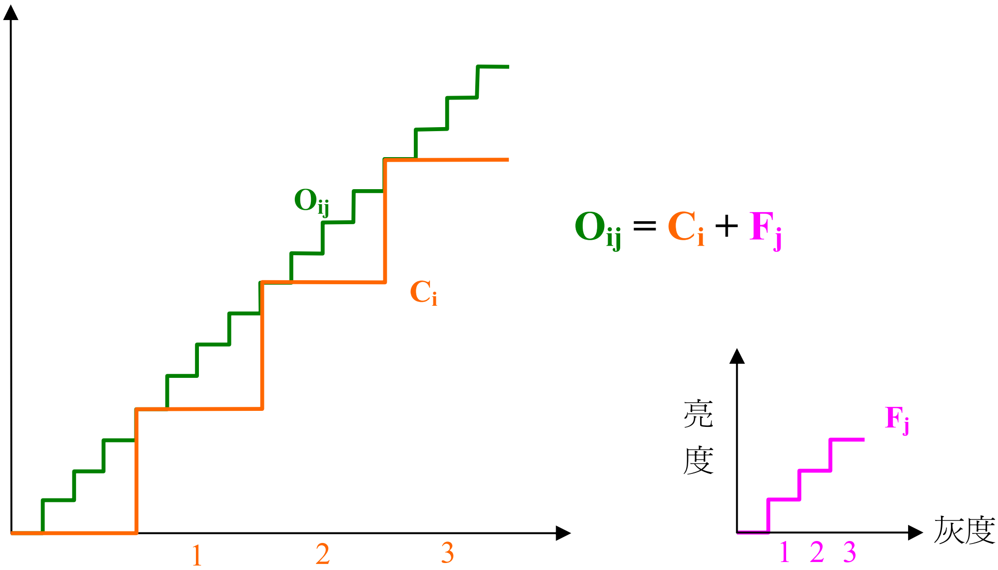


圖 3. 利用兩個二位元灰度可疊加出 16 種灰度

圖 3 顯示，當一個粗調(Coarse)的二位元灰度與細調(Fine)的二位元灰度進行疊加後，若兩者的亮度比爲 4:1，則可以疊加(Overlay)出 16 種灰度，亦即合併後的影像灰度位元加倍，變成 4 位元。

推而廣之，對於一個 n 位元的原始影像 G_o，其位於(x,y)處的灰度爲 $g_o(x,y)$，我們將其分割成兩個 m = n/2 位元的影像，G_c 和 G_f，其位於(x,y)處的灰度爲分別爲 $g_c(x,y)$與 $g_f(x,y)$。如果我們設法將此兩影像分別顯示於面板 c 和面板 f，並安排其光路的光源亮度比值爲 $2^m : 1$，則其所能顯現的亮度種類分別爲，

b_c：0，1，2，3，……，2^m-1

b_f：0，$1/2^m$，$2/2^m$，$3/2^m$，…，$(2^m-1)/2^m$

加以疊加後，其亮度種類數目，即灰度數目，仍可恢復爲 $2^m \times 2^m = 2^{m+m} = 2^{2m} = 2^n$。必須注意的是，兩影像中每個像素的灰度必須先處理如下式，

$$g_c(x,y) = g_o(x,y)/2^m \qquad (1)$$

$$g_f(x,y) = MOD[g_o(x,y), 2^m] \qquad (2)$$

以 4 位元（灰度分佈爲：0，1，2，…，15），解析度 1×16 的下列影像爲例，

$g_o(x,y)$ =

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

其最低灰度的對應亮度= 0，最高灰度的對應相對亮度= 15/16=0.9375。

根據上述公式，粗調面板的灰度分佈爲 $g_c(x,y) = g_o(x,y)/4$，即

$g_c(x,y)$ =

0	0	0	0	1	1	1	1	2	2	2	2	3	3	3	3

其最低灰度的對應亮度= 0，最高灰度的對應相對亮度= 3/4 = 0.75。

細調面板的灰度分佈爲 $g_f(x,y) = MOD[g_o(x,y), 4]$，即

$g_f(x,y)$ =

0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3

其最低灰度的對應亮度= 0，最高灰度的對應相對亮度= 3/4/4 = 0.1875。

則疊加後的影像總灰度仍有 16 種，且影像的空間分佈維持不變，如下所示，

灰度分布 $g_o(x,y)$															
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
相對亮度分布 $b_o(x,y)$															
0	0.0625	0.125	0.1875	0.25	0.3125	0.375	0.4375	0.5	0.5625	0.625	0.6875	0.75	0.8125	0.875	0.9375

也就是說，我們可以用灰度數目僅爲 4 的兩片面板，達成灰度數目增爲 16 的輸出結果。

此種倍位元灰度的影像產生裝置，可以用穿透式及反射式兩種方法，穿透式的系統架構如圖 4 所示，

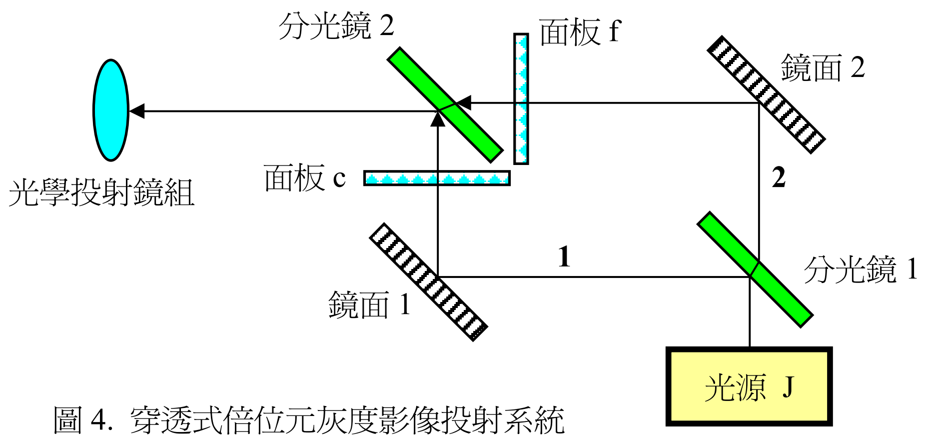


圖 4. 穿透式倍位元灰度影像投射系統

分光鏡 1 將入射於面板的光源(亮度 J)分成 1、2 兩個光路，分別經鏡面 1 與 2 反射至粗調面板 c 與細調面板 f，影像經分光鏡 2 疊加後，再以光學鏡組投射出去。其中，光路 2 的亮度必須衰減 2^m 的強度，我們可控制分光鏡 1，2 的穿透率 t 與反射率 r 的比值來達成。疊加後的影像中，每個像素的亮度可表示如下，

$$
\begin{aligned}
b_o(x,y) &= r^2 \cdot g_c(x,y) \cdot J + t^2 \cdot g_f(x,y) \cdot J \\
&= b_c(x,y) + (1/2^m) \cdot b_f(x,y)
\end{aligned}
\tag{3}
$$

此處 $r + t = 1$，且 $r^2 : t^2 = 2^m : 1$。由於光路 1 與光路 2 的光源會經由分光鏡 2 穿透與反射，所以會浪費部分光源 W_r，其大小為

$$
W_r = 2\,r\,t = \frac{2\sqrt{2^m}}{(\sqrt{2^m}+1)^2} \tag{4}
$$

對於二位元的影像疊加，即 m=2，則 W_r=4/9；而若 m=4，W_r=8/25，亦即當灰度的位元數目愈大，光源浪費愈少。

反射式的系統架構如圖 5 所示，

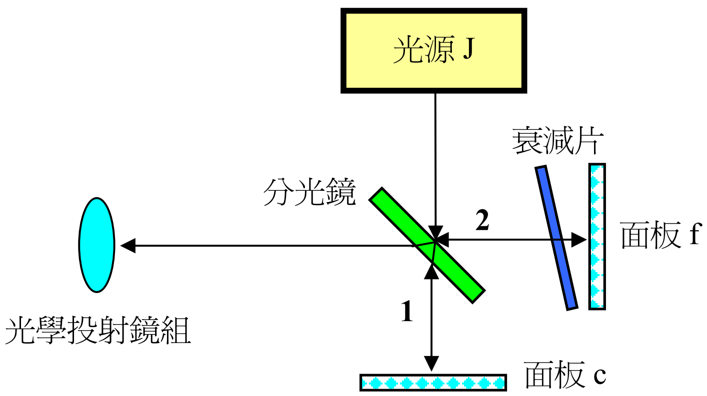


圖 5. 反射式倍位元灰度影像投射系統

如果面板能反射光源(如 LCoS)，原先穿透式中的鏡面即可省略，因此較穿透式的系統簡單許多。面板 c 與 f 將光源反射後，經分光鏡合併，再以光學鏡組投射出去。光路 2 的光

亮度靠衰減片(穿透率爲τ，反射率爲ρ)減少成光路 1 的 2^m 倍。疊加後的影像中，每個像素的亮度可表示如下，

$$
\begin{aligned}
b_o(x,y) &= r\cdot t\cdot g_c(x,y)\cdot J + r\cdot t\cdot \tau^2\cdot g_f(x,y)\cdot J \\
&= b_c(x,y) + (1/2^m)\cdot b_f(x,y)
\end{aligned}
\tag{5}
$$

此處 $r + t = 1$，且 $\tau^2 = 1/2^m$。由於光路 1 與光路 2 的光源也會經由分光鏡與衰減片產生穿透與反射，所以會浪費部分光源 W_t，其大小爲

$$
\begin{aligned}
W_t &= r^2\tau^2 + t^2 + r\rho + r\rho\tau \\
&= (1+\frac{1}{2^m})t^2 - (1+\frac{1}{2^m})t + 1
\end{aligned}
\tag{6}
$$

當 $t=0.5$ 時，W_t 有最小値，可表示如下式，

$$
W_t = \frac{3}{4}(1-\frac{1}{2^m}) \tag{7}
$$

對於單片的系統，其浪費的光源爲 3/4，因此，此種反射式的倍位元灰度系統較單片系統增加了 $1/(1-1/2^m)$倍的光源使用效率。於二位元的影像疊加，即 $m=2$，則 $W_t=9/16$；而若 $m=4$，$W_t=45/64$，亦即當灰度位元數目愈大，光源浪費愈多，恰好與穿透式的系統相反。

2.、實驗佈置圖

本實驗主要在驗證研究構想的可行性，因此採用如圖 4 的穿透式系統架構。爲了簡化實驗所需的零組件，以及增加實驗的彈性，此處利用兩個光源，透過調光器的發光亮度調整來取代鏡面 1 與 2、分光鏡 1。且增加兩個開關來切換光源。系統的示意圖如下，

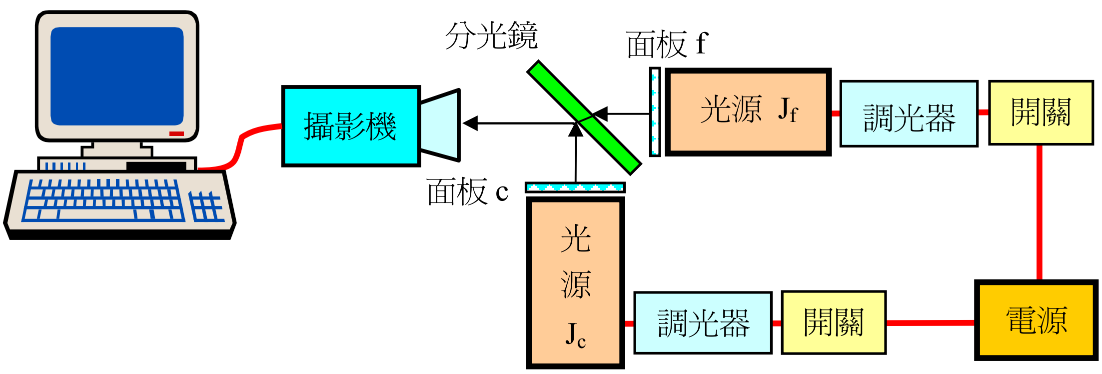
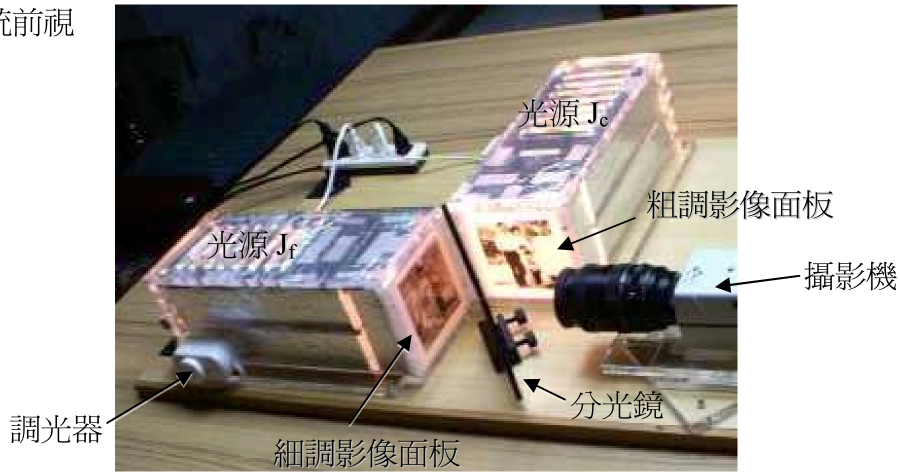


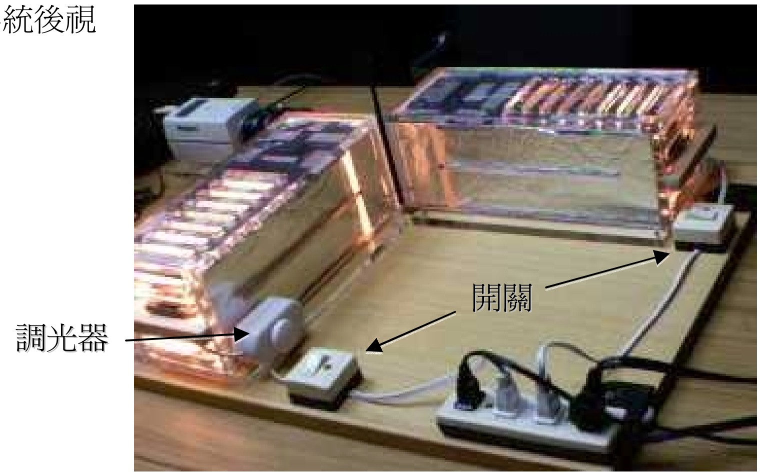
圖 6. 穿透式倍位元灰度影像實驗系統示意圖

[實驗佈置照片]:

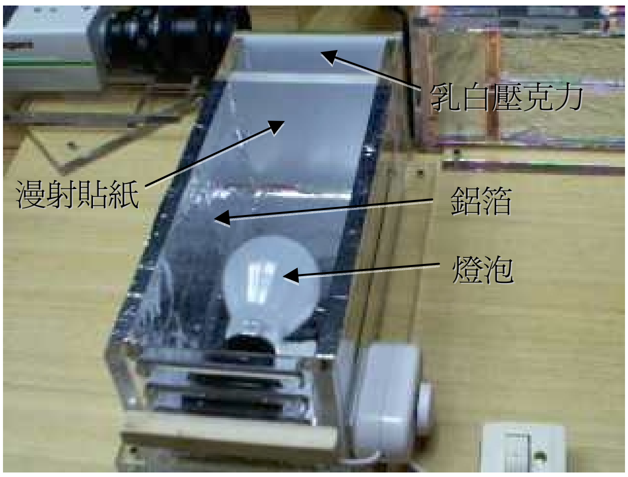
1. 系統前視



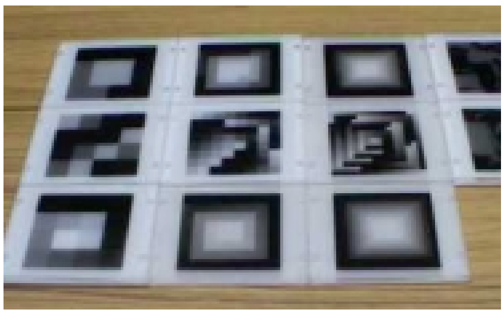
2. 系統後視



3. 光源內部結構



4. 各種測試影像面板



3.、模擬與實驗步驟

[模擬]: 產生位元分割的粗調與細調影像面板的測試圖樣與分析影像的特性

a. 利用公式(1)與(2)，撰寫一電腦語言程式，使其能將各種不同解析度的原始 n 位元灰度的影像分成兩個 m=n/2 位元的影像。
b. 撰寫程式，產生一個 4 位元的測試圖樣，像素解析度為 224×224，每 56×56 個像素恰好用來表現一個灰度。
c. 執行步驟 a 之程式進行影像位元分割。使用影像處理軟體，觀察 Histogram 是否縮減成如預期的灰度數目。將灰度拓展成 0-255，利用噴墨印表機印出原始、粗調與細調的測試投影片，以待後續的實驗。
d. 再撰寫兩程式，分別產生 6 與 8 位元的測試圖樣，像素解析度仍為 224×224，每 28×28 與 14×14 個像素恰好用來表現一個灰度。重複步驟 c。
e. 以數位相機所拍攝的影像，重新取樣使得解析度亦為 224×224，並進行彩色黑白之轉換，灰度為 8 位元。重複步驟 c，產生 4 位元的粗調與細調的展示用影像。
f. 選取步驟 e 中的 4 位元粗調影像，重複步驟 c，產生 2 位元的粗調與細調影像。
g. 選取步驟 f 中的 2 位元粗調影像，重複步驟 c，產生 1 位元的粗調與細調影像。

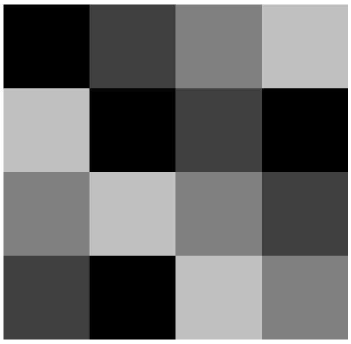
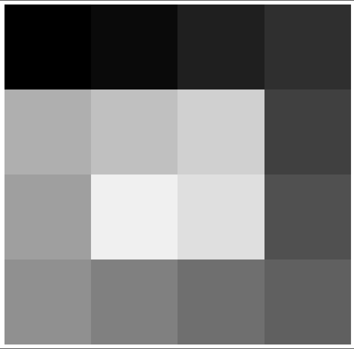
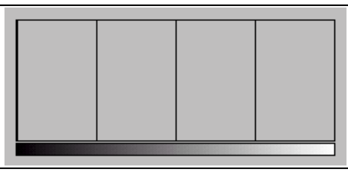
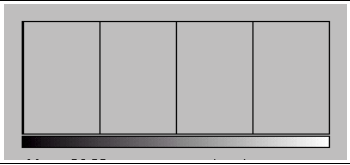
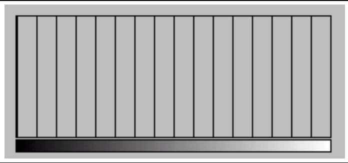
[實驗]: 實際測量測試圖樣位元分割與合成後的灰度變化

a. 建構如圖 6 的系統。將模擬步驟 c 中所製作的測試圖樣投影片，黏貼在透明壓克力板上，並利用乳白壓克力當作背板壓合，完成各種影像面板。
b. 使用一片沒有圖樣的影像面板，以攝影機(取消自動增益控制)連結 PC 取像，利用影像處理軟體，分析測試光源的均勻度。
c. 放置 2 位元的粗調與細調測試圖樣面板，將粗調圖樣面板的光源開關 on，以調光器調整亮度，使得取像後最亮處的灰度大約在 200 左右。
d. 以攝影機連結 PC 取像。於影像處理軟體中，紀錄每一區域的灰度值，繪出歸一化後的亮度與灰度關係直條圖。
e. 將細調圖樣面板的光源開關 on，調整分光境的角度，使得粗調與細調影像能完全重疊。接著以調光器調整亮度，使得疊加影像的灰度變化能產生 4 位元(倍位元)的效果，重複步驟 d。
f. 粗調圖樣面板的光源開關 off，細調圖樣面板的光源開關維持 on，重複步驟 d。
g. 改用 3 位元的粗調與細調測試圖樣面板，重複步驟 c~f。
h. 改用 1、2 與 4 位元的粗調與細調的展示用影像面板，重複步驟 c~f。

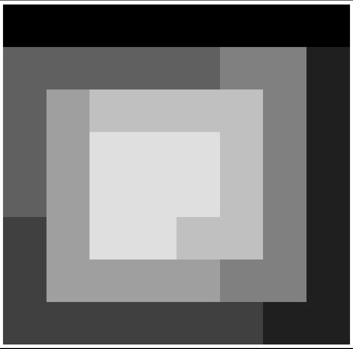
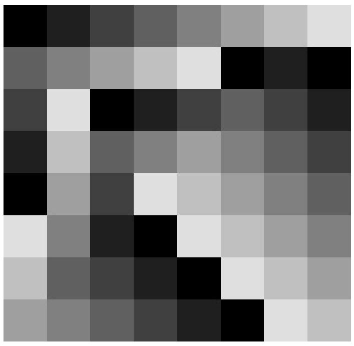
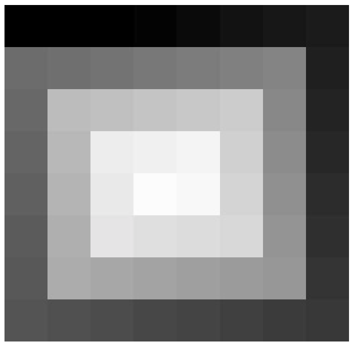
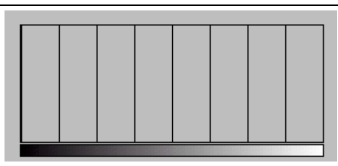
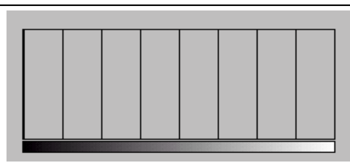
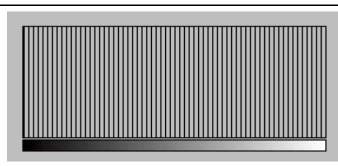
(三)、研究結果與討論

[模擬結果]:

1. 2 位元(灰度 0~3)之測試圖樣：
   粗調、細調與疊加模擬影像各一(編號 C2T_S、F2T_S 與 O4T_S)。

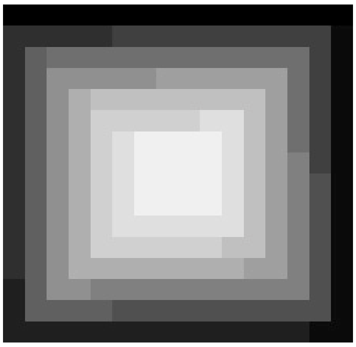
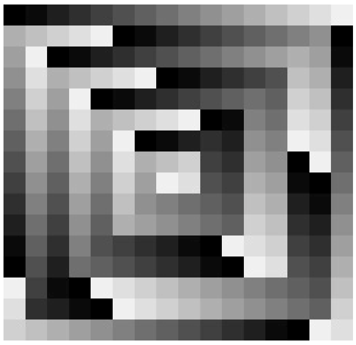
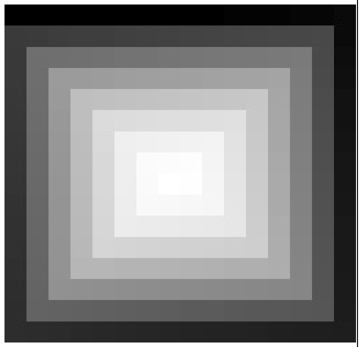
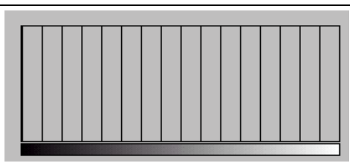
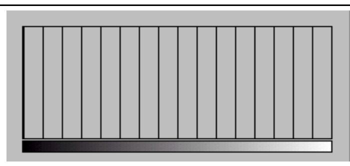
圖樣			
編號	C2T_S	F2T_S	O4T_S
灰度分布			

2. 3 位元(灰度 0~7)之測試圖樣：
   粗調、細調與疊加模擬影像各一(編號 C3T_S、F3T_S 與 O6T_S)。

圖樣			
編號	C3T_S	F3T_S	O6T_S
灰度分布			

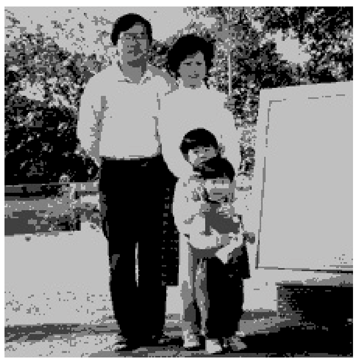
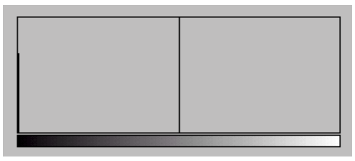
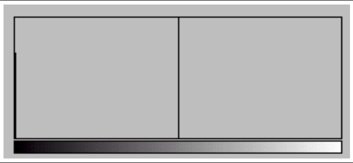
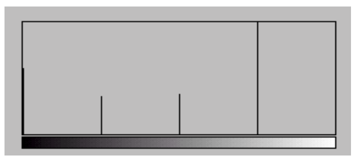
3. 4 位元(灰度 0~15)之測試圖樣：

粗調、細調與疊加模擬影像各一(編號 C4T_S、F4T_S 與 O8T_S)。

圖樣			
編號	C4T_S	F4T_S	O8T_S
灰度分布			

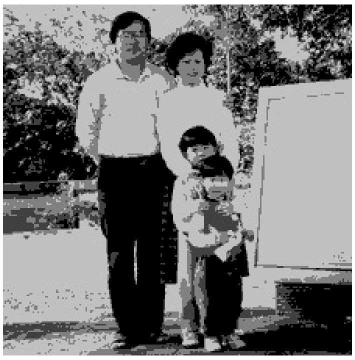
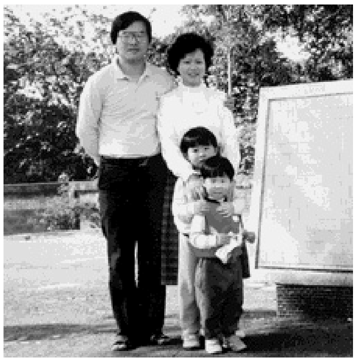
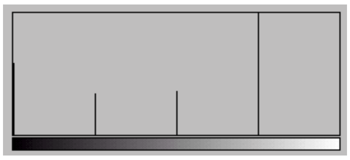
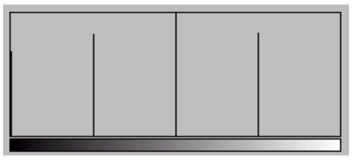
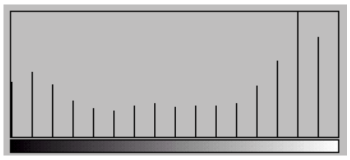
4. 1 位元(灰度 0~1)之展示圖樣：

粗調、細調與疊加模擬影像各一(編號 C1D_S、F1D_S 與 O2D_S)。

圖樣			
編號	C1D_S	F1D_S	O2D_S
灰度分布			

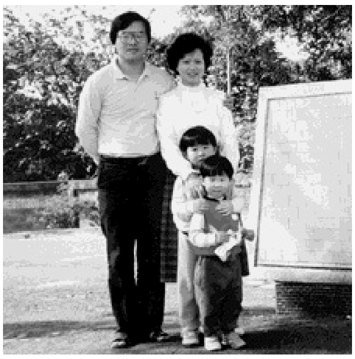
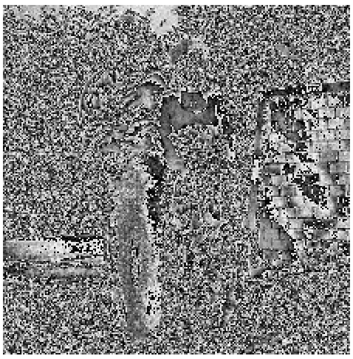
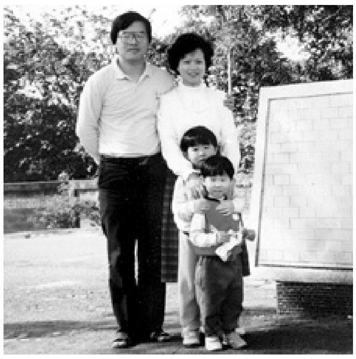
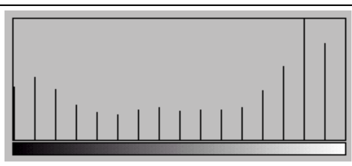
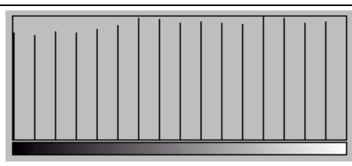
5. 2 位元(灰度 0~3)之展示圖樣：

粗調、細調與疊加模擬影像各一(編號 C2D_S、F2D_S 與 O4D_S)。

圖樣			
編號	C2D_S	F2D_S	O4D_S
灰度分布			

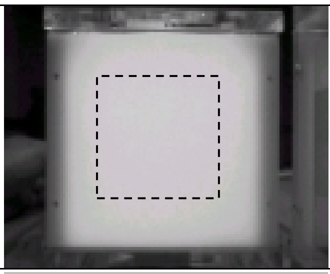
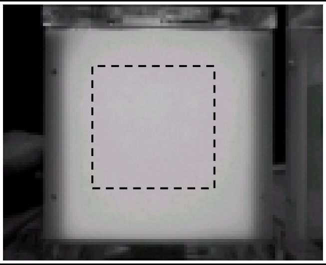
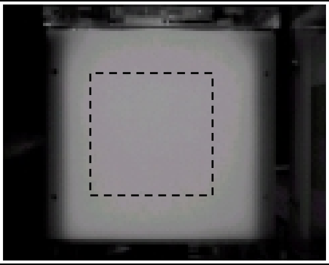
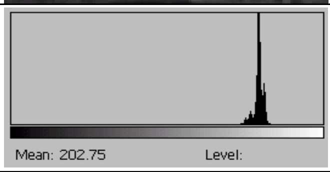
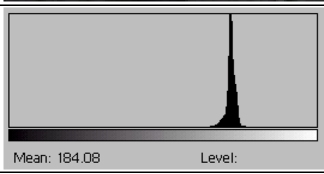
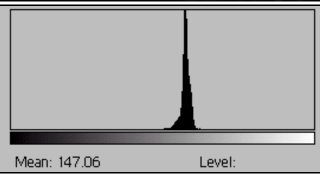
6. 4 位元(灰度 0~15)之展示圖樣：

粗調、細調與疊加模擬影像各一(編號 C4D_S、F4D_S 與 O8D_S)。

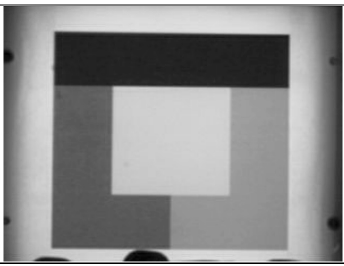
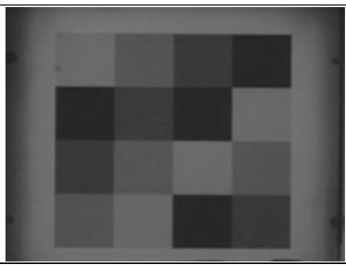
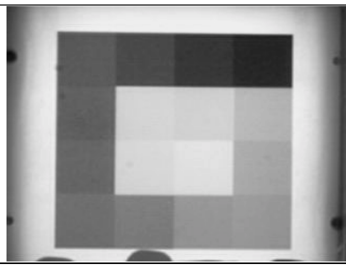
圖樣			
編號	C4D_S	F4D_S	O8D_S
灰度分布			

[實驗結果]:

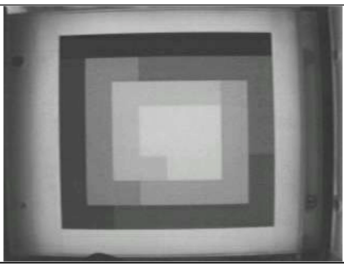
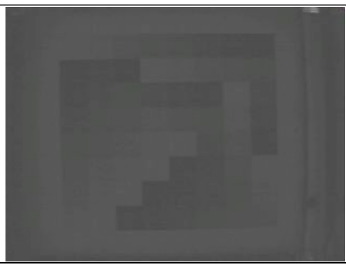
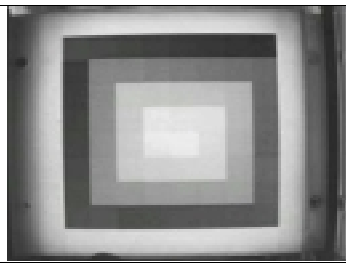
1. 光源均勻度測試 (中間區域取樣分析)

圖樣			
灰度分布			
標準偏差	3.35	3.24	3.23

2. 2 位元(灰度 0~3)之測試圖樣：
粗調、細調與疊加實驗影像各一(編號 C2T_E、F2T_E 與 O4T_E)。

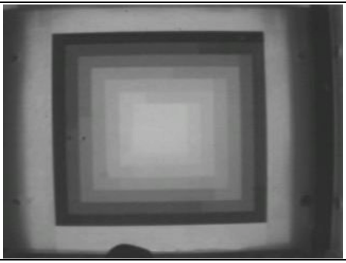
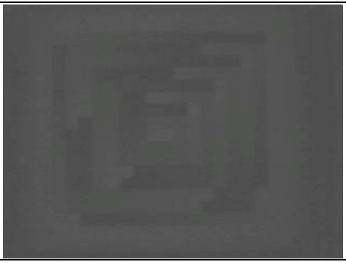
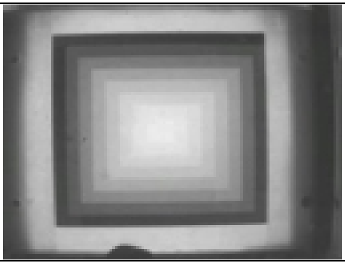
圖樣			
編號	C2T_E	F2T_E	O4T_E

3. 3 位元(灰度 0~7)之測試圖樣：
粗調、細調與疊加實驗影像各一(編號 C3T_E、F3T_E 與 O6T_E)。

圖樣			
編號	C3T_E	F3T_E	O6T_E

4. 4 位元(灰度 0~15)之測試圖樣：

粗調、細調與疊加實驗影像各一(編號 C4T_E、F4T_E 與 O8T_E)。

圖樣			
編號	C4T_E	F4T_E	O8T_E

5. 1 位元(灰度 0~1)之展示圖樣：

粗調、細調與疊加實驗影像各一(編號 C1D_E、F1D_E 與 O2D_E)。

圖樣			
編號	C1D_E	F1D_E	O2D_E

6. 2 位元(灰度 0~3)之展示圖樣：

粗調、細調與疊加實驗影像各一(編號 C2D_E、F2D_E 與 O4D_E)。

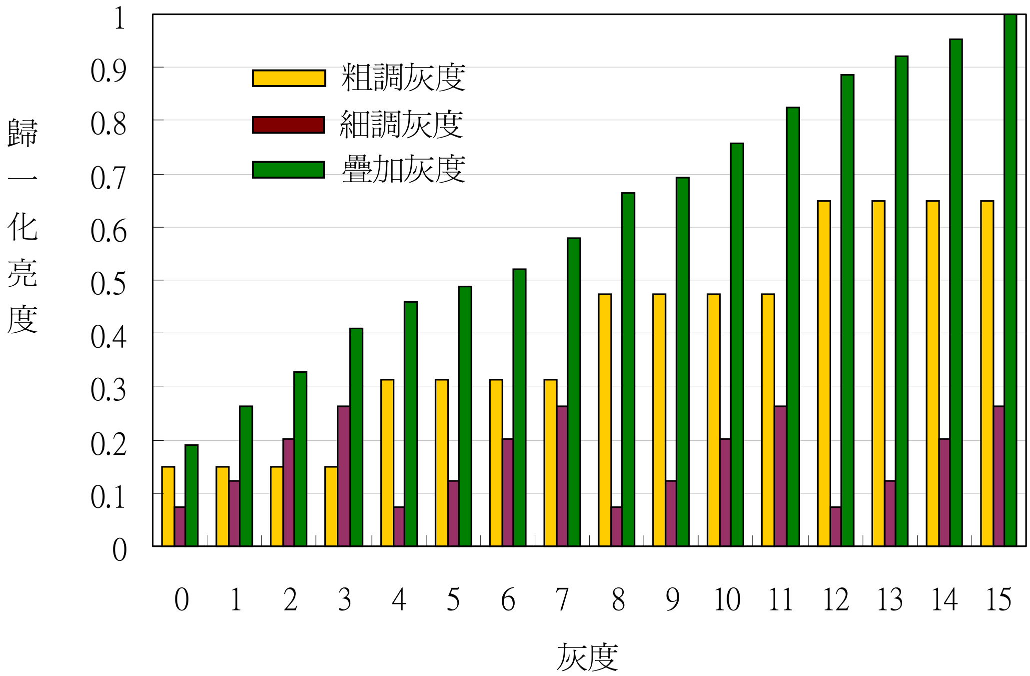
圖樣			
編號	C2D_E	F2D_E	O4D_E

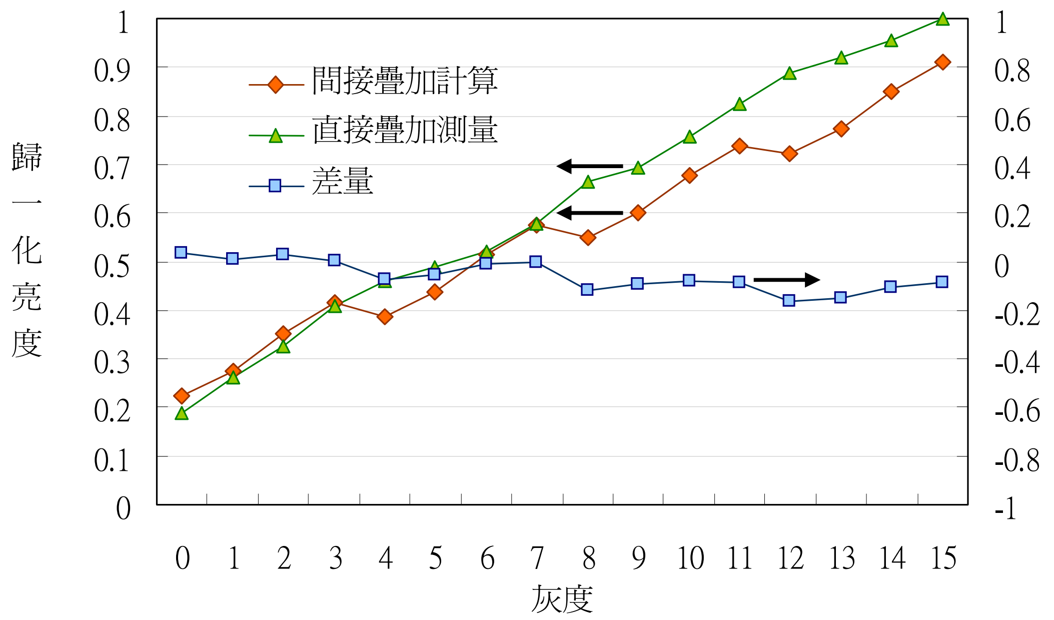
7. 4 位元(灰度 0~15)之展示圖樣：

粗調、細調與疊加實驗影像各一(編號 C4D_E、F4D_E 與 O8D_E)。

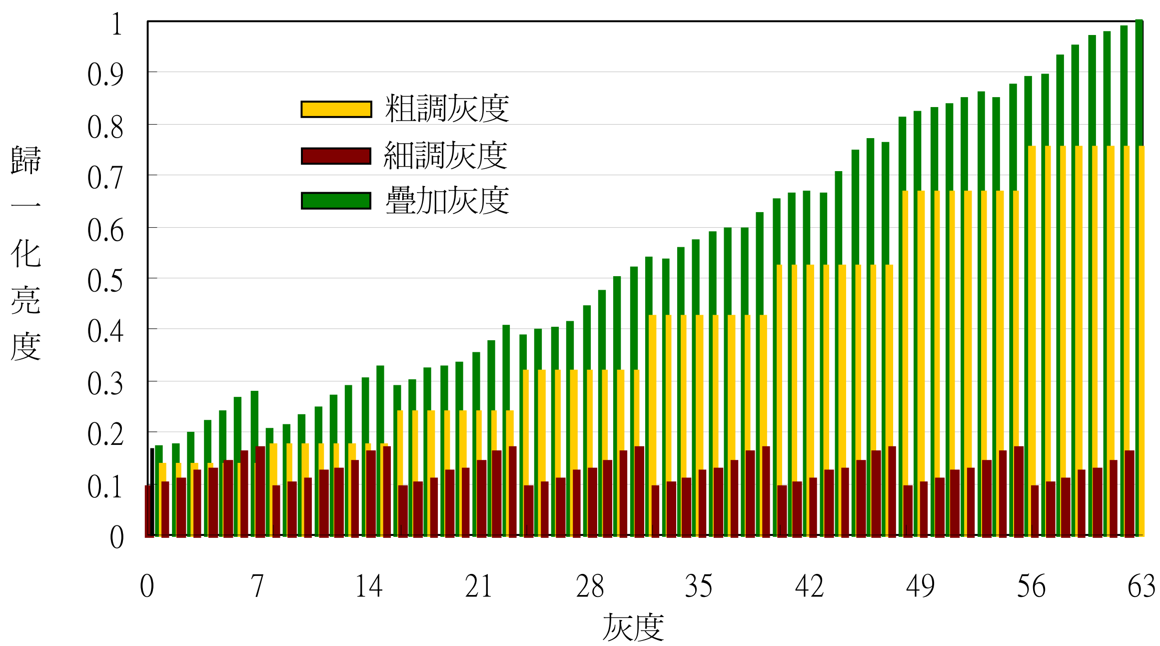
圖樣			
編號	C4D_E	F4D_E	O8D_E

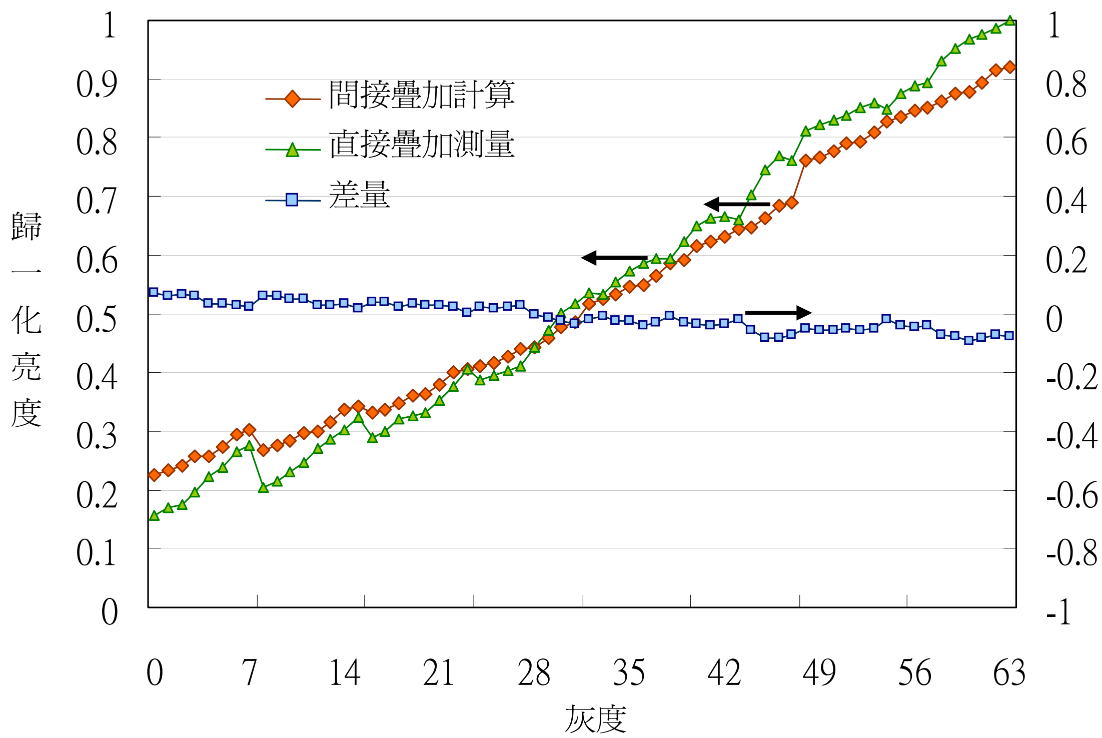
8. C2T_E、F2T_E 與 O4T_E 之歸一化亮度與灰度之關係測量曲線，以及直接疊加與間接計算之差量分析曲線





9. C3T_E、F3TE 與 O6TE 之歸一化亮度與灰度之關係測量曲線，以及直接疊加與間接計算之差量分析曲線





[討論]:

a. 由影像位元分割的模擬結果，可觀察到粗調影像與細調影像的差異度與灰度的位元數目有關，當位元數目愈高，細調影像愈複雜，與粗調影像的差異度愈大。

b. 疊加影像的亮度顯示種類的多寡與光源的均勻度有密切的關係。目前光源均勻度的測試結果，標準偏差約為 3 個灰度，因此，對於 3 位元的疊加影像應已足夠顯示出 64 種亮度以上。

c. 實驗結果顯示，2 位元的疊加影像確實能分辨出 16 種灰度。但是 3 位元的疊加，則在低灰度區域有亮度變化不連續的情形發生，無法完整表現出 64 種灰度。此種現象的產生應該有 2 種原因 ： 一為雖然已取消攝影機的自動增益控制，但是影像擷取裝置仍會對低亮度的像素做增益補償；另一為使用彩色印表機製作面板，其灰度的表現並不是理想的等差變化。

d. 由測試影像的疊加亮度結果顯示，對比大約僅為 5~7，此原因應也是面板的製作與取像

時的增益所造成，必須使用不會反光的面板，以及使用光度計進行測量。在實用上，通常會增加一些偏極片與透鏡等光學元件，以抑制雜散光與增加光源均勻度。

e. 由公式(7)可知，若不計偏極片與其餘光學元件的衰減，對於 1、2、3 與 4 位元的影像疊加，反射式系統架構的光學利用率，可以由原先的 25%，分別提高到 62.5%、43.75%、34.38%與 29.69%。

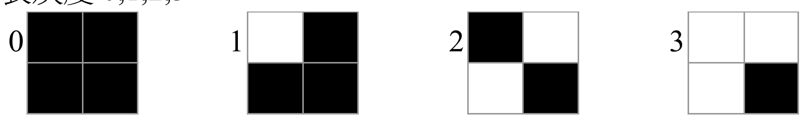
f. 在實際影像的模擬中，當影像顯示尺寸不大時，8 位元與 4 位元的灰度似乎沒有差異，不過，當局部放大時，即可發覺 4 位元的影像品質低落。因此，對於大尺寸的投影系統，8 位元灰度以上的顯示是絕對必要的。

g. 由公式(1)與(2)加以擴展，我們可以推出兩片面板以上的灰度疊加通式，

$$g_k(x,y) = \frac{\mathrm{MOD}[g_o(x,y),\, 2^{\alpha-\beta(k-1)}]}{2^{\alpha-\beta\cdot k}} \qquad (8)$$

此處 $g_k(x,y)$為第 k 片面板位於(x,y)處的像素灰度，α為影像合成後的總位元數，β為單片之位元數，光源強度比為 $2^{\alpha-\beta\cdot k}$: 1。在處理實際的影像資料時，當確定所欲顯示的影像總位元數與所用的面板片數後，代入上式計算，即可獲得每片面板的影像圖樣。上式可用於需兩片面板以上的系統。例如，我們可多增加一道光路，來獲得 3 倍位元灰度的影像顯示。

h. 在液晶顯示面板中，某一像素的灰度是由光源穿透或反射此像素的強度多寡來決定的。而在使用數位微鏡面元件(DMD)為顯示面板的系統中，則是由鏡面彎曲程度造成反射量的變化來決定。我們可以構思其他種方法，例如，使用一個網板(Halftone)來表示一個像素，此網板中，安排適當個數的子像素，像素的灰度高低可由此網板中，子像素能穿透或反射的個數多寡來決定。例如，對於一個 2 位元灰度的像素，其網板可有下列四種，各代表灰度 0,1,2,3。



i. 利用網板來表現一個像素的灰度，會受限於影像的解析度，因為欲表現的灰度愈多，則網板內的子像素需愈多，造成網板尺寸增大，使得影像解析度降低。此時，本研究的倍位元灰度影像產生器正可解決此問題，不但可倍增像素的灰度，亦能提高影像的解析度。此種影像產生器可應用於紅外線景物投射系統[4]中，提供早期用 DMD[5]構成的系統所達不到的強度動態範圍與解析度。

(四)、結論與應用

本研究設計一新型的影像產生機構，可以降低顯示面板的位元灰度顯示驅動電路的困難度，而由投影系統原先的光路加以改良，即可達到高位元灰度顯示的目標。不僅能達到倍位元灰度的顯示效果，亦能提高光源的使用效率。實驗顯示，此種系統很輕易就能獲得平方倍的灰度顯示。無論使用穿透式或反射式的架構，皆可應用於目前單片液晶面板之投影系統中。如圖 7 所示，在反射式的投影系統中，另增一細調面板的光路，以及在影像擷取之後，增加一個粗調與細調之位元分割處理，將粗調與細調影像信號分別輸出到各自的 LCoS 面板。另外，欲達成彩色投影，只要加上色彩切換器(Color Switch)或色彩濾片轉盤(Color Wheel)的同步控制即可。未來甚至可利用網板配合紅外線面板，產生高強度動態範圍與高解析度的紅外線影像，應用於紅外線景物投射系統，提供紅外線影像式飛彈之靜態或即時動態模擬。

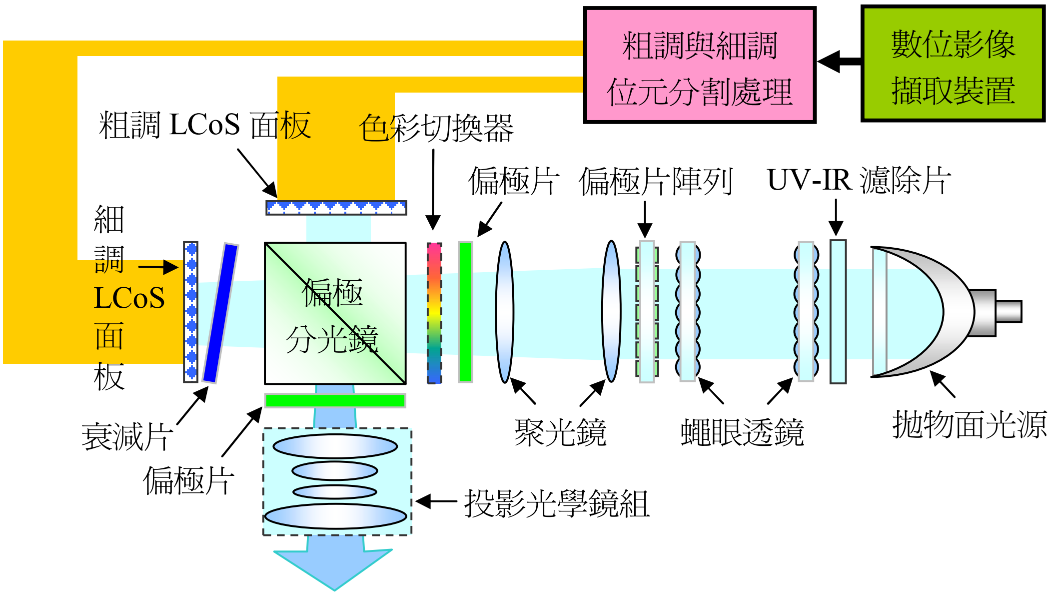


圖 7. 應用倍位元灰度影像產生器架構的反射式 LCoS 投影系統

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THE DOUBLE-BIT GRAY-LEVEL IMAGE PROJECTING SYSTEM

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1. Motivation

For an image projecting system, it is very important to display an image with high color depth, high resolution and high efficiency of illumination of lamp. Many types of micro display panels can be employed in the system, such as liquid crystal display (LCD), digital mirror device (DMD), and liquid crystal on silicon (LCoS) [1,2]. However, it is difficult for a cost-effective projection system to meet the requirements simultaneously, because of the functional limitations of the micro display panels. Is there any appropriate method from system viewpoints to overcome these problems?

Compared with a large panel display, a projection system is versatile to improve its performance regarding the gray levels of image displayed, from the wide choices of micro panels and projecting mechanisms. Furthermore, for enhancing the efficiency of illumination of lamp and reducing cost, the projection system utilizing minimum quantities of micro panel with on-axis optics seems to be the best design. These ideas prompted this research project.

2. Objective

The main purposes of this research are as follows:

1. Design an image projecting system with a capability to double the gray-level bits of image displayed. For example, using two 4-bit micro display panels can achieve an 8-bit image display.
2. The system can not only simplify the electronic circuitry of the micro panel in gray-level enhancement for increasing the color depth, but also improve the efficiency of illumination of lamp.

3. Apply this system to any scene projector which requires generating images with high dynamic range of radiant intensity. For example, it can be utilized in an infrared scene projector for static or dynamic simulations of an infrared imaging seeker.

3. Basic principle

A new image produced from the overlap of two images with the same gray levels, but different brightness, should contain more gray levels than those of the two individual images. The gray-level bits of the new image could be increased, if the brightness ratio is properly adjusted according to the gray levels of the two images. Fig. 1 shows that an example of double-bit gray levels how to be built when the overlap occurs. There are two 4×4 images with 2-bit gray levels, C_i and F_j, respectively. One has a higher brightness, called as the coarse-tune image, while the other has a lower brightness, called as the fine-tune image. If the brightness ratio between them is exactly equal to four, then an overlap image with 4-bit gray levels O_{ij} can be obtained, i.e. the gray-level bits of the new image has been doubled. The right side in Fig. 1 shows that the coarse-tune and fine-tune images have assigned with the same spiral tone but different types of gray-level variation. Obviously, the overlap image will be constructed as a spiral tone with an ascent type.

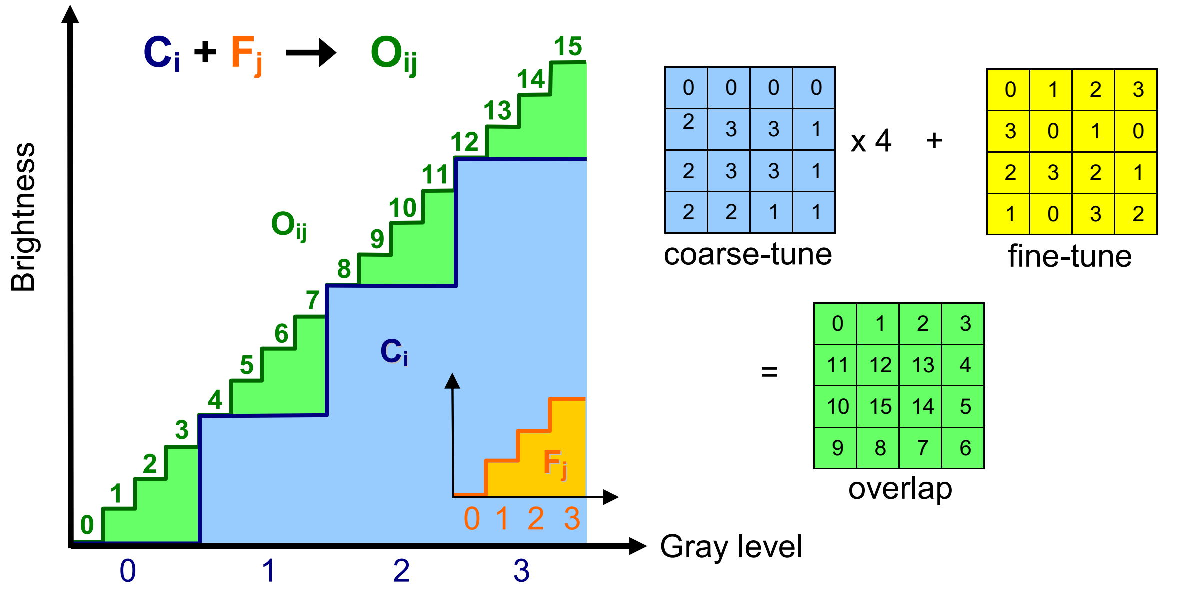


Fig. 1 An example of gray-level bit-doubling. Two gray-level bits can form 4 steps of $C_{i\,(i=0\text{-}3)}$, similarly, 4 steps of $F_{j\,(j=0\text{-}3)}$. If the brightness (step height) ratio between C_i and F_j, is 4 to 1, then 16 steps of $O_{ij\,(i=0\text{-}3;\,j=0\text{-}3)}$ can be obtained when the overlap occurs.

We can extend this concept to construct images with more gray-level bits. On the contrary, any image can be split into two images with less gray-level bits; we will develop an algorithm to process images and apply it to design a double-bit gray-level (DBGL) image projecting system in the following.

For a two-dimensional image G_o with n-bit gray levels 2^n, the gray level of pixel at coordinate (x,y) can be expressed as $g_o(x,y)$. We can split it into the coarse-tune and the fine-tune images, G_c and G_f, with gray-level bits m = n/2. If the two images display on two panels with an illumination ratio, 2^m : 1, and overlap mutually by using a beam splitter, then the gray levels of the overlap image will be recovered to the original one, $2^m \times 2^m = 2^{m+m} = 2^{2\,m} = 2^n$. The gray level of pixel at (x,y) in the G_c and G_f images, $g_c(x,y)$ and $g_f(x,y)$, obtained from processing the original image G_o, are expressed by

$$g_c(x,y) = g_o(x,y)/2^m \quad (1)$$

$$g_f(x,y) = \mathrm{MOD}[g_o(x,y),\ 2^m]. \quad (2)$$

This approach should be also suitable for a projection system using two more display panels. Inducing from the equations (1) and (2), a general formula can be derived for splitting the original image into two more images, is given by equation (3):

$$g_k(x,y) = \mathrm{MOD}[g_o(x,y),\ 2^{\alpha-\beta(k-1)}] \,/\, 2^{\alpha-\beta k} \quad (3)$$

$$\beta = \alpha / s, \quad (4)$$

where $g_k(x,y)$ is the gray level for pixel at (x,y) on the bit-sliced image k (k=1,2,…,s), α is the gray-level bits of the original image and must be divisible by s, the total number of the bit-sliced images, to get the gray-level bits β for each bit-sliced image. The brightness ratio between the original image and the bit-sliced image k is set to $2^{\alpha-\beta k}$: 1.

4. Simulations and Experiments

For evaluating the feasibility of the DBGL approach, the simulation architecture including a computer programming and an equivalent DBGL image projecting system has been developed. Fig. 2a shows the program flow chart. There are two groups of original images, test and demo, which can be chosen for bit-slicing according to equations (1) and (2). Before sent to a projector, each bit-sliced image must be processed with two procedures, gray-level extension and gamma correction, owing to a nonlinear effect of the projector. The two bit-sliced images, coarse-tune and fine-tune, are loaded from different PCs as shown in Fig. 2b. They are adjusted with a proper brightness ratio; arranged to go different optical paths, combined with a beam splitter, and then projected onto a screen.

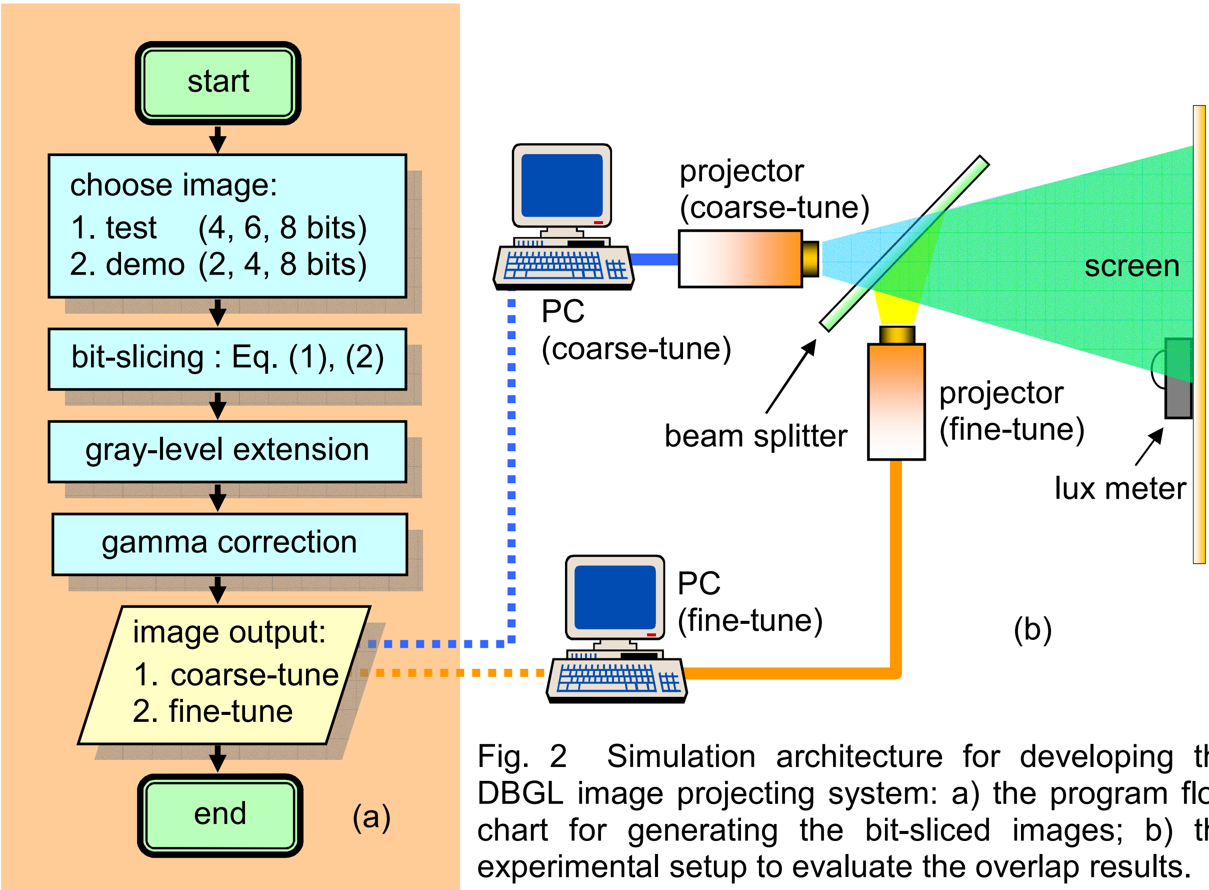
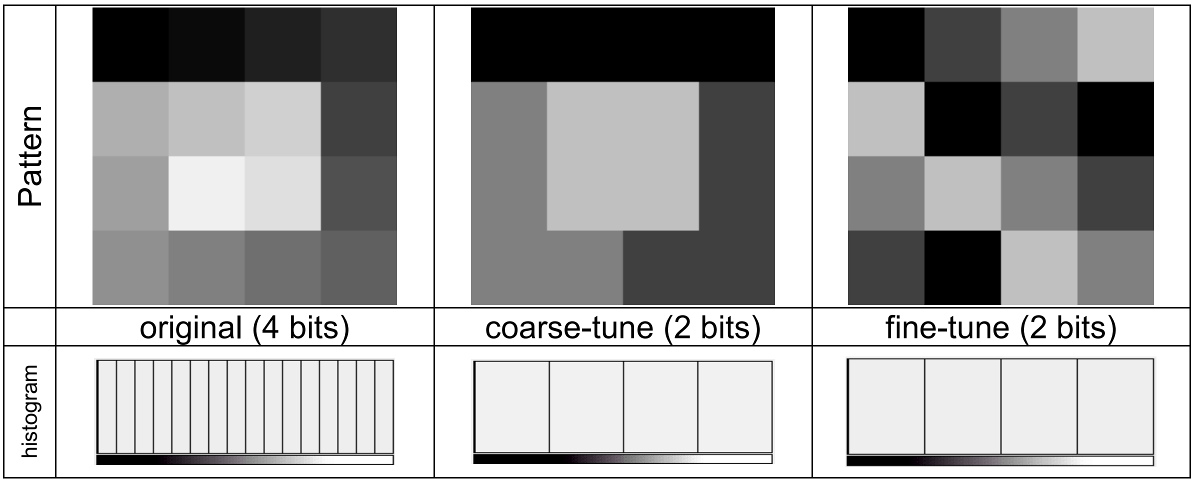
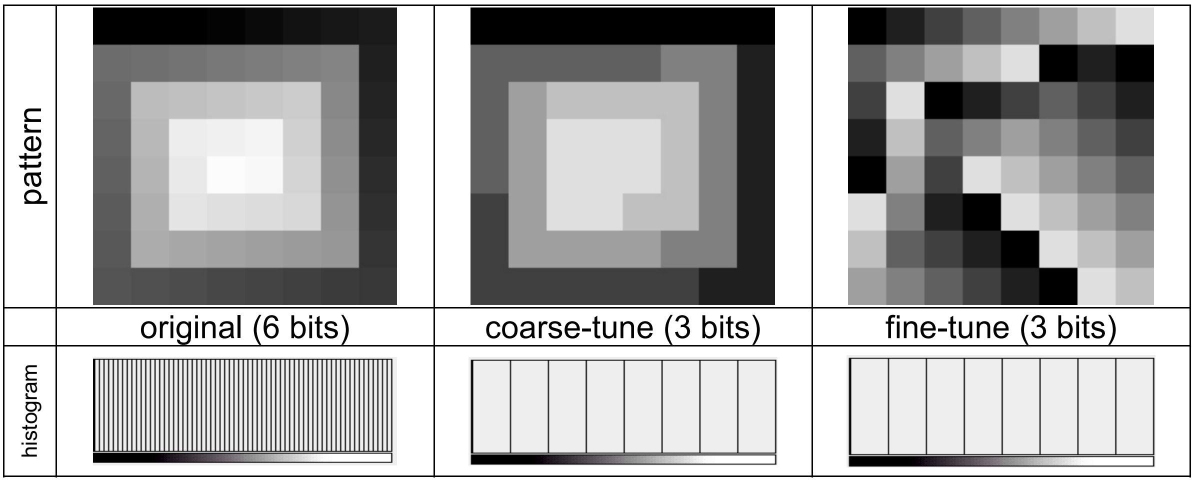


Fig. 2 Simulation architecture for developing the DBGL image projecting system: a) the program flow chart for generating the bit-sliced images; b) the experimental setup to evaluate the overlap results.

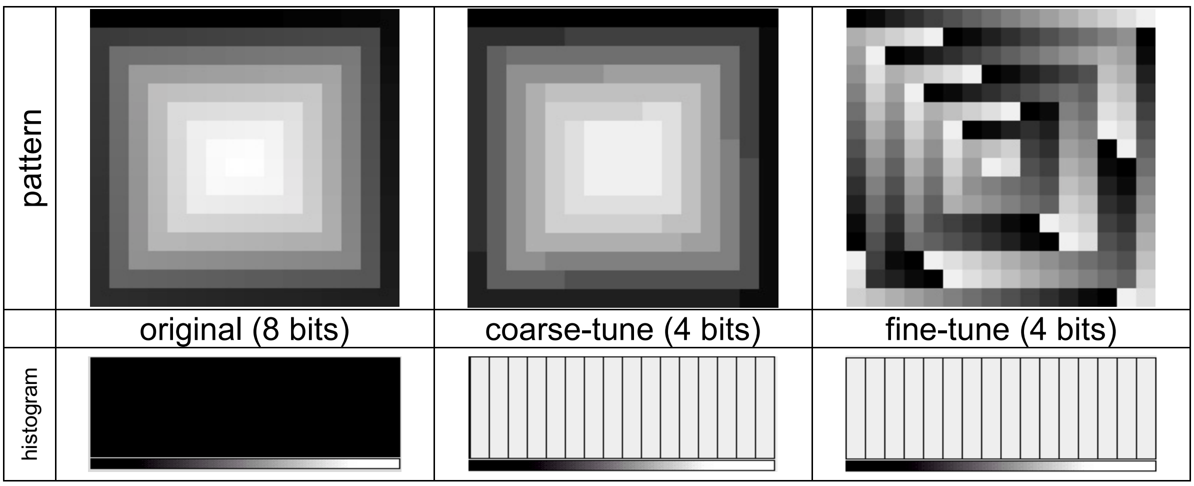
5. Results



(a)

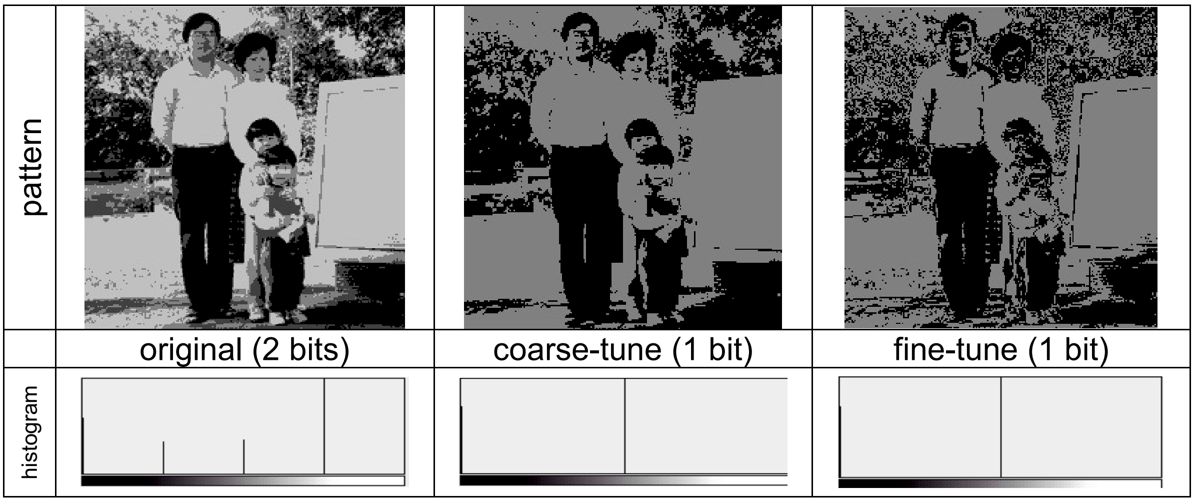


(b)

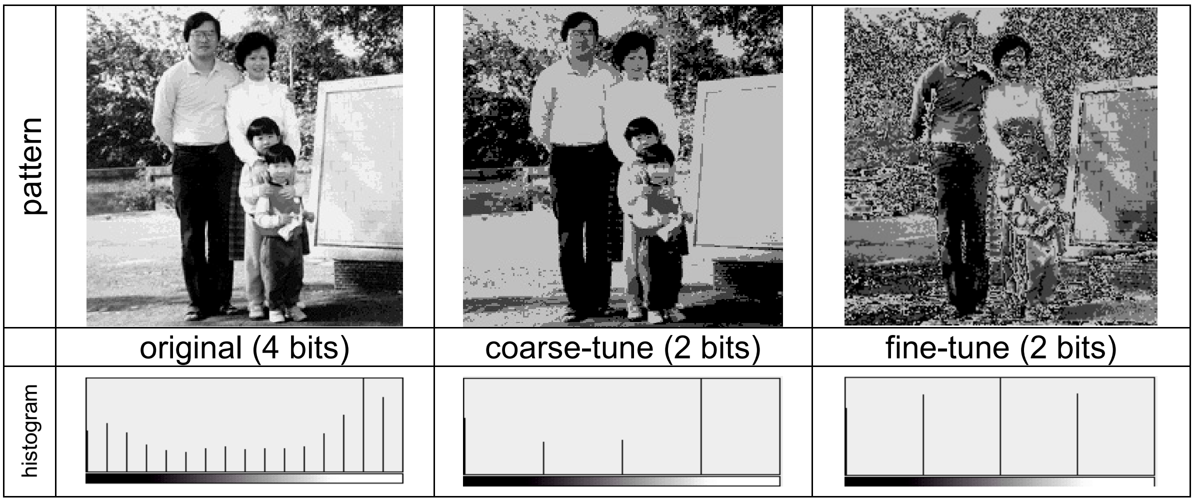


(c)

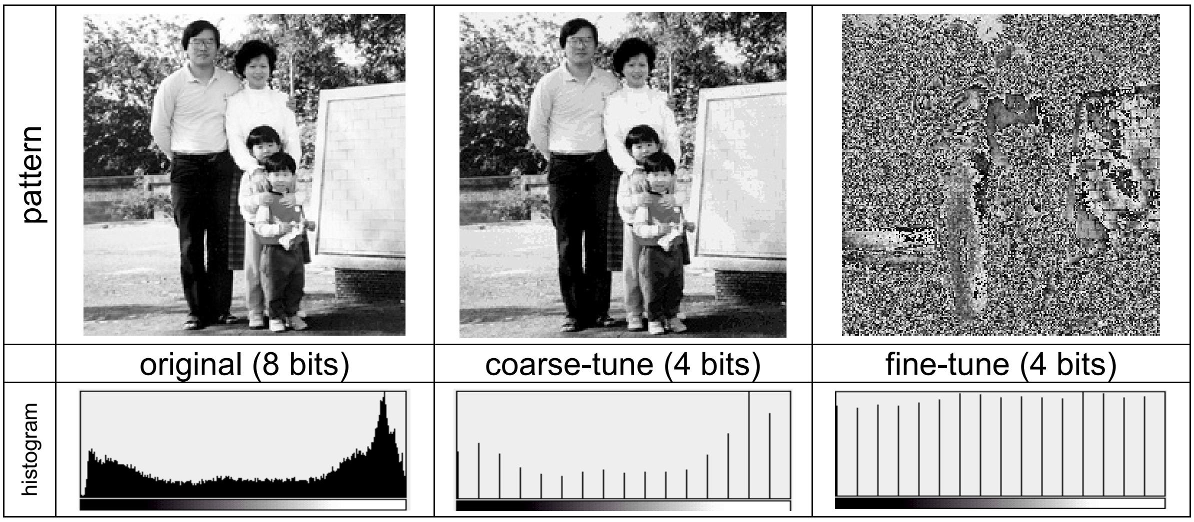
Fig. 3 Computing results of bit-slicing the original test images with various gray-level bits: a) 4; b) 6; c) 8.



(a)



(b)



(c)

Fig. 4 Computing results of bit-slicing the original demo images with various gray-level bits: a) 2; b) 4; c) 8.

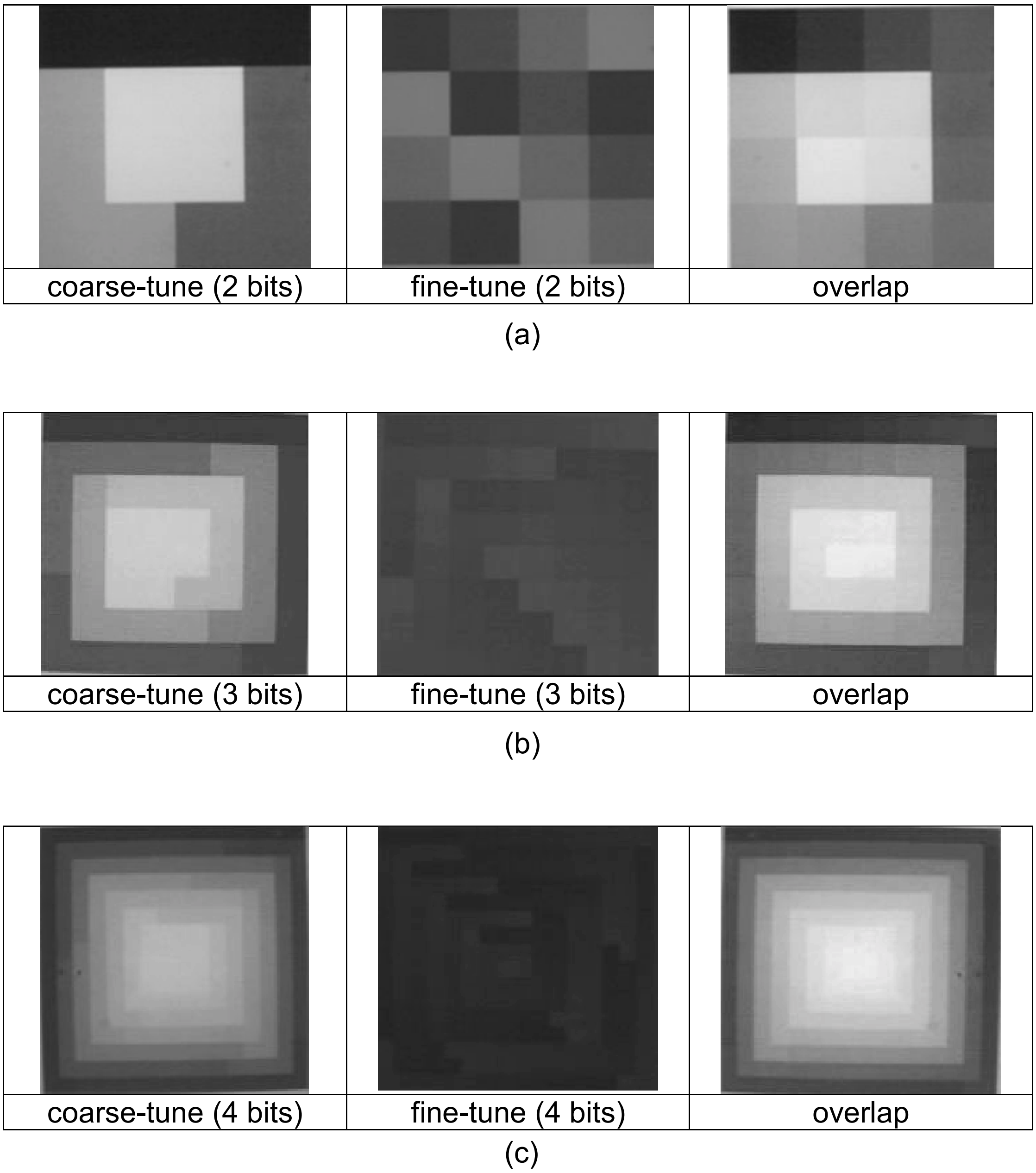


Fig. 5 Experimental results of overlapping the bit-sliced test images with various gray-level bits: a) 2; b) 3; c) 4.

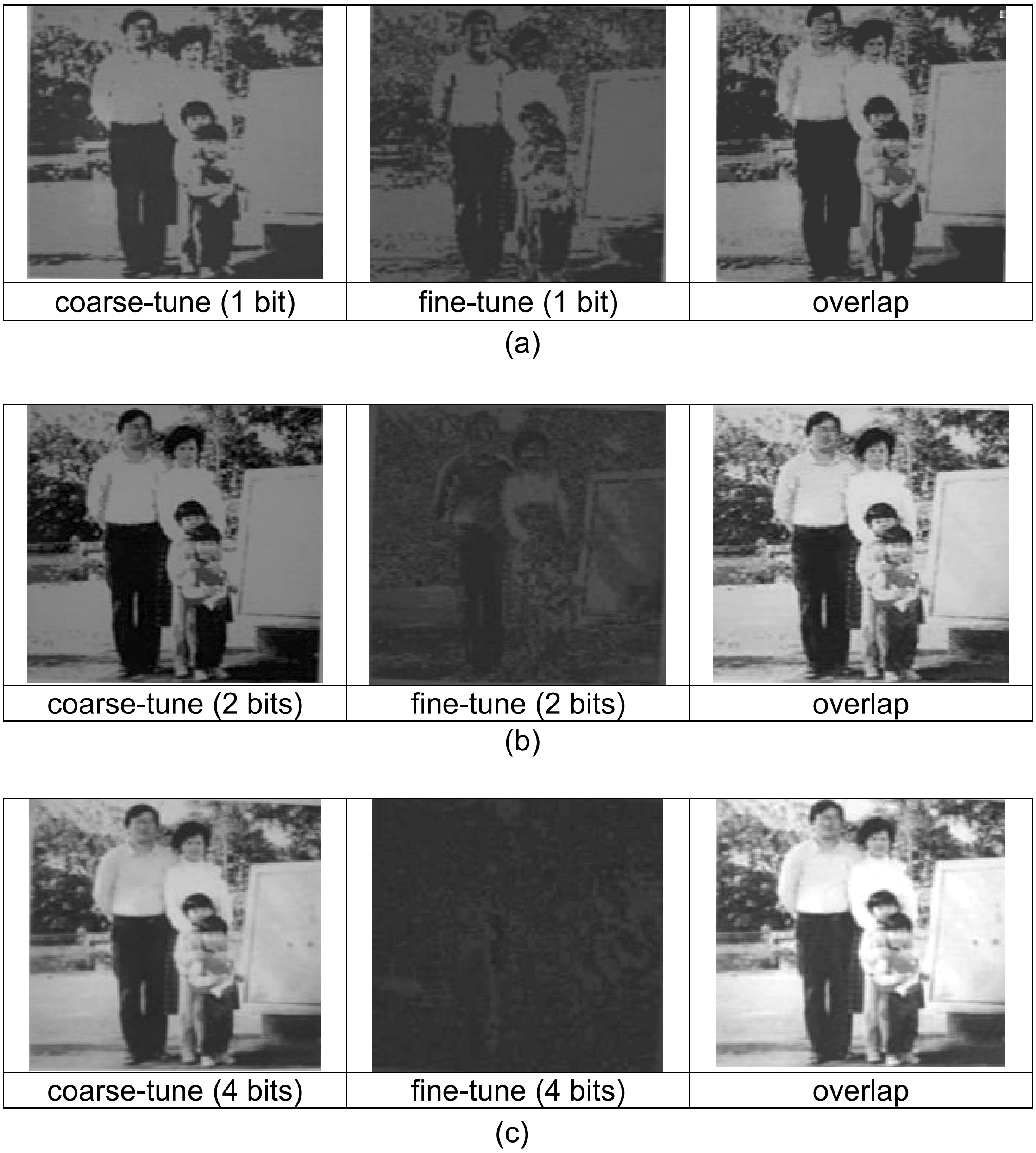
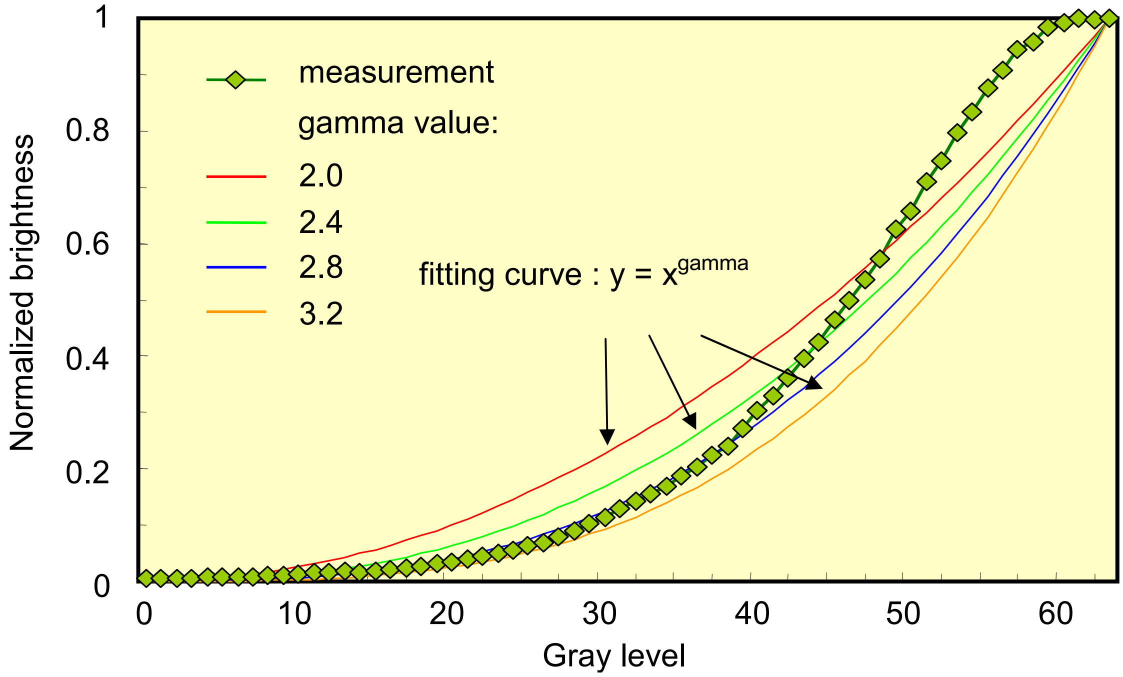


Fig. 6 Experimental results of overlapping the bit-sliced demo images with various gray-level bits: a) 1; b) 2; c) 4.

(a)



(b)

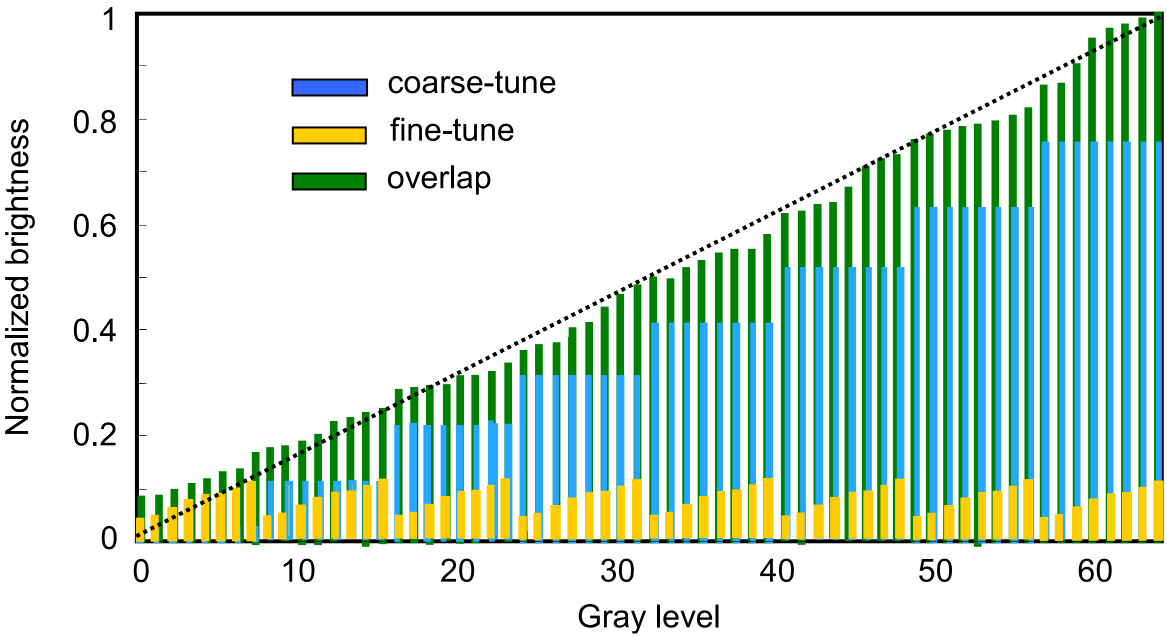


Fig. 7 Experimental results: a) gamma value measurement of the projector used in the research; b) plots of normalized brightness versus gray levels (3 bits) of coarse-tune, fine-tune, and overlap after gamma correction.

6. Discussion

1. The results in Fig. 3 and 4 show that the differences between coarse-tune and fine-tune images are relational with the gray level bits of the original image. The more bits, the more complicated fine-tune image, and the more differences are obtained. Each fine-tune image contributes a fine structure to smooth the roughness in the corresponding coarse-tune images. For the demo images, the smooth features are more evident.

2. The brightness ratio controlled between coarse-tune and fine-tune images in Fig. 5 and 6 can easily be done by using the graphic tools of any software package built in the PC. Certainly, it must be calibrated by a lux meter to meet the requirements for images with various gray-level bits.

3. The resolvable brightness levels of the overlap images are strongly dependent on the uniformity of the illumination on the display panel. Besides, the projector used in this study holds a gamma value about 2.4 as shown in Fig. 7a which will distort the linear relationship between brightness and gray levels. The value has been taken into account to correct the gray levels in the original images. Fig. 7b shows that the overlap results of the test images with 3-bit gray levels. Satisfying linearity of curve proves that the double-bit effect has been achieved.

4. A DBGL image projecting system combining two reflective type panels with on-axis optics can be proposed as shown in Fig.8. Digital video signals from the image grabber are feed into bit-slicing module and split into two parts for the coarse-tune and fine-tune panels, respectively. The illumination from a parabolic surface lamp is filtered through a UV-IR cutter and uniformed by using a pair of fly-eye lenses. It must be condensed by using two condensing lenses, and split by a beam splitter before reach two panels. The illumination reflected from the fine-tune panel is attenuated to lower brightness and combined with that of the coarse-tune panel by the beam splitter, and projected onto a screen. For color images display, a color switch or color wheel should be installed in front of the beam splitter for color sequential control. However, more components such as polarizer and polarizing beam splitter are needed for image contrast enhancement.

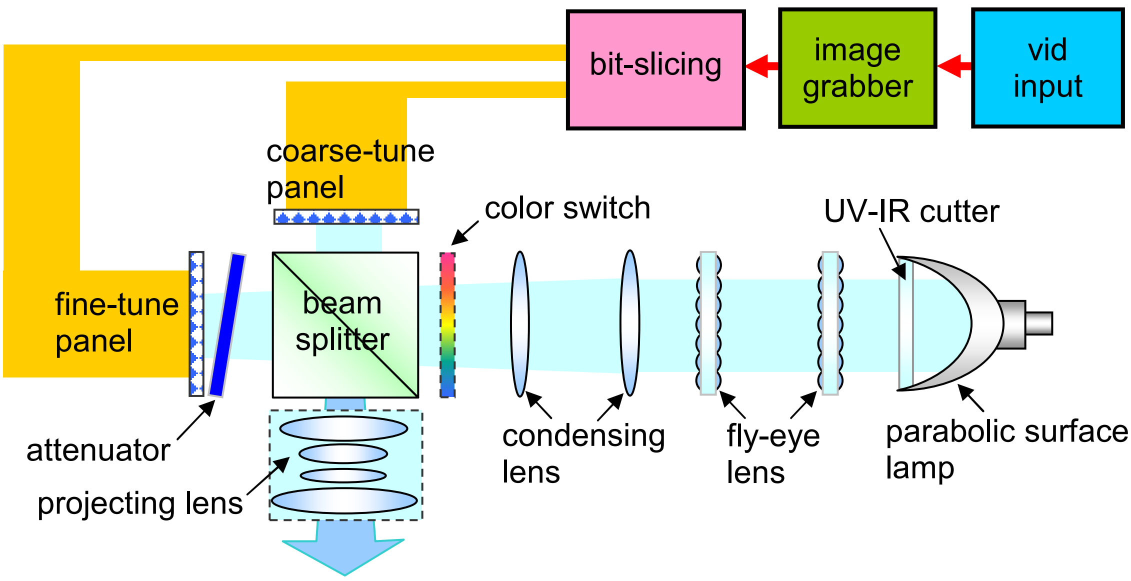


Fig. 8 Proposed DBGL image projecting system.

5. The two display panels used in the DBGL system can be reflective or transmissive type. The reflective system can achieve illumination efficiency as high as 2.5 times (from 25% improved to 62.5%) for 2-bit overlap images. The efficiency in this type is proportional to the gray-level bits inversely. On the contrary, it is proportional to the gray-level bits for the transmissive type.

6. Using halftone patterns to form various gray levels had been adopted in infrared scene projectors [3], however, there is a trade-off between gray levels and image resolution. The more gray-level bits, the less resolution can be obtained as shown in Fig.9. The DBGL approach could be the exact solution for current infrared projectors to overcome the dilemma and to enhance the dynamic range higher than 16 bits.

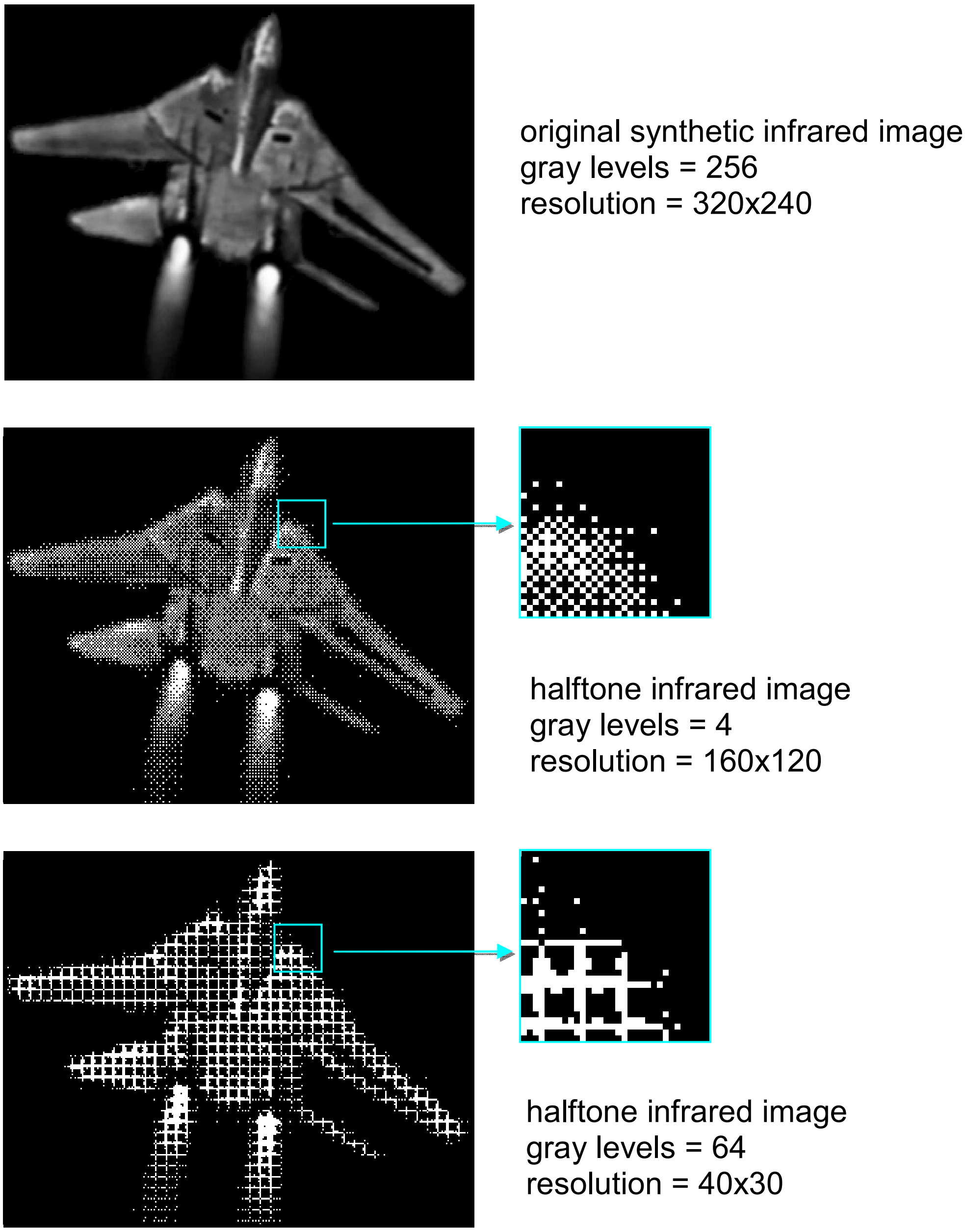


Fig. 9 Infrared image generation with halftone pattern gray levels.

7. Conclusion

A novel image generating mechanism used in projection systems to produce double-bit gray levels been presented. Currently, the concept is verified by computer programming and an equivalent projection system. Experimental results demonstrate the effect of image bit-slicing and overlapping for various gray-level bits successfully. A more bit-multiplying could be achieved by using two more panels and arranging their brightness ratio appropriately. The practical DBGL image projecting system has also been proposed, it seems that a reflective type panel, LCoS or DMD, is more suitable than a transmissive type regarding illumination efficiency improvement. This approach is expected for applications not only in visible light image projectors, but also in infrared scene generators, to highly increase the dynamic range of radiant intensity for static or dynamic simulations of infrared seeker. This research will continue to implement a practical projection system by using any type of micro display panels.

Acknowledgments

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Appendix

In this appendix, we will evaluate the lamp efficiency for transmissive and reflective types of the DBGL image projecting system.

A.1 Transmissive type

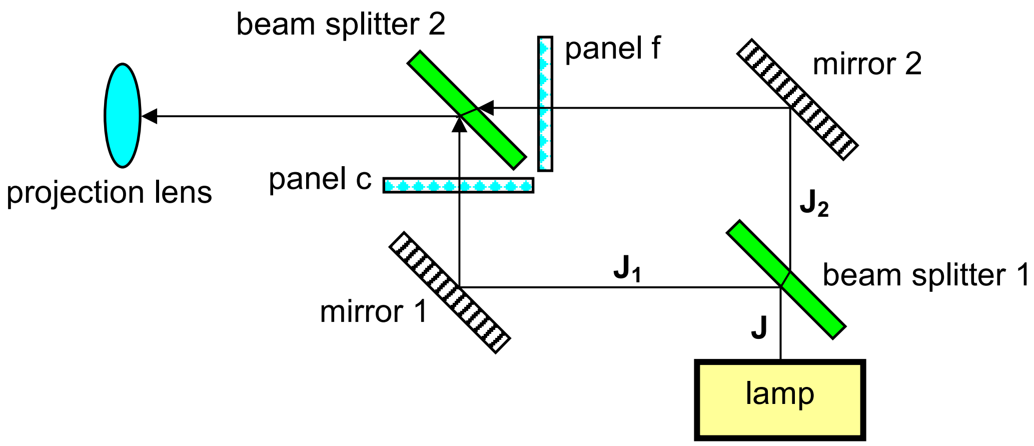

Fig. A1 The DBGL image projecting system utilizing two transmissive type display panels.

The illumination J emitted from lamp is split into two parts, J_1 and J_2, by beam splitter 1 as shown in Fig. A1. J_1 and J_2 will go through optical path 1 and 2, and be reflected by mirror 1 and 2, and then reach the coarse-tune panel c and fine-tune panel f, respectively. Two images are sieved out from panels and combined by beam splitter 2. Finally, the overlap image is projected onto a screen. The brightness on panel f needs to be attenuated to produce a brightness ratio 1: 2^m with that of panel c. We can control the transmittance of beam splitter 1 and 2 to meet this requirement. The brightness of pixel at coordinate (x,y) of the overlap image can be given by,

$$b_o(x,y) = r^2 \cdot g_c(x,y) \cdot J + t^2 \cdot g_f(x,y) \cdot J \qquad \text{(A.1)}$$

where r, t is the transmittance, the reflectance of beam splitter 1 and 2, generally, r + t = 1. Moreover, for the DBGL system, r and t must meet the condition, $r^2 : t^2 = 2^m : 1$. The waste illumination W_r occurred at beam splitter 2 can be given by

$$W_r = 2\,r\,t = \frac{2\sqrt{2^m}}{(\sqrt{2^m}+1)^2}. \qquad \text{(A.2)}$$

The illumination efficiency can be expressed as $E_r = 1 - W_r$, it is proportional to the gray-level bits of bit-sliced images. For example, m=2, E_r=5/9; m=4, E_r=17/25.

A.2 Reflective type

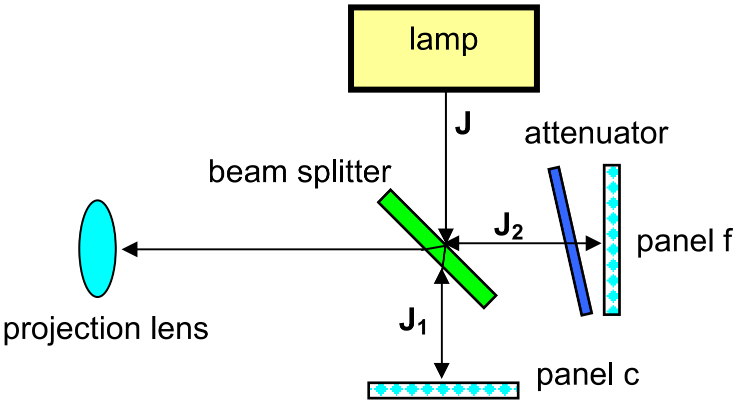

Fig. A2 The DBGL image projecting system utilizing two reflective type display panels.

For a reflective type system, the mirrors used in the transmissive type can be omitted, but an attenuator must be added. This type presents a compact architecture as shown in Fig. A2. The illumination reflected from panels c and f are combined by beam splitter, then projected onto a screen. Brightness in optical path 2 is attenuated by an attenuator with transmittance τ and reflectance ρ to $1/2^m$ times of that of optical path 1. The brightness of pixel at coordinate (x,y) of the overlap image can be given by,

$$b_o(x,y) = r \cdot t \cdot g_c(x,y) \cdot J + r \cdot t \cdot \tau^2 \cdot g_f(x,y) \cdot J \qquad \text{(A.3)}$$

where $r + t = 1$, $\tau^2 = 1/2^m$. The waste illumination W_t occurred at beam splitter and attenuator can be given by

$$W_t = r^2\tau^2 + t^2 + r\rho + r\rho\tau = (1+\frac{1}{2^m})t^2 - (1+\frac{1}{2^m})t + 1 \qquad \text{(A.4)}$$

Differentiate Eq. (A.4), we will find that W_t has a minimum value when t=0.5, it can be expressed by

$$W_t = \frac{3}{4}(1-\frac{1}{2^m}) \qquad \text{(A.5)}$$

The illumination efficiency can be expressed as $E_t = 1 - W_t$, it is proportional to the gray-level bits of bit-sliced images inversely. For example, m=1, E_t=5/8; m=2, E_t=7/16; m=4, E_r=19/64. For a conventional on-axis system, i.e. m=0, E_t is only equal to 1/4. Therefore, the DBGL system with reflective type will increase the illumination efficiency from 25% improved to 62.5% for 2-bit overlap images.

評　　語

（1）本作品是設計一新型的影像投射系統，可將影像顯示的灰度位元增加一倍，是具有創新的研究主題。

（2）利用數值模擬與實驗之方法，証實其灰度值及影像可視性之改善，有其完整的研究成果，具有實用價值之潛力。

（3）作者表達能力及方法與結果之講解，顯示生動而充分了解。

（4）本作品研究的成果，顯示相當優良，論文展示也清楚且優良。