

# Thermal and Night Vision Image Visibility and Enhancement

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# OUTLINE

- Introduction
- Measures of image enhancement
- Visibility images (Weber, Michelson, and other VIs)
- Visibility images with gradients
- Application of visibility images to thermal and night vision images
- Examples
- Summary

# Abstract

- This paper offers a review of effective methods of image representation, or visibility images in enhancement applied to the thermal images and night vision images.
- The quality of images is estimated by quantitative enhancement measures, which are based on the Weber-Fechner, Michelson, and other parameterized ratio and entropy-type measures.
- We also apply the concept of visibility images, by using different types of gradient operators which allow for extracting and enhancing features in images.
- Examples of gradient visibility images, gradient, Weber-Fechner, and Michelson contrast, log and power Michelson and Weber visibility images are given. Experimental results show the effectiveness of visibility images in enhancing thermal and night vision images.

# QUANTITATIVE MEASURE OF IMAGE ENHANCEMENT

The standard EME measure is defined by the ration of local characteristics, when dividing the image by blocks of the same size  $L_1 \times L_2$ ; the number of them  $k_1 k_2$ , where  $k_i = \lfloor N_i / L_i \rfloor$ ,  $i = 1, 2$ , The EME measure of the grayscale discrete image  $\{f_{n,m}\}$  of size  $N_1 \times N_2$  pixels is defined as

$$EME(f) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} \frac{\max_{k,l}(f)}{\min_{k,l}(f)}. \quad (1)$$

Here,  $\max_{k,l}(f)$  and  $\min_{k,l}(f)$  are the maximum and minimum of the image inside the  $(k, l)$ th block, respectively. It should be said that Fechner modified the Weber statement about the constant for the ratio, as

$$W = \frac{|\Delta f_{n,m}|}{f_{n,m}} \rightarrow F = k \frac{|\Delta f_{n,m}|}{f_{n,m} + \min(f)}.$$

For a color image  $\{f_{n,m}\}$  in the RGB model, when the image  $f = f_{n,m}$  is the triplet of three colors, namely, red, green, and blue, i.e.,  $f = \{f_R, f_G, f_B\}$ , a similar measure which is called the EMEC is calculated [8],

$$EMEC(f) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} \frac{\max_{k,l}(f_R, f_G, f_B)}{\min_{k,l}(f_R, f_G, f_B)}. \quad (2)$$

Here, in each  $(k, l)$ -th block, the min/maximum image values are calculated by  $\min[f_R(n, m), f_G(n, m), f_B(n, m)]$  and  $\max[f_R(n, m), f_G(n, m), f_B(n, m)]$ .

In the XYZ model, the EMEC measure is calculated similarly, only over the X, Y, and Z components, i.e.,  $f = \{f_X, f_Y, f_Z\}$ . The CMYK color space is defined with four colors, namely, cyan, magenta, yellow, and black, i.e.,  $f = \{f_C, f_M, f_Y, f_K\}$ . The enhancement measure EMEC is calculated by

$$EMEC(f) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} \frac{\max_{k,l}(f_C, f_M, f_Y, f_K)}{\min_{k,l}(f_C, f_M, f_Y, f_K)}. \quad (3)$$

# Image Gradients

When processing  $f \rightarrow g$  the image, grayscale or color, the concept of enhancement measure is used after processing the image, and enhancement measures of new image is compared with the original one. In many methods, such as the alpha-rooting, the enhancement of the image is parameterized.

Therefore, the concept of the optimal parameter(s) is defined as the parameter(s) that maximizes (or minimizes) the EME or EMEC.

The concept of EMEC was also used effectively for enhancing the color images in the quaternion space, wherein the color components are processed as one unite, not separately.

# Parameter Selection by EMEs

When processing  $f \rightarrow g$  the image, grayscale or color, the concept of enhancement measure is used after processing the image, and enhancement measures of new image is compared with the original one. In many methods, such as the alpha-rooting, the enhancement of the image is parameterized.

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# Weber and Michelson Contrast Visibility Images

The Weber law related visibility image is defined as follows:

$$W(n, m) = k \frac{|f_{n,m} - \text{mean}(f_{n,m})|}{f_{n,m} + \varepsilon}. \quad (4)$$

The mean operator is defined as the windowed-mean at pixel  $(n, m)$ . For instance, the mean can be used with windows  $3 \times 3$ , representing the square, cross, or X-window. The small positive number  $\varepsilon$  can be used in the case, when image has zeros. The scaling coefficient  $k$  is for mapping the visibility image to the standard range  $[0, 255]$ .

The concept of the Michelson visibility image (MVI) is based on the Michelson visibility measure (MVM) defined as

$$MVM(f) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} \left[ \frac{\max_{k,l}(f) - \min_{k,l}(f)}{\min_{k,l}(f) + \min_{k,l}(f)} \right]. \quad (5)$$



The Agaian-Michelson measure of image enhancement is defined, by using the logarithm function,

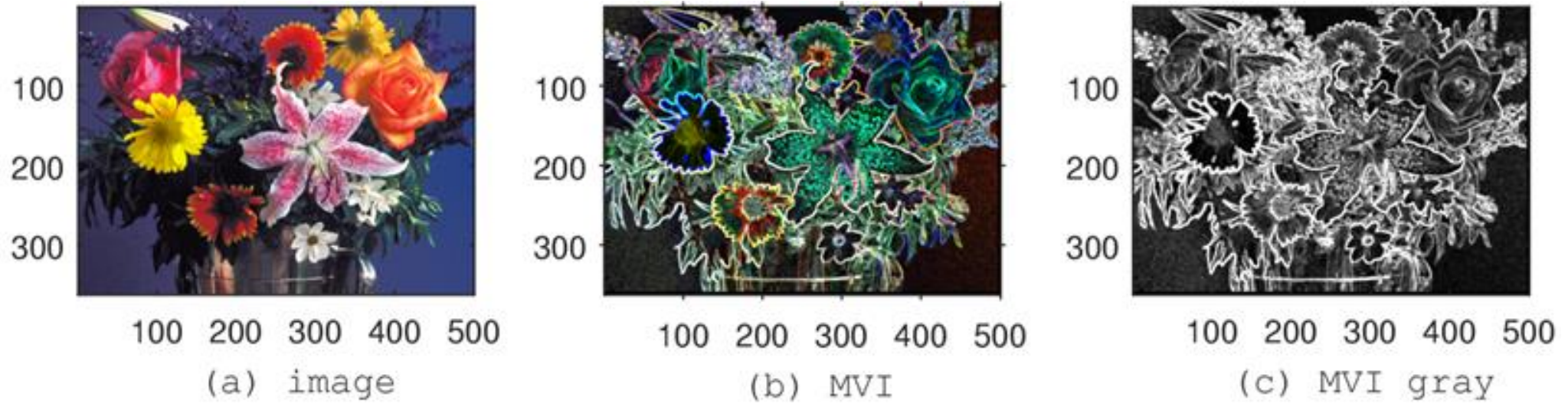
$$AMVM(f) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} 20 \log_{10} \left[ \frac{\max_{k,l}(f) - \min_{k,l}(f)}{\min_{k,l}(f) + \min_{k,l}(f)} \right].$$

The MVI of the image  $f$ , as a prototype of the image, is calculated by

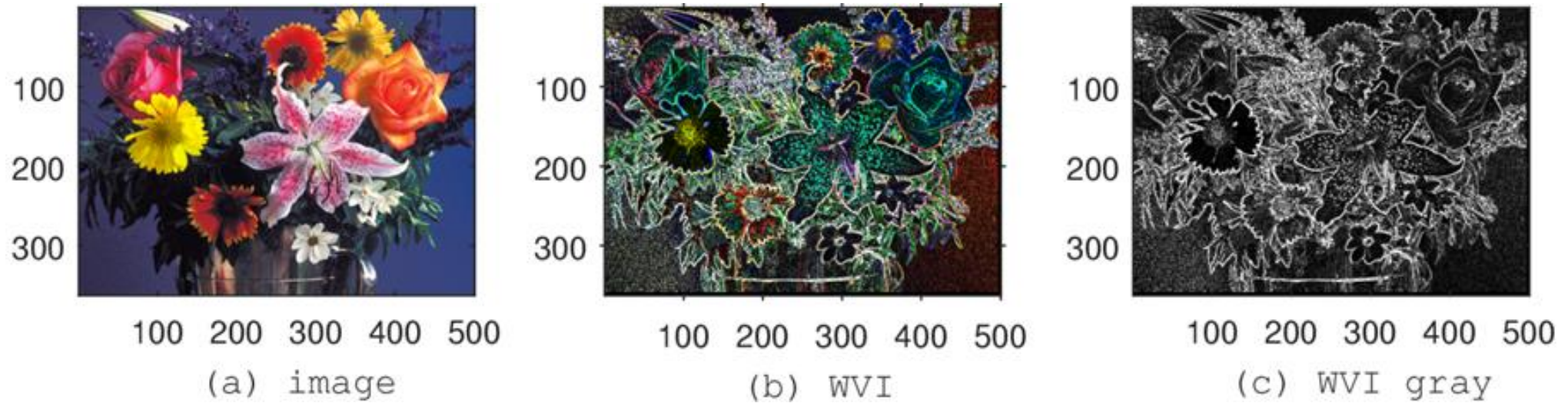
$$M(n, m) = MVI(f)_{n,m} = k \frac{\text{Max}_W(f_{n,m}) - \text{Min}_W(f_{n,m})}{\text{Min}_W(f_{n,m}) + \text{Min}_W(f_{n,m})}. \quad (6)$$

Here, the local min and max operations are considered in the general case, i.e., with a given window,  $W$ , usually of small size and with the center at  $(0,0)$ .

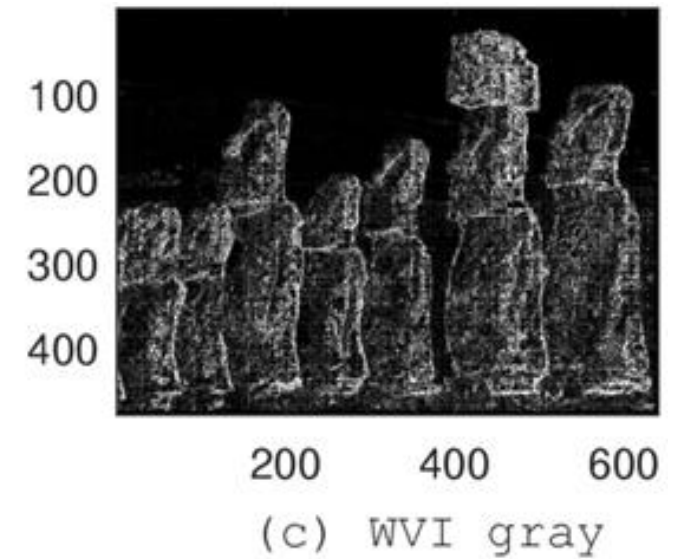
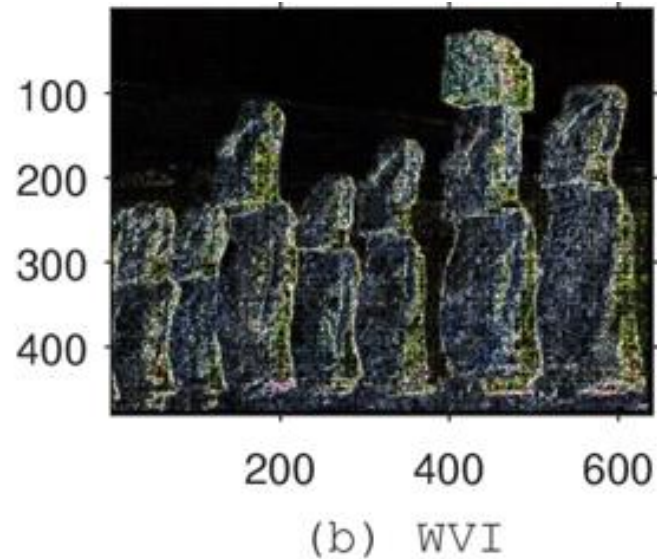
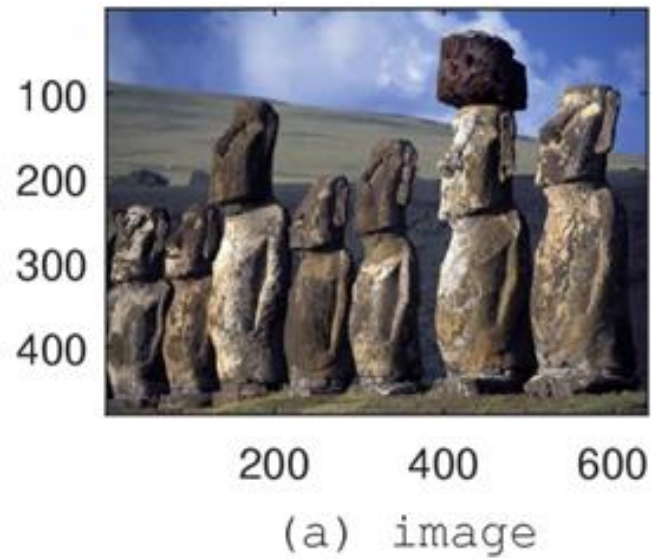
The MVI for the color images is calculated in a similar way, only by all color components, as in the definition of the EMEs measure in Eqs. 2 and 3.



**Fig. 1** (a) The image, the Michelson visibility images in (b) colors and (c) grays.



**Fig. 2** (a) The image, the Weber visibility images in (b) colors and (c) grays.



**Fig. 3** (a) The image, the Weber visibility images in (b) colors and (c) grays.

## Nonlinear Operations over Visibility Images

On visibility images, such as the WVI and MVI, different operations can be applied to increase more the quality and visibility of the images. For example, we can use the power, logarithm, and multiplication of different visibility images, as well as consider linear combinations of visibility images or combinations with original images. Such operations can be parameterized, and then optimal, or best parameters can be selected for image enhancement, by using the chosen measure.

A few examples of such visibility “tank” images are illustrated in a few next figures.

The consequent calculation of Michelson visibility images, i.e., visibility of visibility images is also demonstrated.

Original image



(a)

EME-Weber visibility image



(b)

Michelson visibility image



(c)

3x3 Gradient-Weber visibility image



(d)

**Fig. 4** (a) The original infrared “tank” image, (b) the WVI, (c) the MVI, and (d) 2<sup>nd</sup> order gradient WVI.

log EME-Weber visibility image



(a)

log Michelson visibility image



(b)

power-2 EME-Weber visibility image



(c)

power-2 Michelson visibility image



(d)

**Fig. 5** The logarithm of the (a) WVI and (c) MVI, and the square of (c) WVI and (d) MVI.

2nd Michelson visibility image



(a)

3rd Michelson visibility image



(b)

4th Michelson visibility image



(c)

5th Michelson visibility image



(d)

**Fig. 6** (a) The original infrared “tank” image, (b) the WVI, (c) the MVI, and (d) 2<sup>nd</sup> order gradient WVI.

## Linear Combination of Visibility Images

We consider a linear combination of different visibility images, namely the following visibility images.

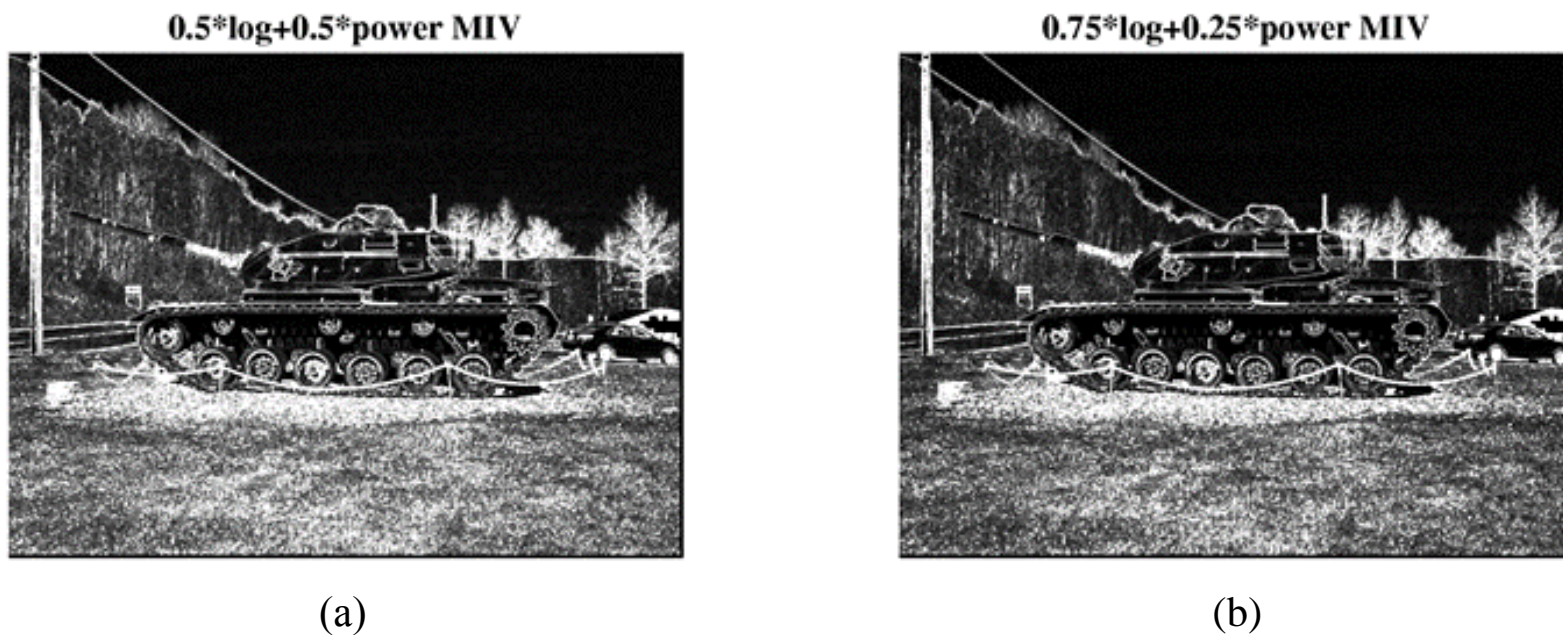
If images are with the Michelson measure of enhancement, a new visibility image is calculated by

$$Y(n, m) = Y_{a,\gamma}(n, m) = k[a \log M(n, m) + (1 - a)M(n, m)^\gamma], \quad (8)$$

where the parameter  $a \in [0,1]$ ,  $\gamma > 0$  is parameter of power, and  $k$  is coefficient for scaling the image.



Figure 6 shows the visibility images for the cases  $a = 0.5, \gamma = 1$  in part (a) and  $a = 0.75, \gamma = 1$  in part (b).



**Fig. 7** The linear combinations Michelson visibility images.

## Multiplication of Visibility Images

Now, we consider the multiplicative visibility images, that are calculated by the following equations:

$$X_{\gamma}(n, m) = kM(n, m)^{\gamma} f_{n,m}, \quad (9)$$

shown below for  $\gamma = 1$  and 5, and

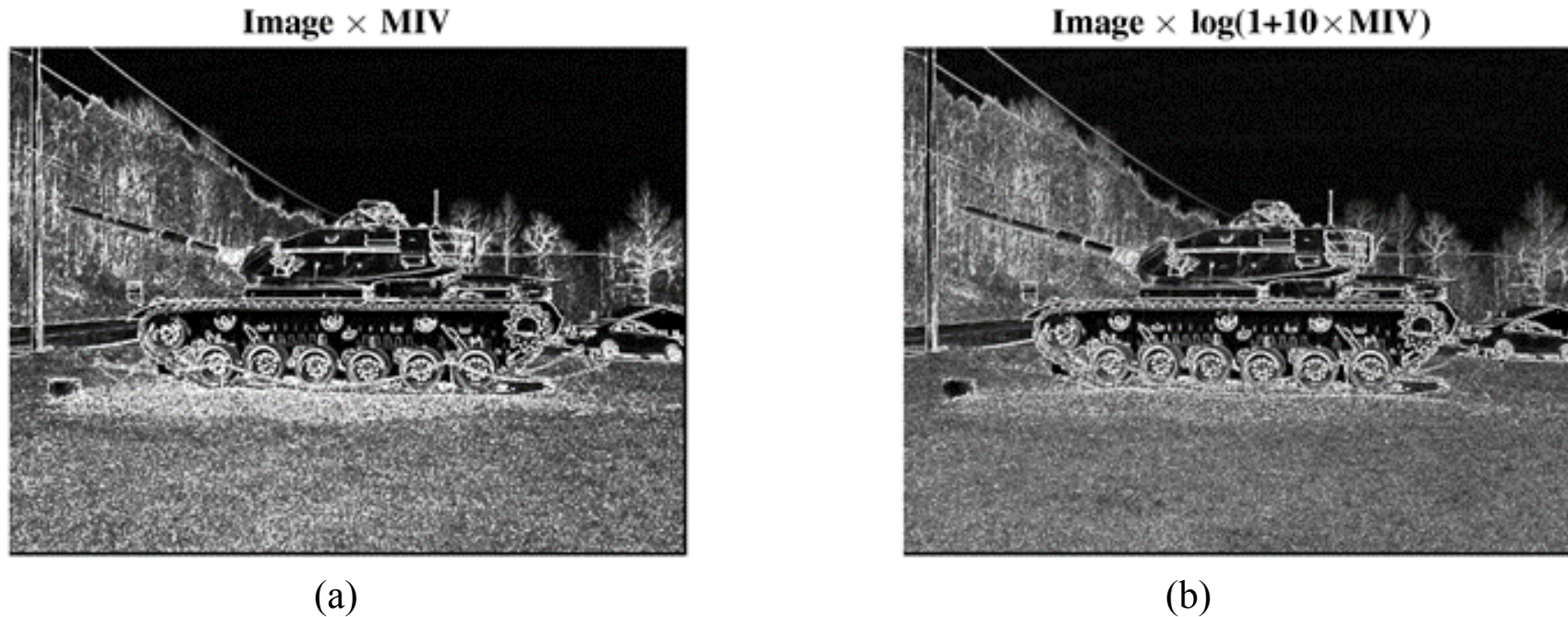
$$X_a(n, m) = kf_{n,m} \cdot \log(1 + aM(n, m)), \quad (10)$$

shown for  $a = 10$ .



**Fig. 8** (a) The “tank” image and (b) Michelson visibility image  $X_{\gamma}(n, m)$ , for  $\gamma = 5$ .

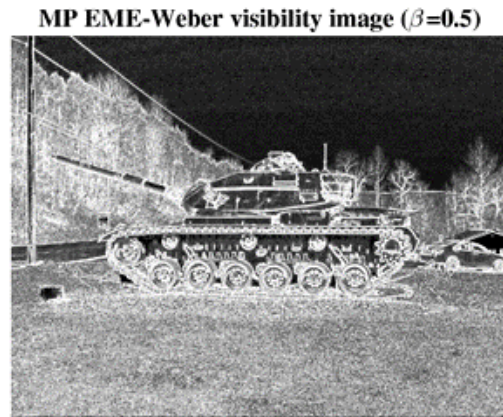
# Multiplication of Michelson Visibility Images with Logarithm function



**Fig. 9** Michelson visibility images (a)  $X_\gamma(n, m)$ , for  $\gamma = 1$ , and (b)  $X_a(n, m)$ , for  $a = 10$ .

# Comparison: Multiplication of Weber and Michelson Visibility Images

$$Y_{\beta}(n, m) = kW(n, m)^{\beta} f_{n,m} \quad \text{and} \quad kW(n, m)^{\beta} f_{n,m} \quad (11)$$



(a)



(b)



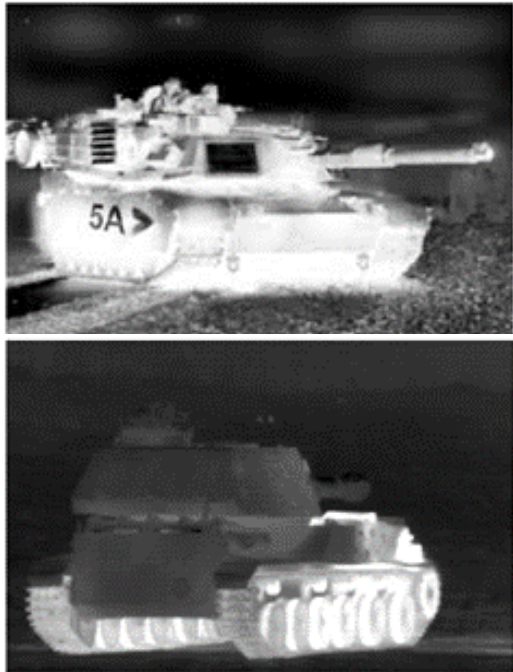
(c)



(d)

**Fig. 10** (a,b) The Weber and (c,d) Michelson visibility images for  $\beta = 0.5$ .

Figure 11 shows the original images of tanks in parts (a) and the corresponding Weber and Michelson visibility images in parts (b) and (c), respectively



(a)

(b)

(c)

**Fig. 11** (a) Original images of two tanks and their (b) Michelson and (c) Weber visibility images.

These grayscale images can be recolored in the RGB model, by using the concept of the Golden ratio.

Figure 12 shows the recolored images of Fig. 10 in the RGB model, when the gray are map to colors as :  $(r, g, b) = (1, \sqrt{\Phi}, \Phi) \times \text{Grays}$ , and the Gold ratio  $\Phi = 1.6180$

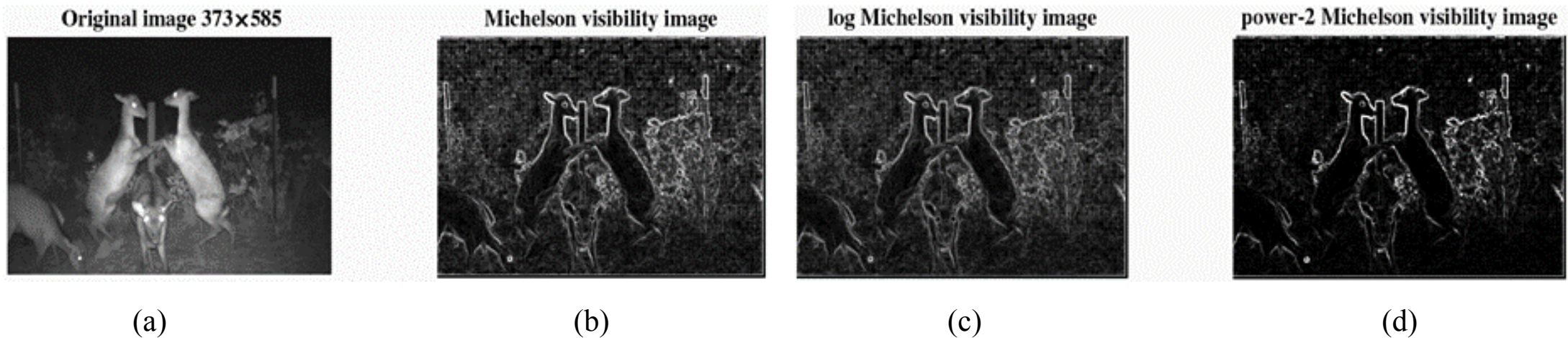


**Fig. 12** Recolored images of Fig. 11 in the color model with the Golden Ratio:  
 $(1, \sqrt{\Phi}, \Phi) \times \text{Grays}$ , where  $\Phi = 1.6180$ .

## Visibility of Night Images: Examples

Consider a few examples of visibility images on the night image of deers.

Figure 13 shows the original “deers” image in part (a) and Michelson visibility images,  $M(n, m)$ ,  $\log(1 + M(n, m))$ , and  $M^2(n, m)$  in parts (b), (c), and (d), respectively.

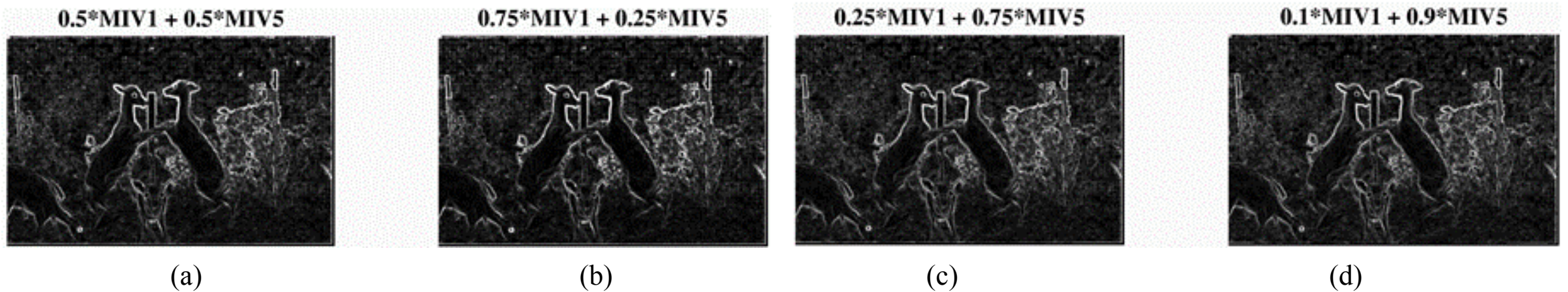


**Fig. 13** (a) The original image and (b)-(d) the Michelson visibility images.

## Michelson Visibility Night Images: Examples

Figure 14 shows the linear combinations of Michelson visibility images with their powers,

$$X(n, m) = aM(n, m) + (1 - a)M^\beta(n, m), \text{ when } \beta = 5.$$

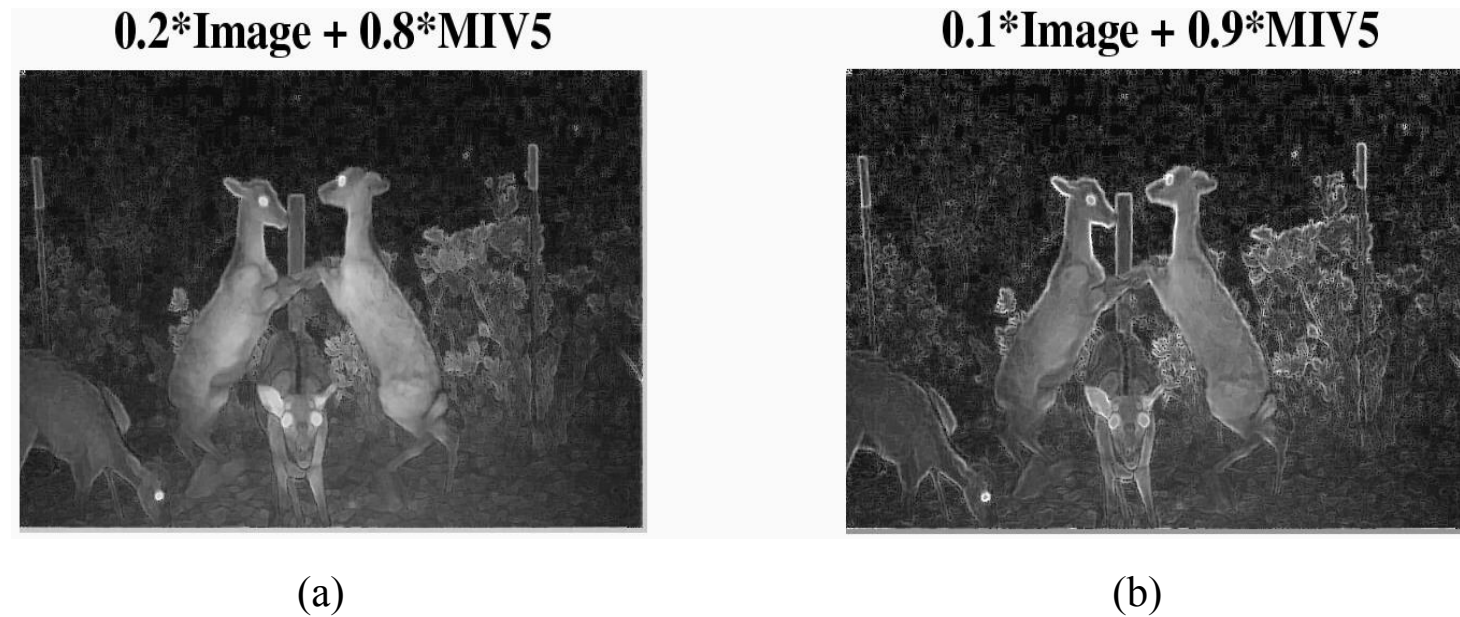


**Fig. 14** (a) Different combinations of Michelson visibility images with the 5th powers ( $\beta = 5$ ), when (a)  $a = 0.5$ , (b)  $a=0.75$ , (c)  $a = 0.25$ , and (d)  $a = 0.1$ .



Figure 14 shows the linear combinations of Michelson visibility images with their powers,

$$Y(n, m) = af_{n,m} + (1 - a)M^\beta(n, m), \quad \text{when } \beta = 5.$$



**Fig. 15** (a) Linear combinations of the image and the 5<sup>th</sup> Michelson visibility image, when (a)  $a = 0.2$  and (b)  $a = 0.1$ .

# CONCLUSION

In this paper, we discuss the application of different type visibility images of infrared and night images. The concept of visibility images is derived from the quantitative measures of grayscale and color images, which are used effectively in image enhancement and face recognition.

We focus of the Weber and Michelson visibility images and linear and nonlinear operations over such visibility images. Different examples of gradient visibility images, gradient, Weber-Fechner, and Michelson contrast, log and power Michelson and Weber visibility images are illustrated.

Experimental results show the effectiveness of visibility images in enhancing thermal and night vision images. In the authors' book, many other enhancement images are given, as well as visibility images, which can also be used to enhance the infrared and night images.

## References

- [1] A.M. Grigoryan, S.S. Agaian, “Image Processing Contrast Enhancement,” p. 22, Wiley Encyclopedia of Electrical and Electronics Engineering (2017), (doi: 10.1002/047134608X.W5525.pub2)
- [2] A.M. Grigoryan, S.S. Agaian, Quaternion and Octonion Color Image Processing with MATLAB, SPIE PRESS, vol. PM279 (2018), (<https://doi.org/10.1117/3.2278810>)

**Thank you**