Color Visibility Images and Measures of Image Enhancement

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OUTLINE

- Introduction
- Quantative Enhancement Measures
- EME for grayscale and color images
- Visibility Grayscale Images

  Weber-Fechner visibility images

  Michelson visibility images
- Visibility Measures Related to EMEs
- Color Visibility Images
- Examples
- References
- Summary

Abstract

- In this paper, we introduce the human visual system-based several new
  a) methods to visualize the very small differences in intensities without big changes of primary image information
     and
  b) measures that quality the visuality of both grayscale and color images.
- Several illustrative examples are presented.
- The proposed concepts can be used for many image processing, computer vision and recognition system applications.

Introduction

- The goal of this paper is to improve the visibility (detail discrimination of an image) of gray, color and video sequences in different scales.
- We introduce the human visual system based several new gradient operators for color images. The concepts of Weber-Fisher law-related visibility operators and images are presented as important characteristics of the image. We also consider the visibility images related to the Michelson contrast and EME type measures as tools in face detection, and facial image representation.
- To measure the quality of images, the EME measure is used for image enhancement of grayscale images and color images transformed to quaternion space.
- This measure can be compared with the Weber-Fechner law of the human visual system. Weber stated that the smallest noticeable change in the image intensity is proportional to the original intensity (before adding the difference).

Example of color image enhancement

Figure 1 shows the color "peppers" image in part (a). The color image composed by the measure of enhancement of visibility color images (EVCI) of three color components of the image is shown in (b) and the grayscale component of the color EVI in (c).

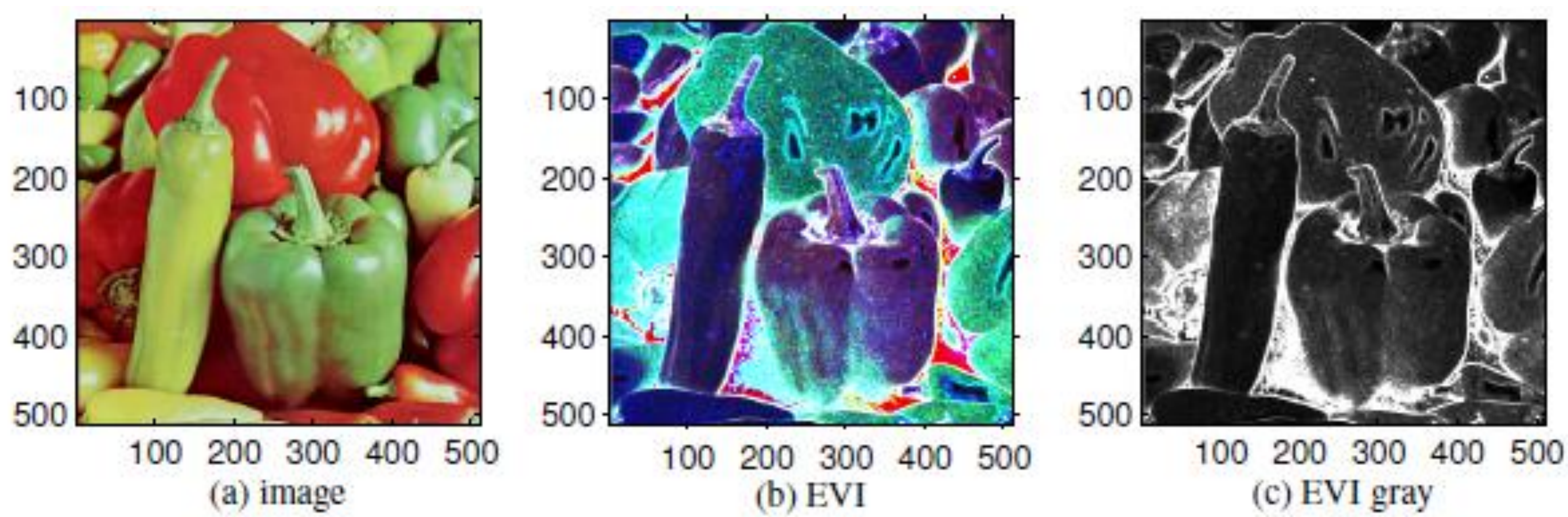


***Figure 1**. (a) The color image, (b) the EVCI, and (c) the grayscale image of the EVCI.*

Quantitative Enhancement Measure

The image enhancement measure estimation (EME) is based on the idea of calculating a visibility image which is defined as the ratio of maximums and minimums. The image $f_{n,m}$ of size $N \times M$ is divided by small blocks of size 7×7 each, for instance, with number along the dimensions $k_1 = \lfloor N/7 \rfloor$ and $k_2 = \lfloor M/7 \rfloor$ with the floor rounding. The quantitative measure of the image after enhancement, $f_{n,m} \rightarrow g_{n,m}$, is defined by

$$EME(g) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} 20 \ln \frac{\max_{k,l}(g)}{\min_{k,l}(g)}. \qquad (1)$$

Here, $\max_{k,l}(g)$ and $\max_{k,l}(g)$ respectively are the maximum and minimum of the image $g_{n,m}$ inside the (k, l)th block.

$EME(g)$ is called a measure of enhancement of the image f,

$$EME(g) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} 20 \left[\ln \max_{k,l}(g) - \ln \max_{k,l}(g) \right].$$

It shows the range of intensity of the image in the logarithm scale. The measure $EME(g)$ determines the average-block scale of intensity in the image.

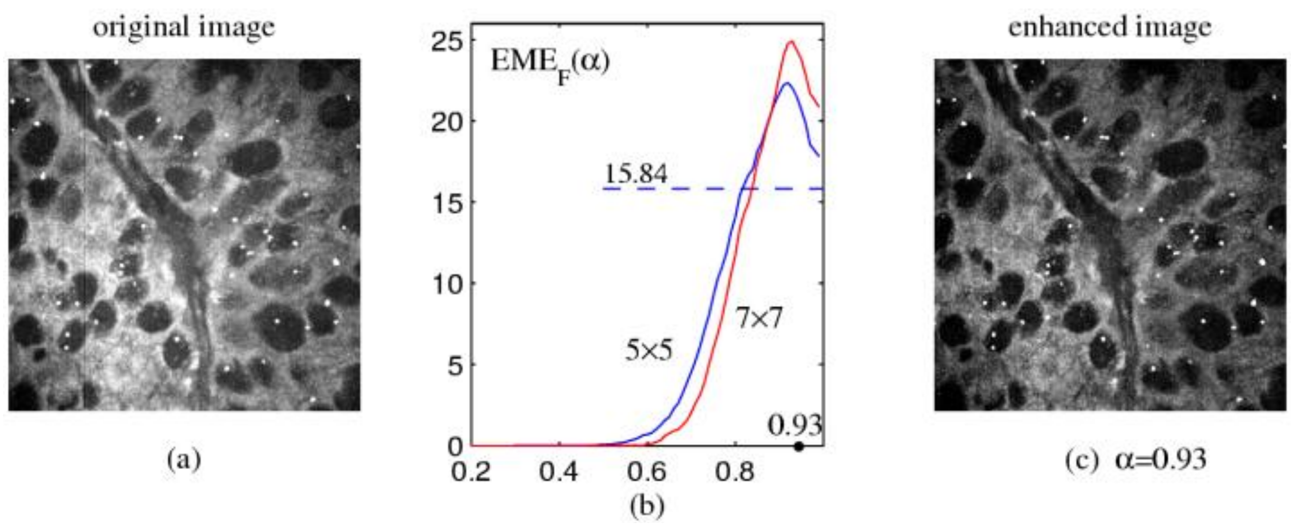


Figure 2. *(a) The original grayscale image, (b) two graphs of the EME measure,* $EME(\alpha)$*, and (c) the image enhanced by 0.93-rooting method.*

The Weber-Fechner law of the human visual system states that in the image intensity, the smallest noticeable change, Δf, is proportional to the original intensity f,

$$|\Delta f|/f \approx \text{const} \approx 0.015.$$

Difference operator Δf at the pixel (n, m) can be written

$$(\Delta f)_{n,m} = f_{n,m} - \text{Mean}\left(f_{n,m}\right),$$

The first order Weber visibility image is defined as

$$W(f)_{n,m} = k\,\frac{\left|f_{n,m} - \alpha\text{Mean}\left(f_{n,m}\right)\right|}{f_0 + f_{n,m}}, \qquad (2)$$

where k and $\alpha > 0$ are constants.

Example 1: Figure 3 shows the “cameramen” image in part (a) and the Weber visibility image in part (b), which is calculated by using the 3×3 cross-window.

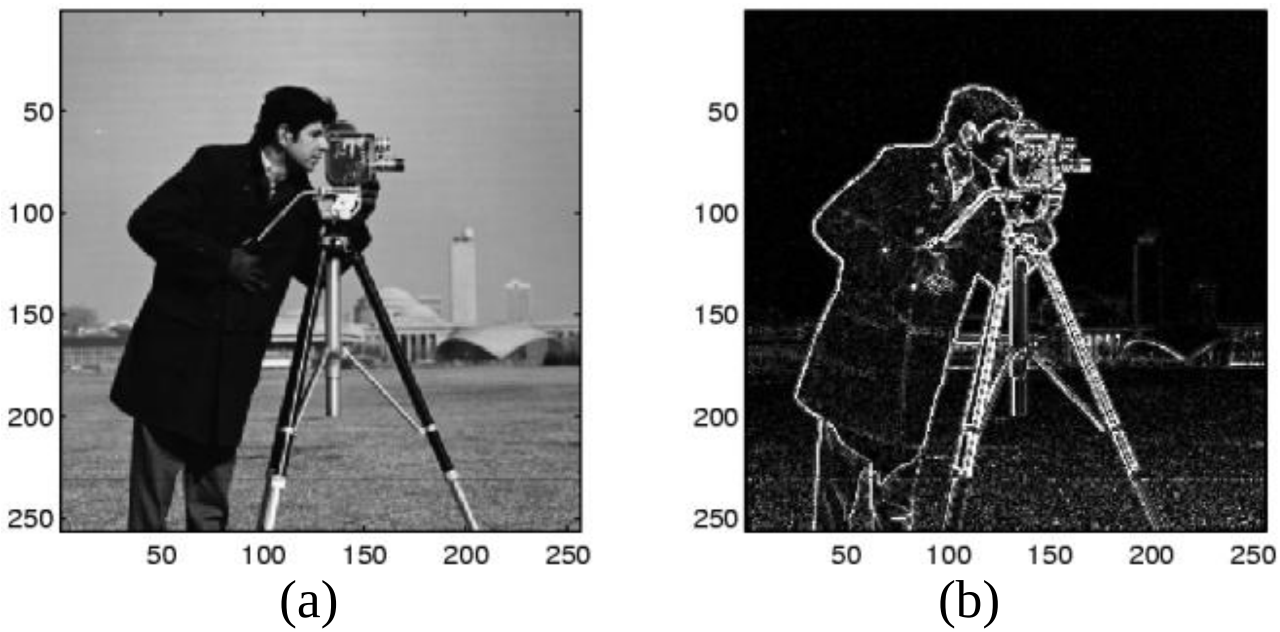
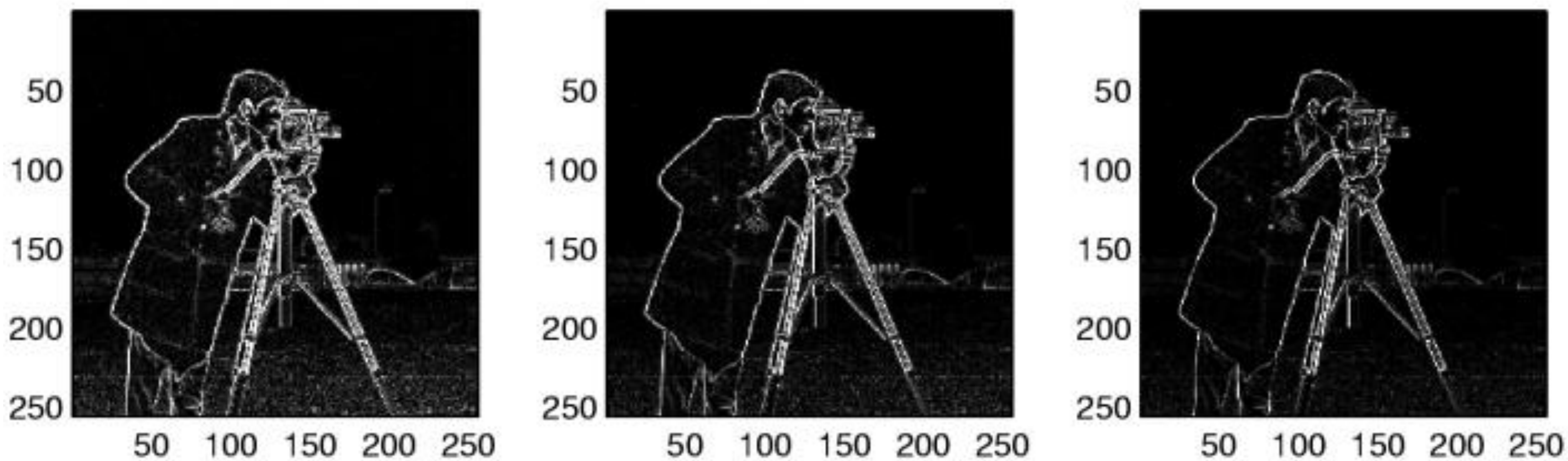


Figure 3. *(a) The grayscale image. (b) The Weber visibility image.*

The **Weber visibility image** can also be modified by using the sine function with a given frequency ω_0,

$$A: f_{n,m} \to A(f)_{n,m} = \sin\left[\omega_0 A(f)_{n,m}\right].$$



(a) (b) (c)

Figure 4. *The Weber-Grigoryan visibility image for the frequency* ω_0 *equal (a)* 0.75 *(b)* 0.5 *and (c)* 0.35.

Michelson visibility image of image $f_{n,m}$ is calculated by using the ratios of difference of the local maximum and minimum to their sum at each pixel,

$$C(f)_{n,m} = k\frac{\max_W(f_{n,m}) - \min_W(f_{n,m})}{\max_W(f_{n,m}) + \min_W(f_{n,m})}, \qquad (3)$$

where k is a constant.

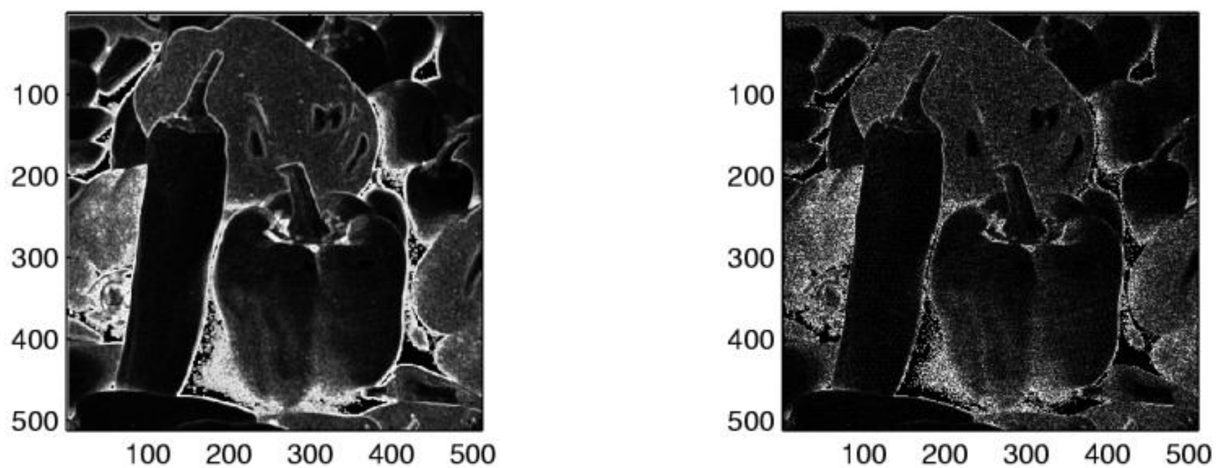


Figure 5. *(a) The Michelson visibility "cameraman" image. (b) The Weber visibility image*.

Different modifications of the Michelson visibility image can be used, including the Agaian-DelMarco visibility images:

$$C_4(f)_{n,m} = k\frac{\sqrt{[\max_W(f_{n,m}) - f_{n,m}][f_{n,m} - \min_W(f_{n,m})]}}{\max_W(f_{n,m}) + \min_W(f_{n,m})},$$

$$C_5(f)_{n,m} = k\sqrt{\frac{[\max_W(f_{n,m}) - f_{n,m}][f_{n,m} - \min_W(f_{n,m})]}{[\max_W(f_{n,m}) + f_{n,m}][f_{n,m} + \min_W(f_{n,m})]}}.$$

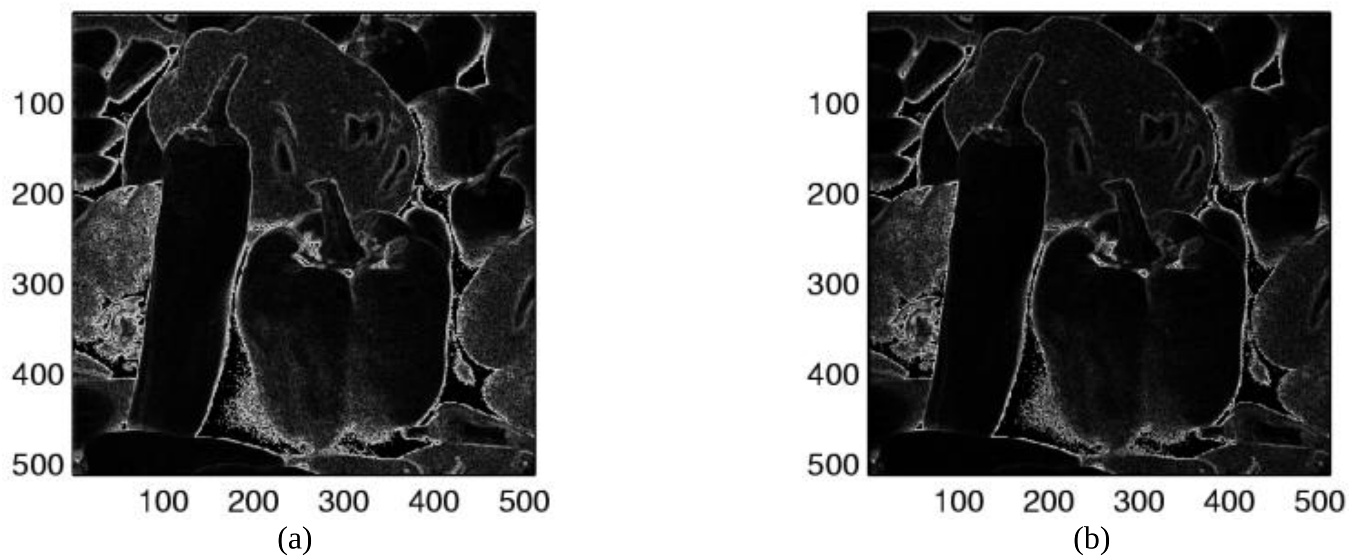


Figure 6. *The Michelson visibility "cameraman" image (a) $C_4(f)$ and (b) $C_5(f)$* **.**

The **EME related visibility image** of $f_{n,m}$ at the pixel (n, m) is defined as follows:

$$E(f)_{n,m} = \text{k}\ln\left[\frac{\max_W(f_{n,m})}{\min_W(f_{n,m})}\right], \tag{4}$$

where k is a constant.

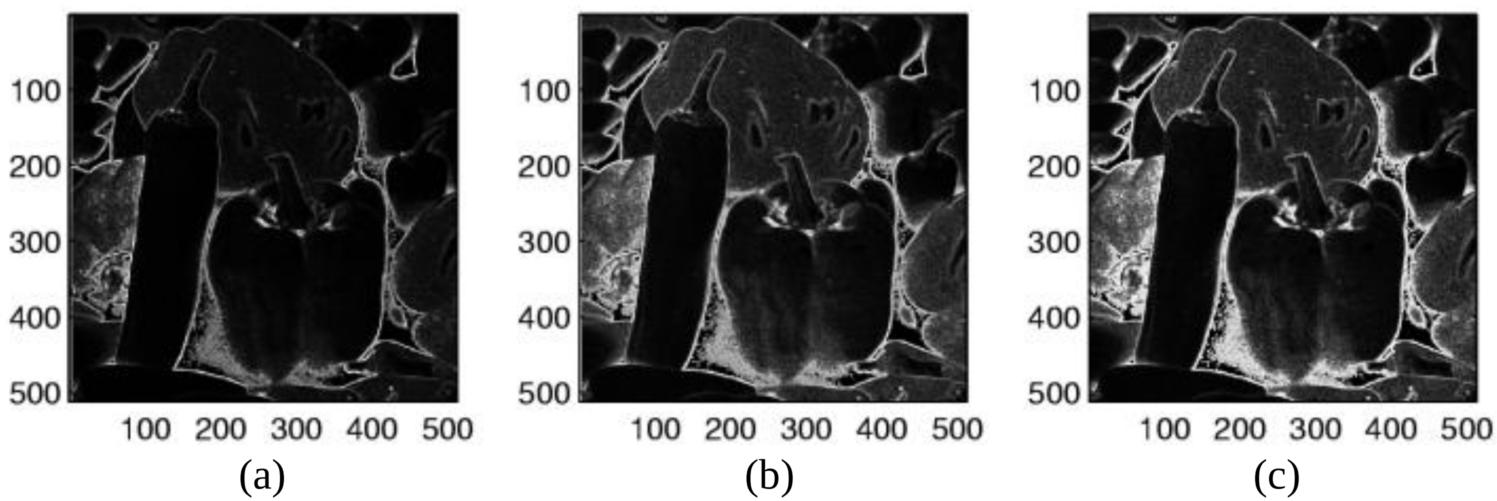


Figure 7. *(a) The EME measure visibility image. (b) The image in (a) in the logarithm scale. (c) The Michelson visibility image*.

It is interesting to note that the EME visibility image can also be defined by using the same definition on the EME visibility image itself, instead of the original image. In other words, the following image is calculated

$$LE(f)_{n,m} = \mathrm{k}\ln\left[\frac{\max_W\left(E\left(f_{n,m}\right)\right)}{\min_W\left(E\left(f_{n,m}\right)\right)}\right]. \qquad (5)$$

It is clear that the EME measure can be calculated from its EME visibility image as the sum of values of the visibility image at centers of blocks. If the size of blocks is 3×3, the EME image calculated only at the centers of the blocks is a down-sampled representation of the EME image.

Color Visibility Images (RGB Model)

The concepts of visibility images can be applied component-wise for color images. The color image is represented at each pixel as $f_{n,m} = \left(r_{n,m}, g_{n,m}, b_{n,m}\right)$. The EME visibility color image (EVCI) is defined by

$$E\left(f_{n,m}\right) = \left[E\left(r_{n,m}\right), E\left(g_{n,m}\right), E\left(b_{n,m}\right)\right],$$

where the color components of this image are calculated as

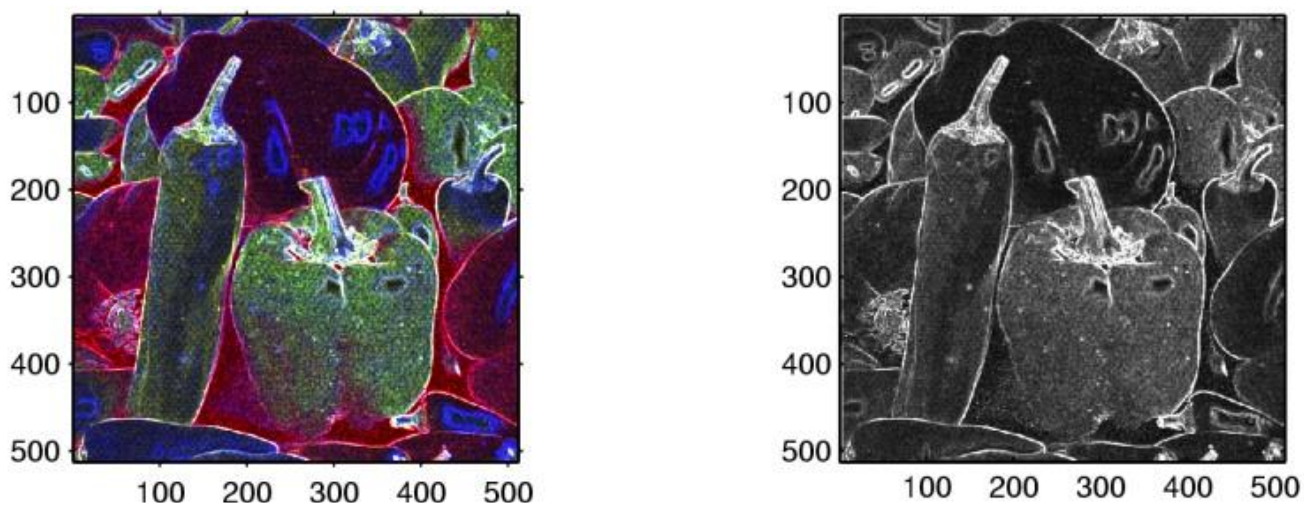
$$E\left(c_{n,m}\right) = \mathrm{k}\ln\left[\frac{\max_W\left(c_{n,m}\right)}{\min_W\left(c_{n,m}\right)}\right].$$

Here, $c_{n,m}$ is one of the color components of the image, the red, green, or blue.

The color components of the **multiplicative visibility color** image (MEVCI) are calculated by

$$E(c_{n,m}) = k\ln\left[\frac{\max_W(c_{n,m})}{\min_W(c_{n,m})}\right](c_{n,m})^{\beta}, \qquad (6)$$

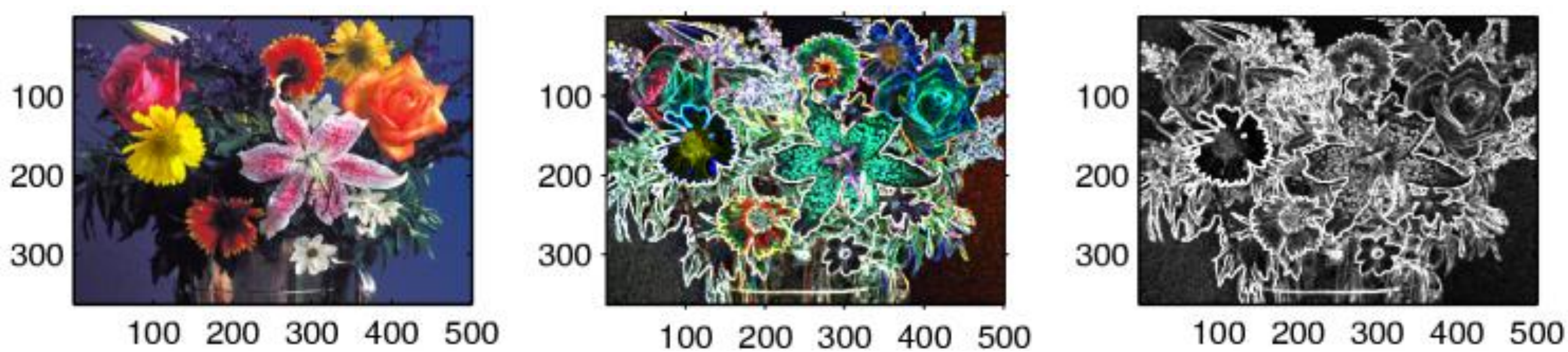
where β is the new parameter.



(a) (b)

Figure 9. *(a) The MEVCI of the “peppers” image and (b) the grayscale image of the MEVCI* (case β=1).

Example 2: We consider the β=1 case with the color "flowers" image that is shown in Figure 10 in part (a). The color image composed by the EME visibility images of three color components is shown in part (b) and the grayscale component of this image in part (c).



(a) (b) (c)

Figure 10. *(a) The color "flowers" image, (b) the MEVCI, and (c) grayscale image of the MEVCI*.

Example 3: The β=1 case. Figure 11 shows the multiplicative MEVCI of the “flowers” image. The color image is in part (a) and its grayscale image in part (b).

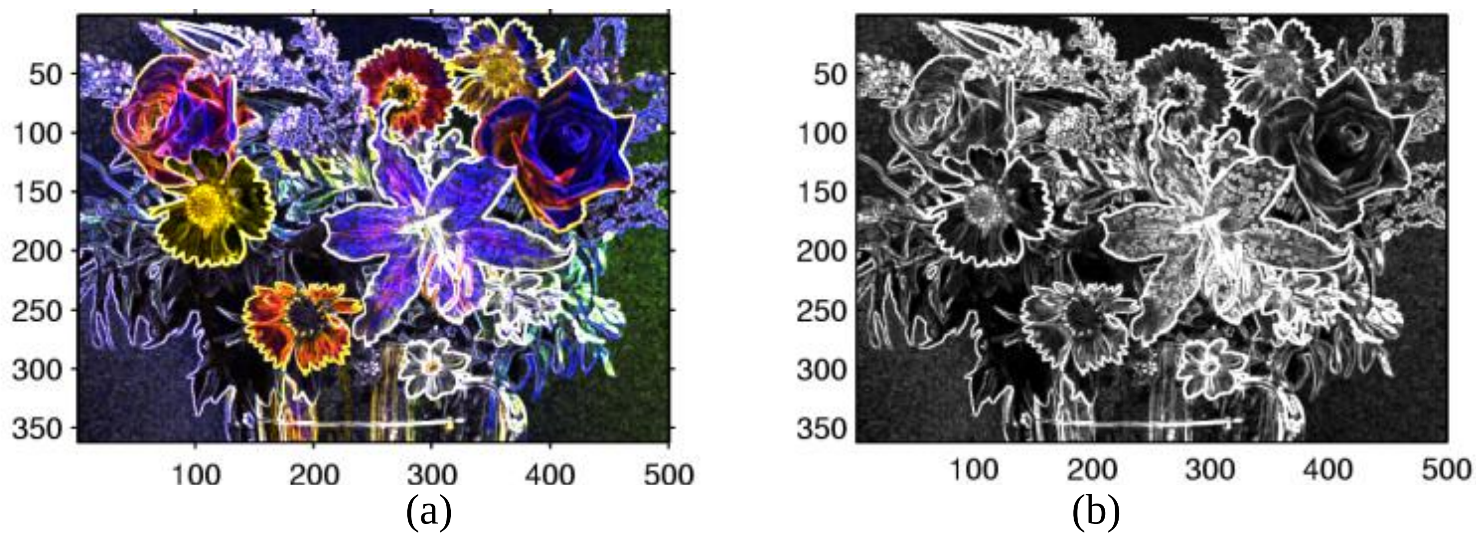


Figure 11. *(a) The “flowers” MEVCI image, and (c) the grayscale image of the MEVCI.*

Other Multiplicative Visibility Color Images

The Weber visibility color image (WVCI) is defined by the operator

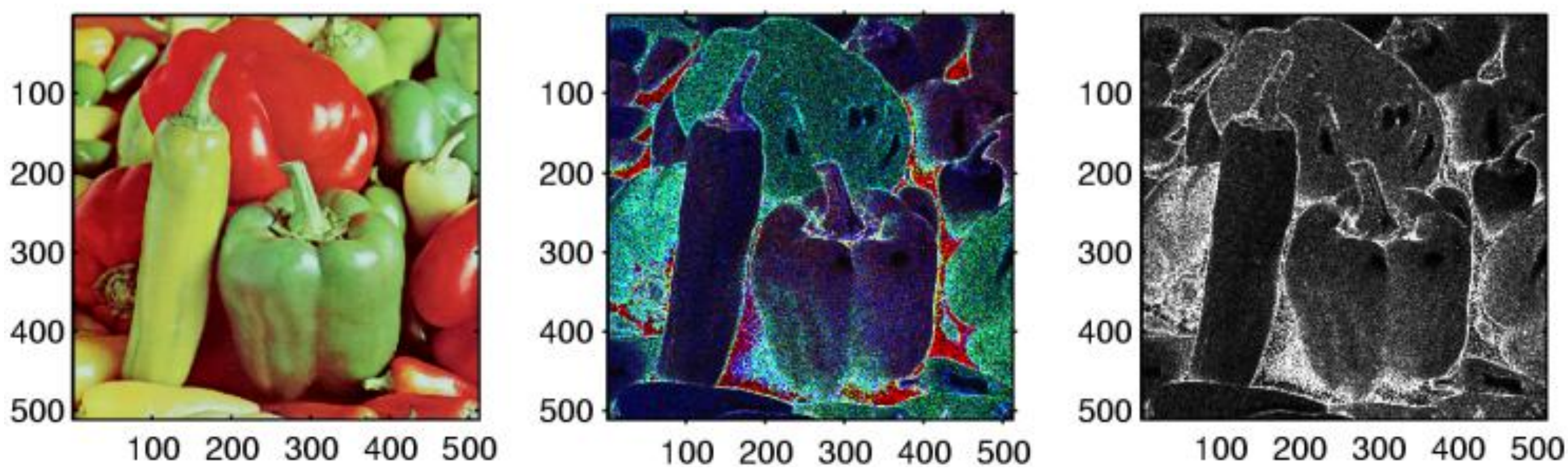
$$V(f_{n,m}) = [V(r_{n,m}), \mathrm{V}(g_{n,m}), V(b_{n,m})]$$

where the color components of this image are calculated as

$$V(c_{n,m}) = \mathrm{k}\frac{|c_{n,m} - \mathrm{max}_W(c_{n,m})|}{c_{n,m} + \varepsilon_0}, \qquad (7)$$

Here, the image $c_{n,m}$ is used for color components $r_{n,m}$, $g_{n,m}$, and $b_{n,m}$.

Example 4: Figure 12 shows the image in part (a), and the color image composed by the Weber visibility images of three color components, the red, green, and the blue, in (b). The grayscale component of the visibility image is shown in (c).



(a) (b) (c)

***Figure 12**. (a) Color image, (b) the WVCI image, and (c) the grayscale image of the WVCI.)*

The **Michelson visibility color image** (MVCI) is defined as

$$C(f_{n,m}) = [C(r_{n,m}), \mathrm{C}(g_{n,m}), C(b_{n,m})],$$

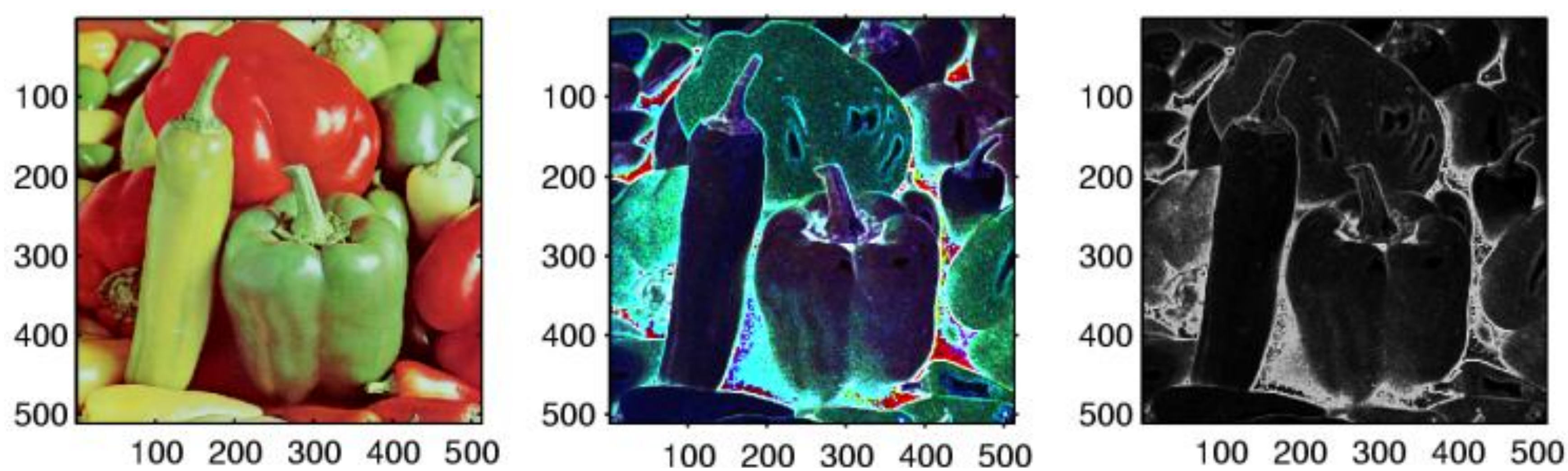
where the color components of this image are calculated by

$$C(c_{n,m}) = \mathrm{k}\frac{\left|\max_W(c_{n,m}) - \min_W(c_{n,m})\right|}{\max_W(c_{n,m}) + \min_W(c_{n,m})}. \qquad (8)$$

The multiplicative Michelson visibility color image is defined with the color components that are calculated by

$$C(c_{n,m}) = \mathrm{k}\left[\frac{\left|\max_W(c_{n,m}) - \min_W(c_{n,m})\right|}{\max_W(c_{n,m}) + \min_W(c_{n,m})}\right](c_{n,m})^{\beta}. \qquad (9)$$

Example 5: Figure 13 shows the color “peppers” image in part (a), and the color image composed by the Michelson visibility images (MVI) of three color components in part (b). The grayscale component of the MVCI is shown in part (c).



(a) (b) (c)

Figure 13. *(a) Color image, (b) the MVCI image, and (c) the grayscale image of the MVCI*.

Summary

The concepts of the color visibility images have been introduced with examples that include the related to the Weber-Fisher visual law and Michelson contrast definition, as well as new visibility images that can be used in color image representation and processing, computer vision and recognition system applications.

References

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5. ...