IMAGE ENHANCEMENT IN PROJECTORS VIA OPTICAL PIXEL SHIFT AND OVERLAY

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SETUP

- Known target image I_T with size $2n \times 2n$
- Pixel in I_T is denoted by $I_T(i,j)$ where $1 <= i,j <= 2n$
- I_T is normalised: $0 <= I_T(i,j) <= 1$
- Projector with resolution $n \times n$

GOAL

- Find image I with size $n \times n$
- I is shifted and overlay with itself to enhance I_R
- I_R is perceptual close to I_T
- I is shifted by s_X, s_Y : $\{-0.5, 0.5\}$

$$I_T(i,j) \approx \frac{1}{2} I\left(\left\lceil \frac{i}{2} \right\rceil, \left\lceil \frac{j}{2} \right\rceil\right) + \frac{1}{2} I\left(\left\lceil \frac{i}{2} + s_y \right\rceil, \left\lceil \frac{j}{2} + s_x \right\rceil\right)$$

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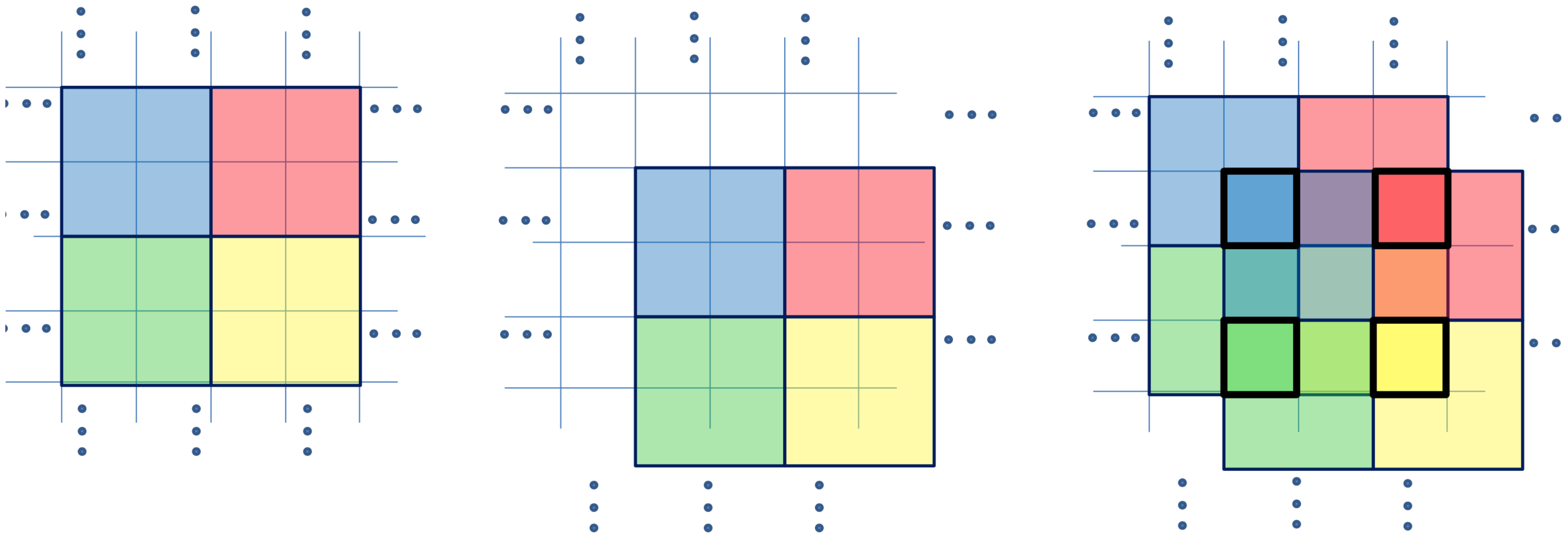
Equation 1



SHIFT AND OVERLAY OF $S_X = S_Y = 0.5$

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Figure 1

EQUATION

- $\mathbf{AI} \approx \mathbf{I_T}$
- I_T is a known column vector of size **4n^2 x 1**
- **A** is a known matrix of size **4n^2 x n^2**
- I can be found by solve the constrained **linear least square problem**

SOLVING EQUATION

- $\mathbf{AI} \approx \mathbf{I_T}$ (2) can be re-expressed as $\min_{\mathbf{I}} \frac{1}{2}\mathbf{I}^T\mathbf{A}^T\mathbf{A}\mathbf{I} - \mathbf{I}^T\mathbf{A}^T\mathbf{I_T} \quad s.t. \quad 0 \leq \mathbf{I} \leq 1$ (SAJADI Behzad et al. 2013 Equation 3)
- defining $J = \mathbf{A}^T\mathbf{A}$
- $h = \mathbf{A}^T\mathbf{I_T}$
- This equation is solved with **Gaussian Belief Propagation** which is faster as **Jacobi** or **Gauss-Seidel** methods. Although it does **not always return** a **solution**.

SOLVING EQUATION

$$\max_{\lambda,\gamma\geq 0} \min_{\mathbf{I}} \frac{1}{2}\mathbf{I}^T J\mathbf{I} - \mathbf{I}^T h - \mathbf{I}^T \gamma + (\mathbf{I} - 1)^T \lambda$$

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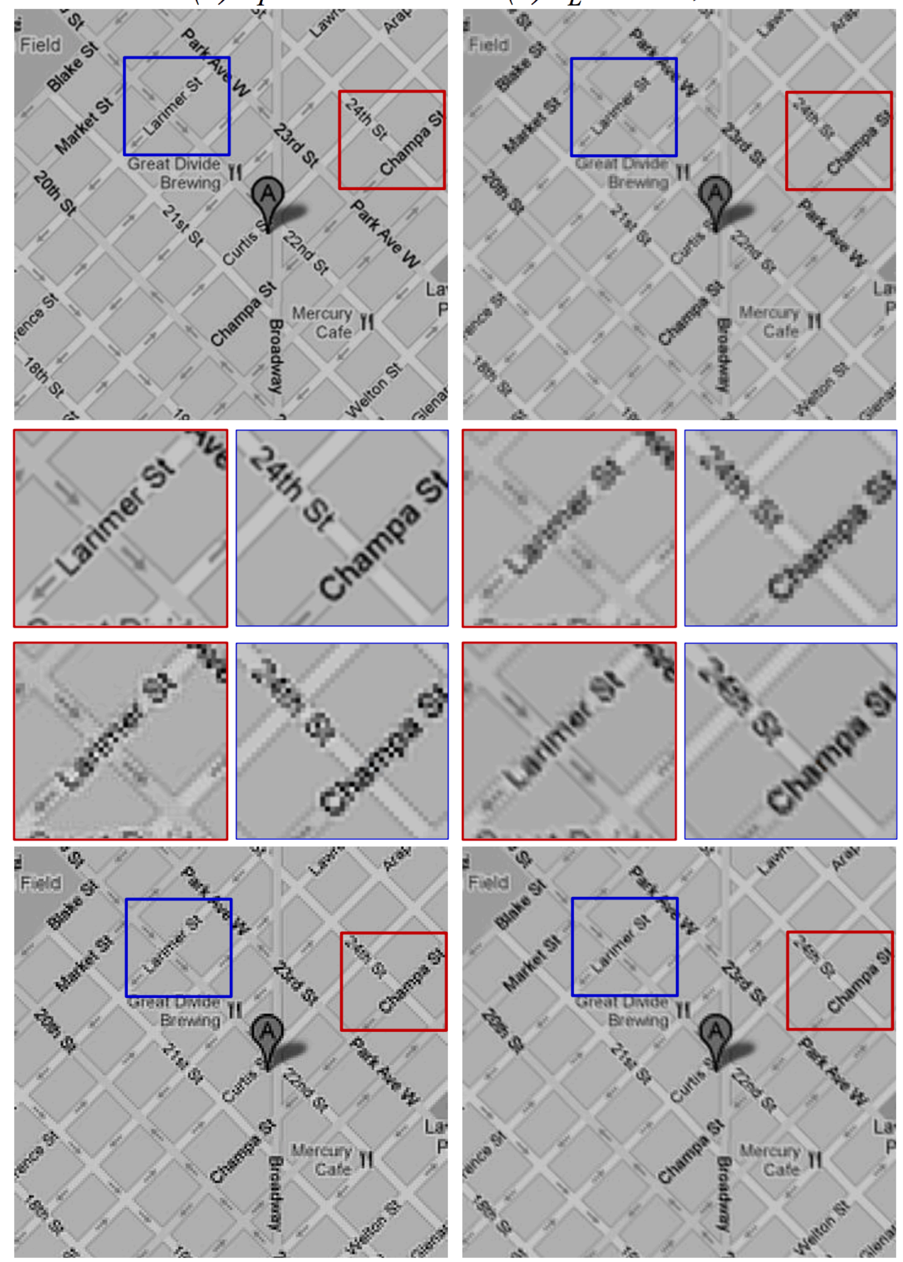
Equation 4

EVALUATION

- Mean CIELAB distance value
- SSIM index [Wang et al. 2004, Image quality assessment: From error measurement to structural similarity]

(a) I_T (b) I_L: ΔE=8.3, SSIM=0.63



(c) I (d) I_R: ΔE=6.5, SSIM=0.75

COMPARISON OF TARGET IMAGE (UP, LEFT), DOWNSAMPLED IMAGE (UP, RIGHT), OPTIMAL INPUT OF IMAGE (DOWN, LEFT) AND RESULTING IMAGE WITH OPTIMAL INPUT (DOWN, RIGHT)

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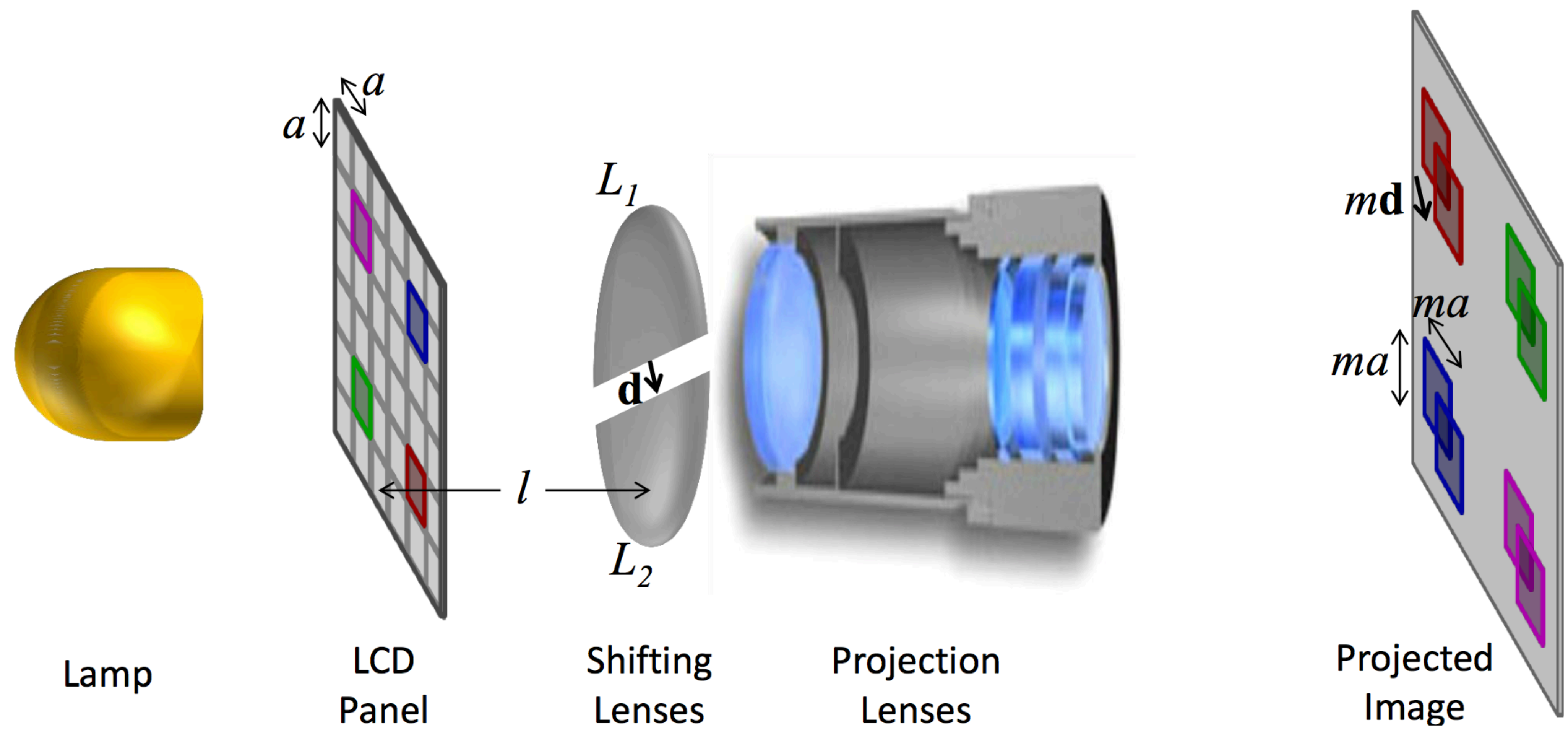
Figure 2



OPTICAL SETUP OF THE PROJECTOR WITH SHIFTING LENSES

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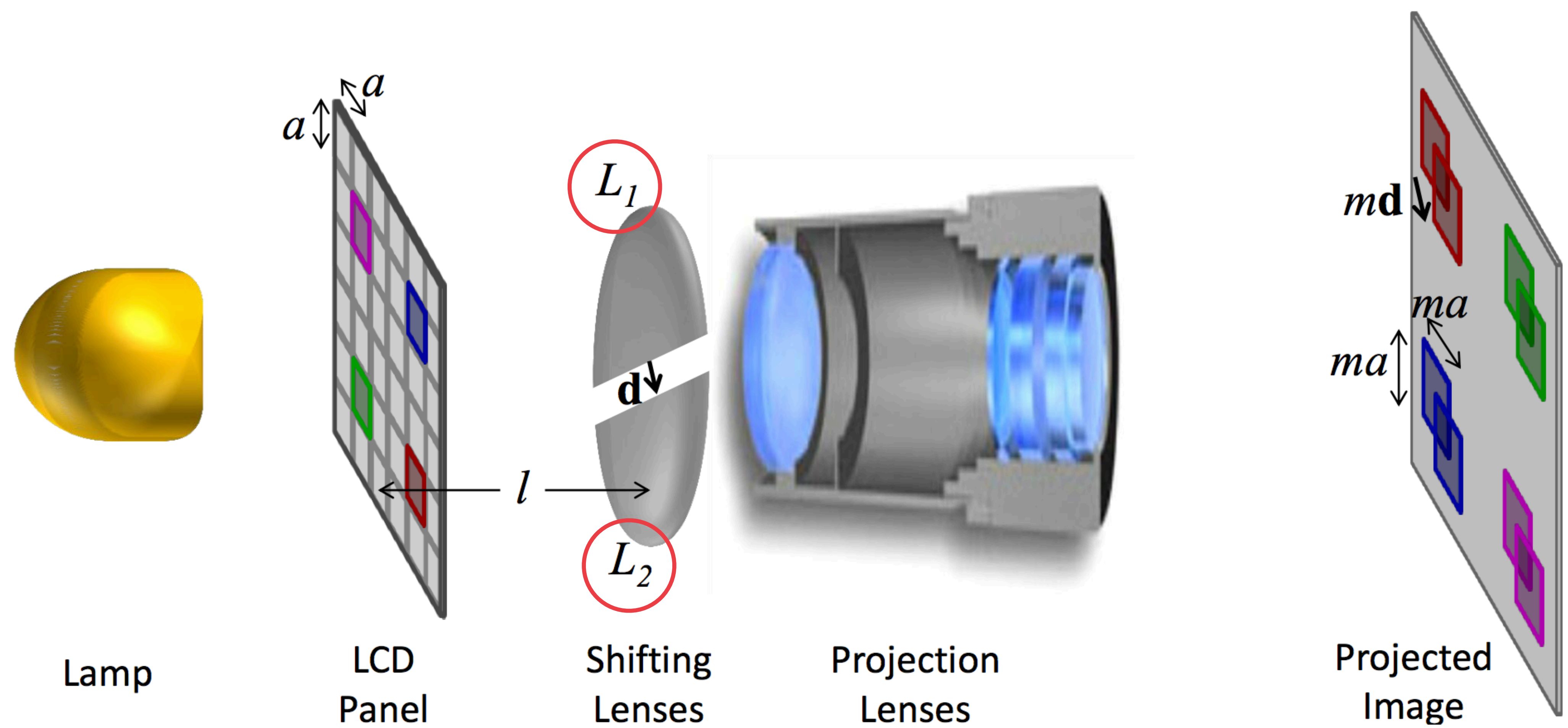
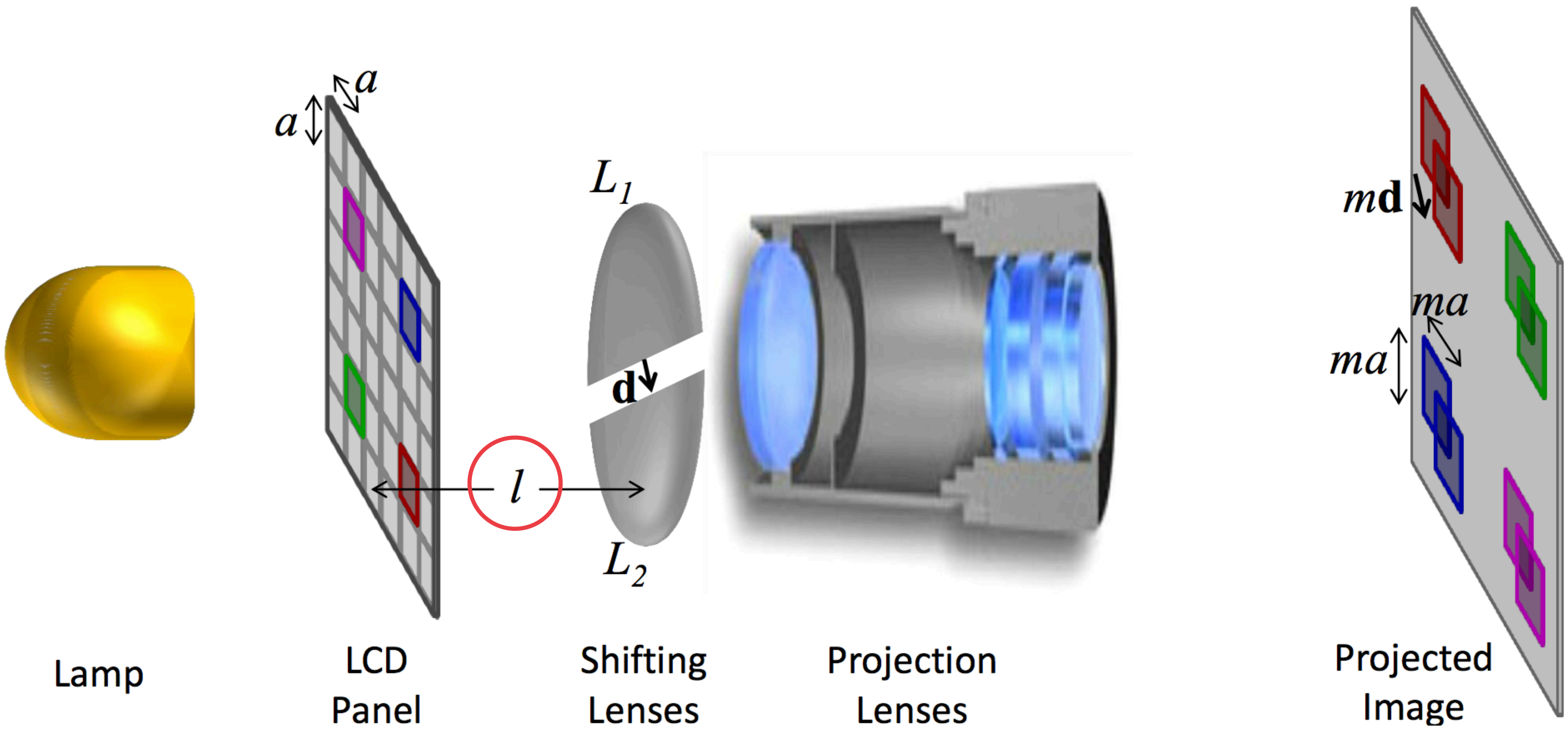
Figure 3

SHIFTING LENSES



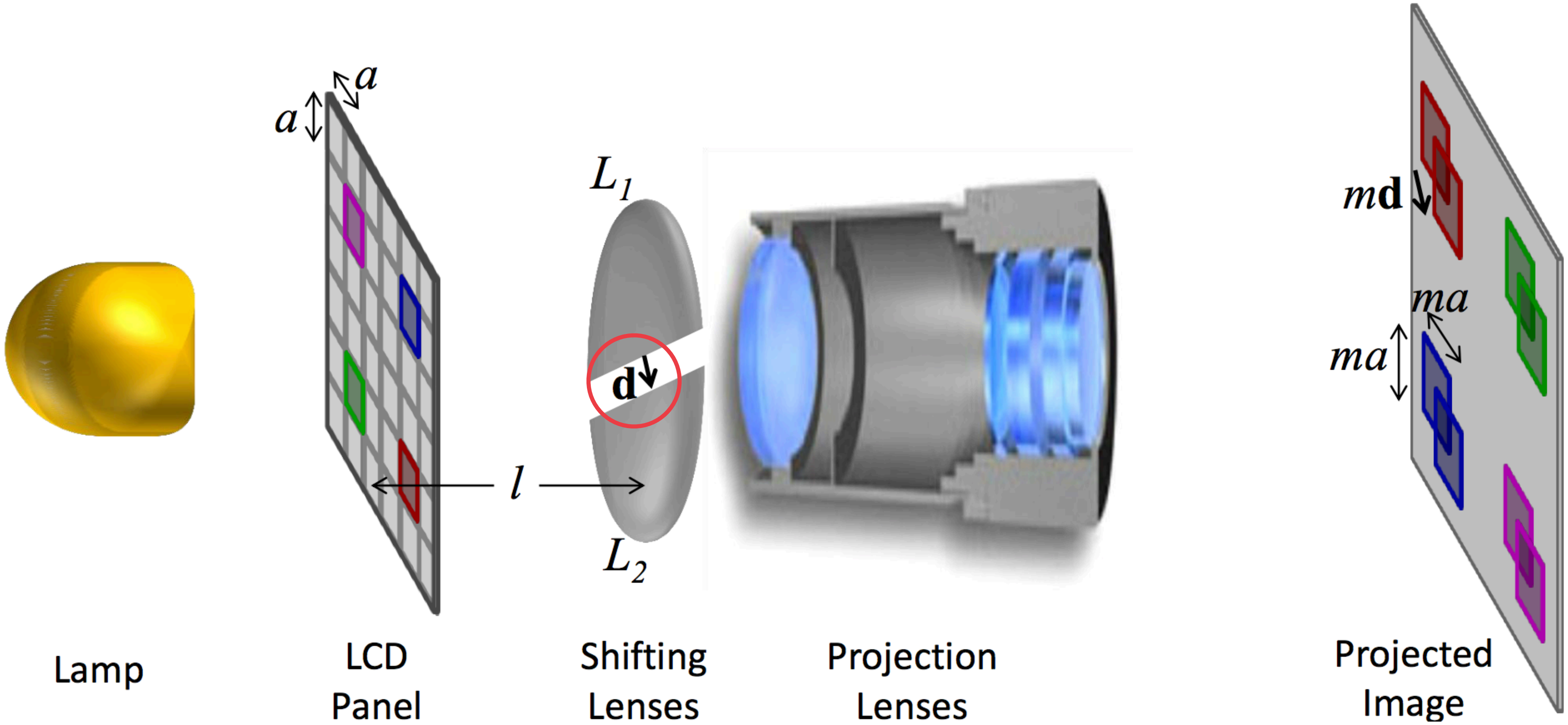
The lenses have the same focal length f

MAGNIFICATION



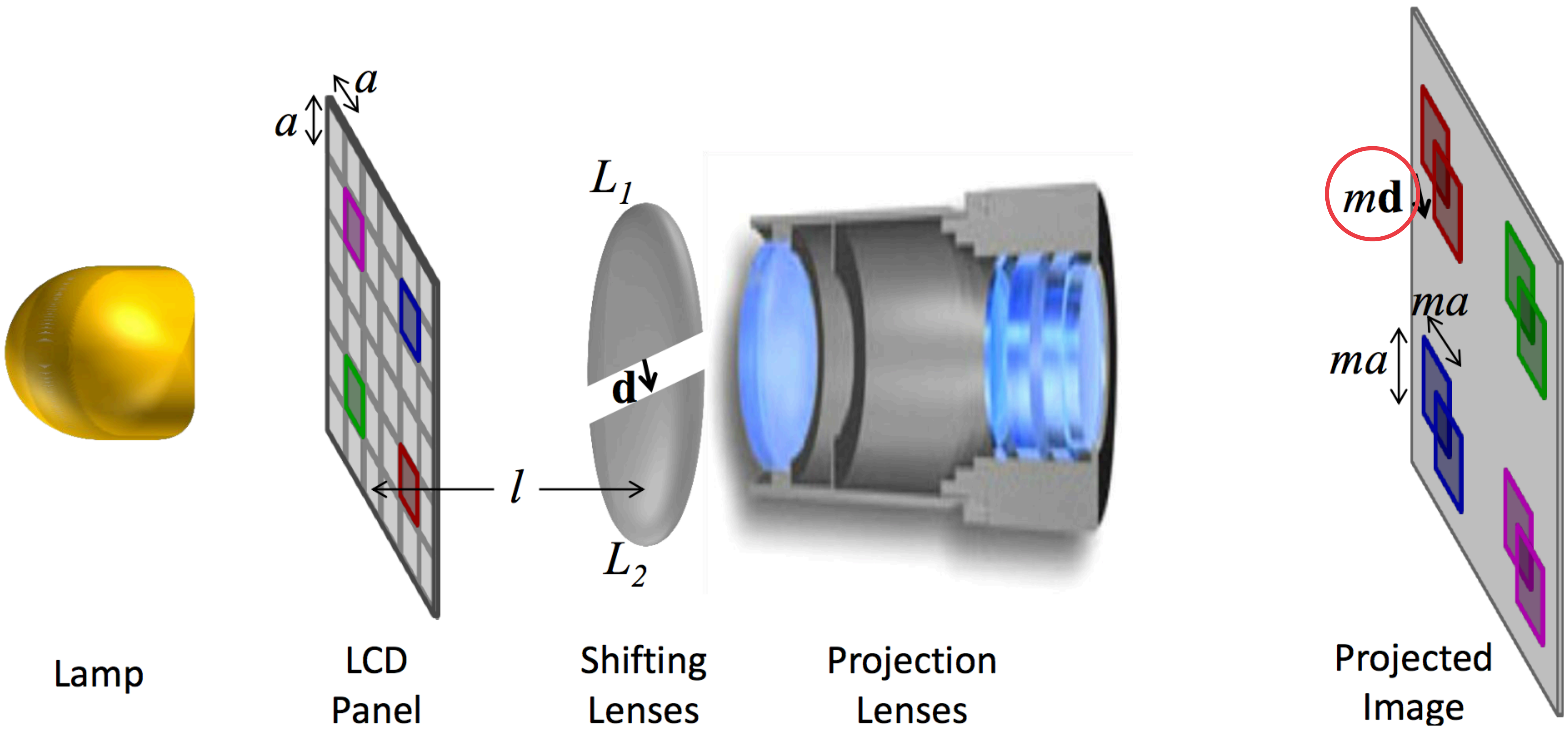
When placed at distance l from the LCD panel, we obtain a magnification m = f/(l-f)

DISTANCE BETWEEN OPTICAL AXES



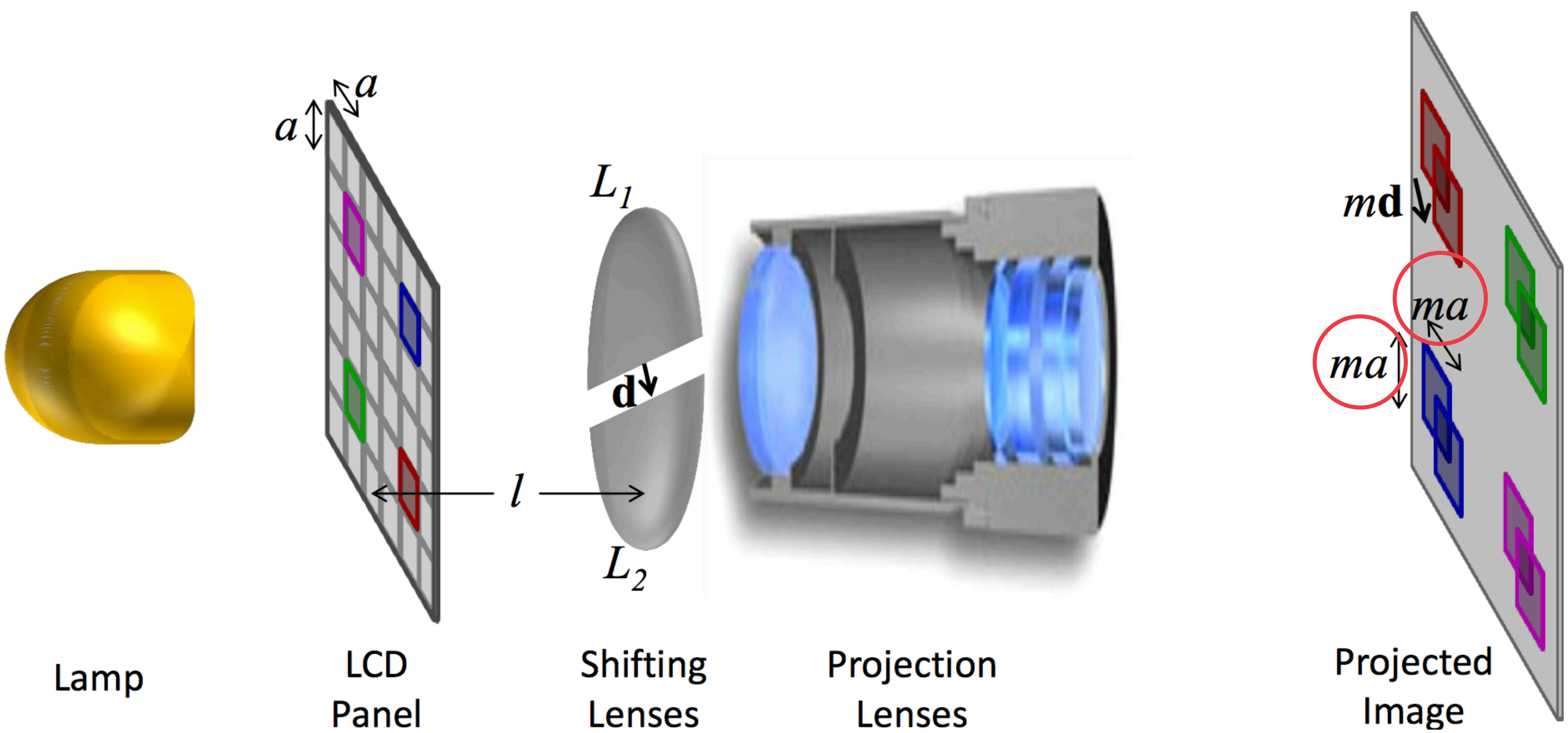
$$d=(d_X,d_Y)$$

MAGNIFICATION OF DISTANCE



Pixel p is at position m and position md, because it is shifted by d

MAGNIFICATION OF UNITS



Pixel p is with unit size a, is magnified as ma

Shift between two copies is therefore:

$$(s_x, s_y) = \frac{(1+m)\mathbf{d}}{ma} = \frac{(1+\frac{f}{l-f})\mathbf{d}}{\frac{f}{l-f}a} = \frac{\frac{l}{l-f}\mathbf{d}}{\frac{f}{l-f}a} = \frac{l\mathbf{d}}{fa}$$

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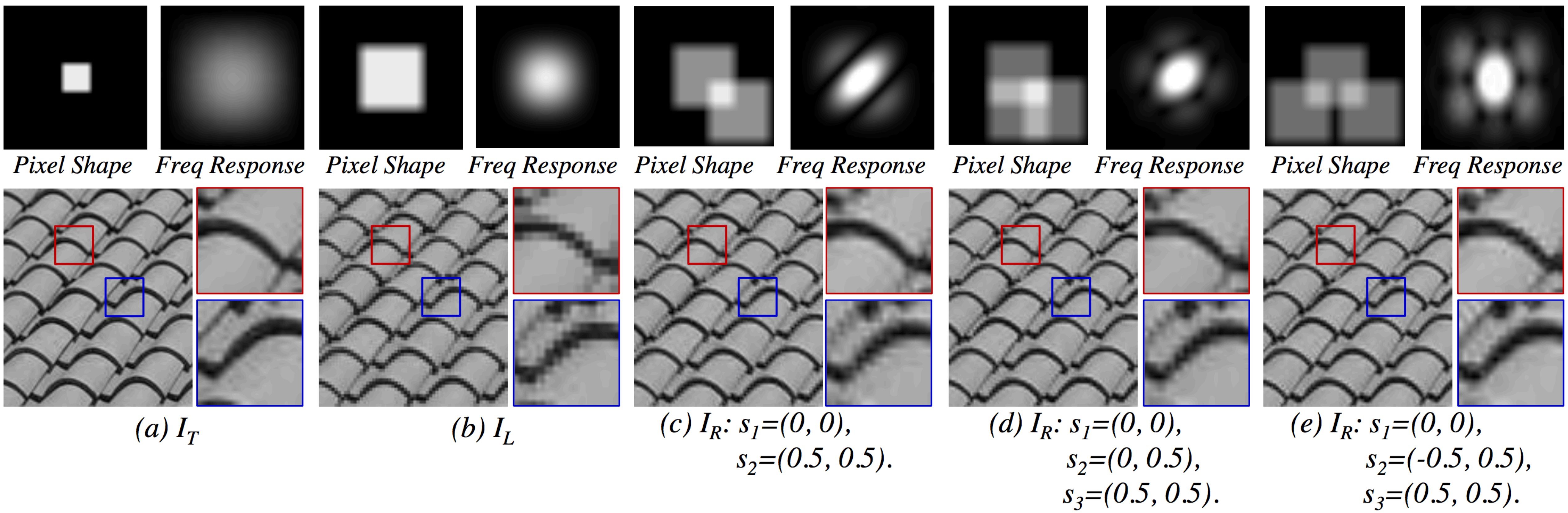
Equation 5

IMPROVEMENTS

- Multiple Overlays
- General Shifts
- Multiple Channels

MULTIPLE OVERLAYS

- Instead of using only two pixels, use multiple (m) pixels
- Can be obtained by using k Lenses
- Equation 1 can be as following $I_T(i,j) \approx \frac{1}{m}\sum_{p=1}^{m} I\left(\left\lceil \frac{i}{2} + s_y(p) \right\rceil, \left\lceil \frac{j}{2} + s_x(p) \right\rceil\right)$



COMPARISON OF (A) TARGET IMAGE, (B) LOW RESOLUTION IMAGE, (C) RESULTING IMAGE WITH SHIFT ONE SHIFT OF (0.5,0.5), (D) RESULTING IMAGE WITH TWO SHIFTS OF (0,0.5) AND (0.5,0.5) AND (E) RESULTING IMAGE WITH TWO SHIFTS OF (-0.5,0.5) AND (0.5,0.5)

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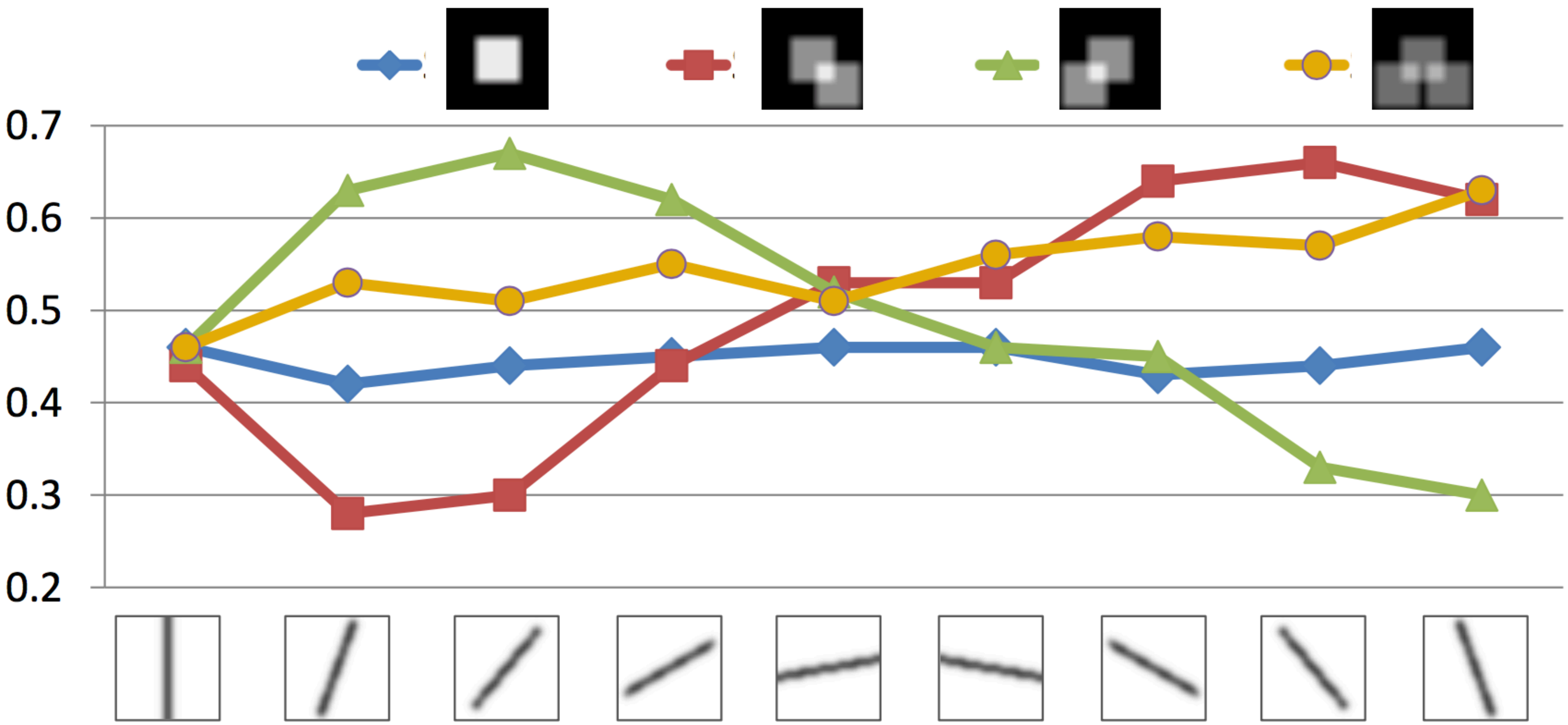
Figure 4



HOG COMPUTED WITH DIFFERENT PIXEL SHAPES. BLUE IS ONLY A LOWER RESOLUTION, WHEREAS GREEN AND RED ARE PIXEL SHAPES WITH ONLY ONE SHIFT AND RED IS A PIXEL SHAPE WITH TWO SHIFTS

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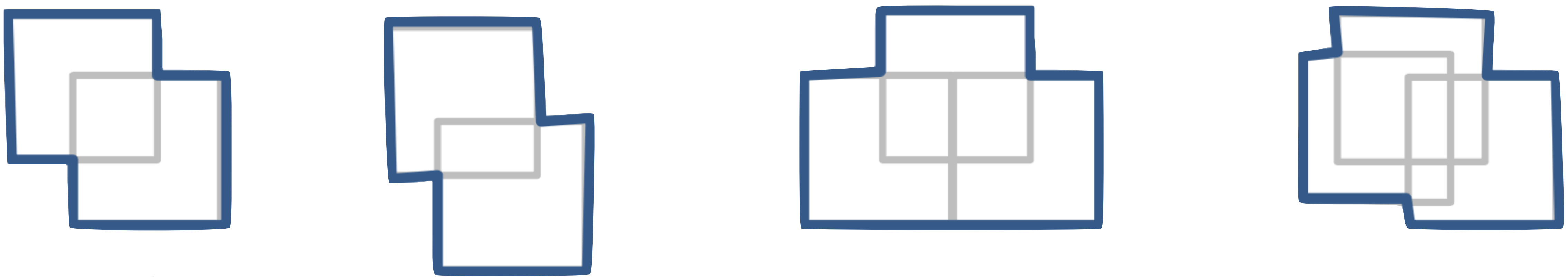
Figure 5

GENERAL SHIFTS

- Instead of shifting by half a step, shift by something between 0 and 1
- Dimensions of **A** and I_T change relative to **k**
- Equation 1 change as following $I_T(i,j) \approx \frac{1}{2} I\left(\left\lceil \frac{i}{k} \right\rceil, \left\lceil \frac{j}{k} \right\rceil\right) + \frac{1}{2} I\left(\left\lceil \frac{i}{k} + s_y \right\rceil, \left\lceil \frac{j}{k} + s_x \right\rceil\right)$



DIFFERENT PIXEL SHAPES WITH DIFFERENT K VALUE FOR A SHIFT

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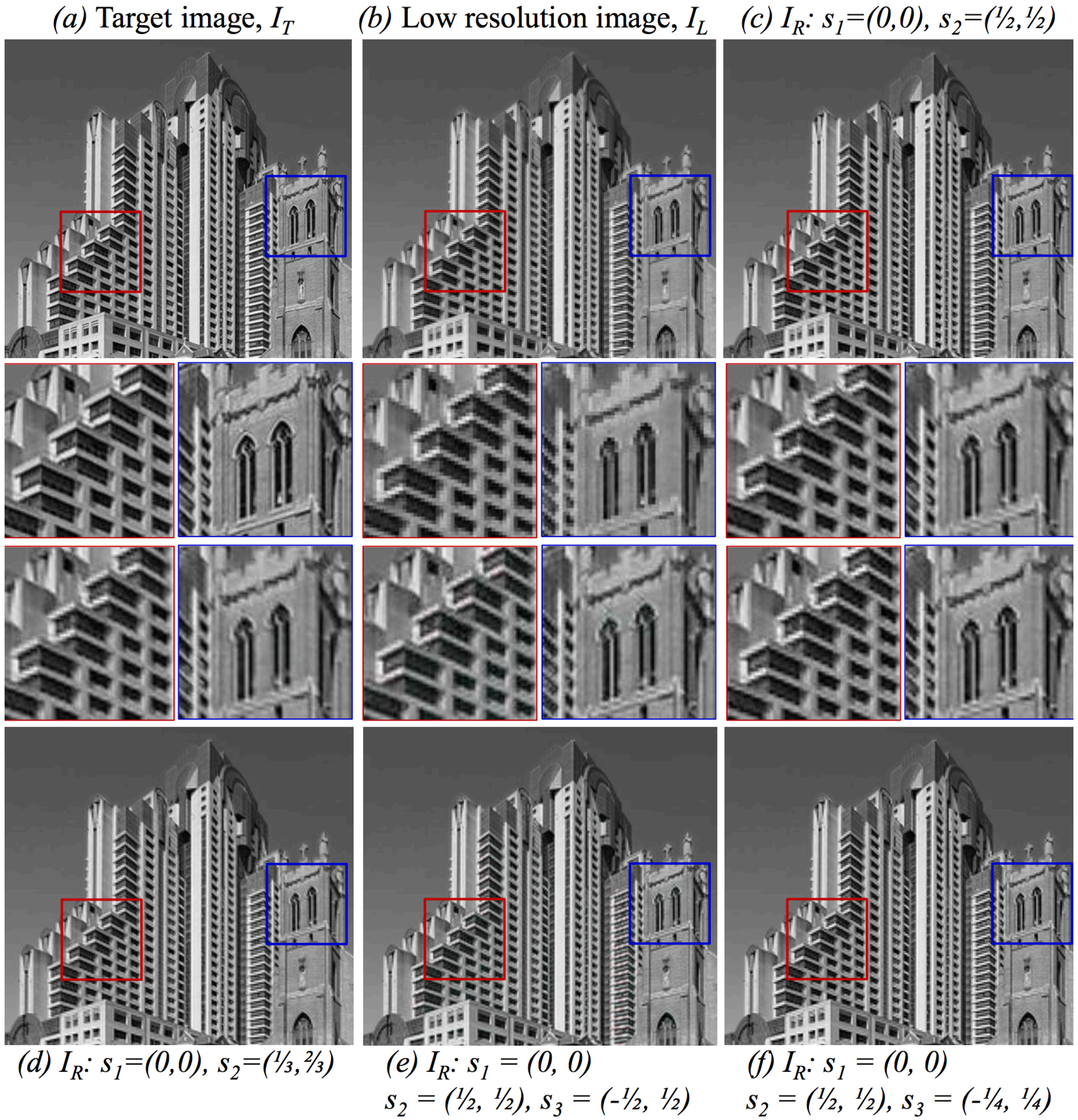
Figure 6



COMPARISON OF THE RESULT OF THE TARGET IMAGE, THE LOW RESOLUTION IMAGE, A SINGLE SIMPLE SHIFT OF (0.5,0.5), A SINGLE SHIFT OF (0.33…, 0.66…), TWO SHIFTS OF (0.5,0.5),(-0.5,0.5) AND TWO SHIFTS OF (0.5,0.5),(0.25,0.25)

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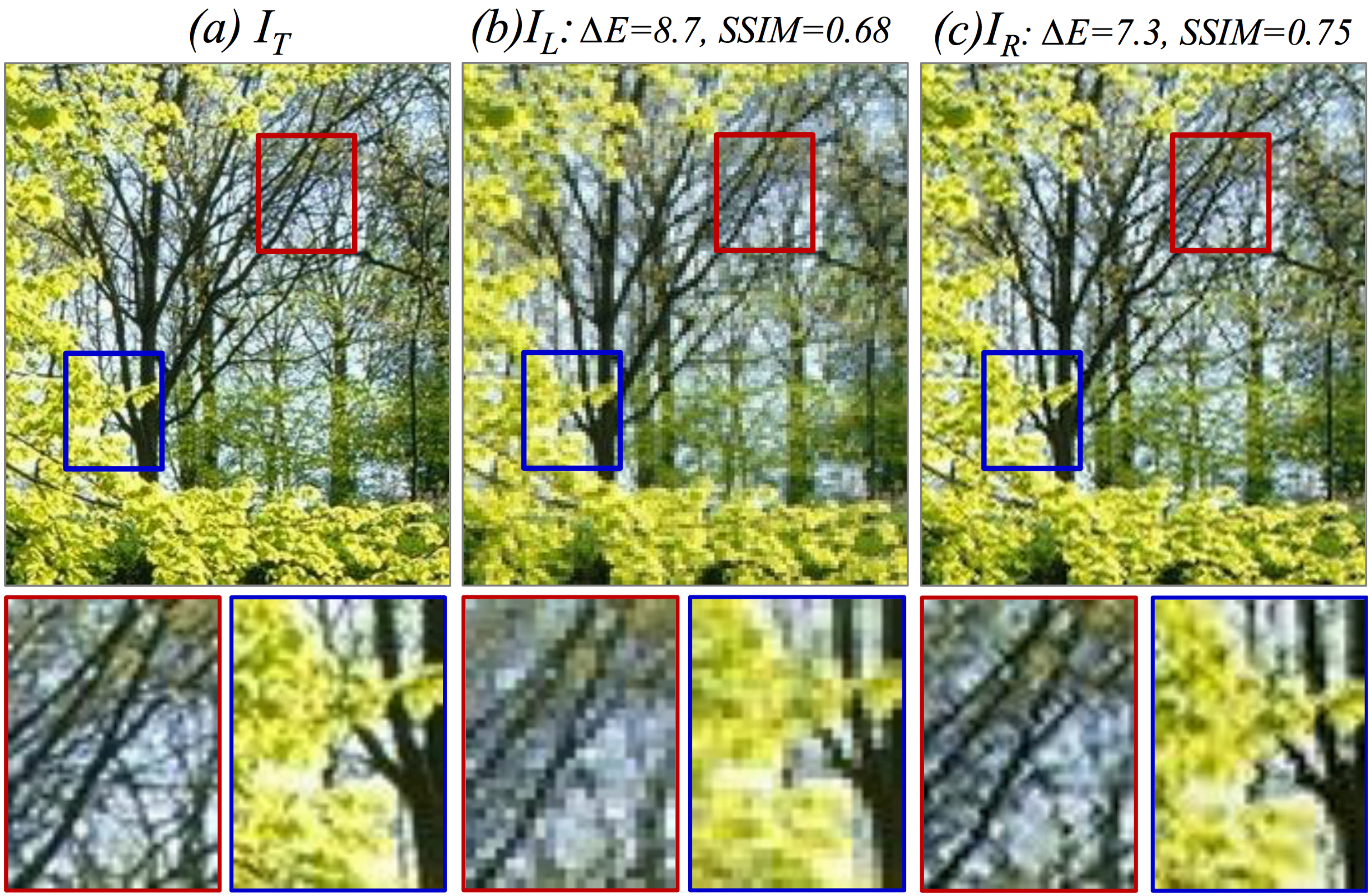
Figure 7

MULTIPLE CHANNELS

- Instead of calculation everything for one image, it has to be calculated for the r, g and b channels
- Illumination does not have to be the same
- Equation 1 change as following $I_t^l(i,j) \approx \frac{1}{m}\sum_{p=1}^{m} I^l\left(\left\lceil \frac{i}{2} + s_y(p) \right\rceil, \left\lceil \frac{j}{2} + s_x(p) \right\rceil\right), l \in \{r,g,b\}$



COMPARISON OF A COLOR IMAGE WITH A LOW RESOLUTION IMAGE AND AN RESULTING IMAGE WITH TWO HALF STEP SHIFTS

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Figure 8

DISADVANTAGES

Thank you for your attention

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