Front. Comput. Sci., 2019, 13(3): 665–667
https://doi.org/10.1007/s11704-019-8165-6

LETTER

A visual hierarchical framework based model for underwater image enhancement

Bo WANG (✉)[1], Chongyi LI[2]

1 School of Physics and Electronic-Electrical Engineering, Ningxia University, Yinchuan 750021, China
2 Department of Computer Science, City University of Hong Kong, Hong Kong 999077, China

1 Introduction and main contribution

Although there are various computer vision based processing methods for underwater image enhancement, some of them have to be implemented under given priors and the performance of these approaches is still limited. We propose a visual hierarchical framework based model inspired by retinal mechanism, which restores the distortion from color cast and increases contrast simultaneously for underwater images by simulating visual processing of the mammalian retina. The RGB components and brightness of the input image are transmitted from the sampling of rod and cone photoreceptors to the higher visual cortex V4 via sub-layers of bipolar cells, amacrine cells, retinal ganglion cells (RGCs), lateral geniculate nucleus (LGN) and V1 respectively. The flowchart of our presented framework is shown in Fig. 1. Each layer in this procedure is designed in the light of color processing mechanism existing in the human visual system (HVS) from the retina to the higher visual cortex [1,2]. Then, a robust image formation model is employed for scene recovery with restricted transmission map and estimated background light.

The main contributions of this work can be summarized as follows:

1) We propose a more integrated retinal mechanism inspired model for color correction and contrast improvement of underwater images.

Received May 1, 2018; accepted November 21, 2018

E-mail: tjuwb@nxu.edu.cn

2) The proposed model can provide background light estimation in the pre-processing step without independent algorithm for this operation.

3) With more general maximum intensity prior for transmission map estimation, the scene recovery can be readily obtained via a restricted image formation model.

2 Single underwater image enhancement based on visual hierarchical framework

2.1 Rod and cone photoreceptor layer

The information processing in vertebrate retina starts with rod and cone photoreceptors which are two basic types of cells. The former are highly light-sensitive and used for vision under dark or dim conditions, the latter are capable of responding to color vision. There are three kinds of cone cells which are maximally sensitive to the long-wavelength (Red), medium-wavelength (Green) and short-wavelength (Blue) of the light from input information, namely L, M and S cone cells respond to R, G and B components respectively. The brightness of dark regions and color information are firstly sampled by rod and cone photoreceptors and then RGB components are transformed into LMS space.

2.2 Bipolar cells layer

The direct way from photoreceptors to RGCs is through bipolar cells layer. There are two primary classes of bipolar cells: On and Off bipolar cells, which response to light on-set and light off-set respectively. Although there are at least 13

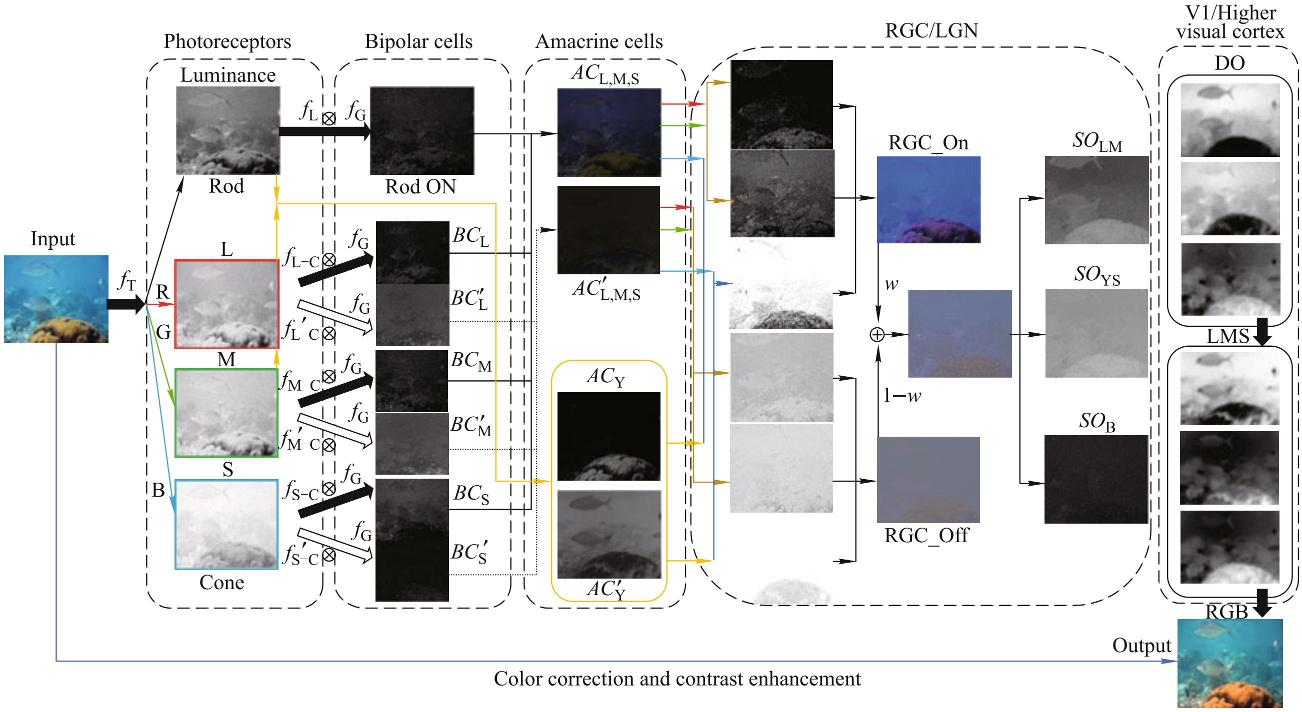

Fig. 1 The diagram of the visual hierarchical framework

various types of bipolar cells systematically transforming the input signals in different ways, midget, S-cone-selective and diffuse bipolar cells are three commonly discussed ones for color vision in primate based on the dendritic morphology.

It is demonstrated that most of cone cells connect with at least one On type and one Off type bipolar cells, which in turn link respectively to On and Off RGCs. As a matter of fact, the RF of major bipolar cells referred to as a difference of Gaussian (DOG) function is composed of a large inhibitory surround and a small excitatory center. In addition, chromatic opponent as well as high-acuity signals can be transmitted via neurons with this RF type.

2.3 Amacrine cells layer

In all mammalian retinas, AII amacrine cells play a crucial part for visual processing under both photopic and scotopic conditions. In fact, only On type rod bipolar cells transmit their outputs to the specific AII amacrine cells. On the other hand, the activities of On type cone bipolar cells via sign-conserving gap junctions and Off type cone bipolar cells via inhibitory synapses are modulated by the AII amacrine cells. By this means, rod bipolar cells ultimately inhibit or excite the Off or On RGCs.

2.4 RGCs and LGN layer

The RGCs are located in the output layer of vertebrate retina, which receive various cone information sent through different bipolar and amacrine cells, and then transmit signals to LGN layer. It is proved that the cells in RGCs and LGN layer have similar properties with regard to RF consisting of a larger inhibitory annular surround and a smaller excitatory center. There are three kinds of single-opponent neurons with selective connections at the level of RGCs considered in this paper in accordance with [3].

2.5 V1 layer and higher visual cortex

Compared with aforementioned sub-layers in the retina, double-opponent cells extensively exist in V1 layer, i.e., primary visual cortex. It is revealed that the most significant characteristic of double-opponent color cells in V1 is a kind of spatially transformed RF, which is capable of local color contrast detection. One of the typical RFs structure called concentric type is found to have both spatially and spectrally opponent, which is beneficial to color constancy. Based on the operation of the outputs deriving from LGN type-II single-opponent cells, the response of V1 double-opponent cells can be readily constructed exploiting two different scales.

2.6 Image formation model

We follow the simplified image formation model developed in [4] to depict an underwater scenario which is given in

Eq. (1). The image intensity of each pixel in each color channel is comprised of two components: background light and attenuated signal. The transmission map describes the proportion of the scene radiance reaching the camera without scatter or absorption.

$$I^c(x) = J^c(x)t^c(x) + B^c(1 - t^c(x)), \quad c \in \{r, g, b\}, \tag{1}$$

where $I(x)$ denotes the observed intensity at pixel x, the scene radiance $J(x)$ blended with the transmission map $t(x)$ represents the direct attenuation, while the second term related to the background light accounts for remaining portion.

According to [5], a general and effective method to estimate transmission map is proposed based on the maximum intensity prior (MIP) which takes advantage of the difference between the maximum intensity of the red channel and that of the green and blue channels. The larger values of the difference represent the closer scene points from the camera because the attenuation of red light is less than that of farther scene points. Hence, the process can be computed as follows:

$$D(x) = \max_{x\in\Omega, c\in r} I^c(x) - \max_{x\in\Omega, c\in\{g,b\}} I^c(x), \tag{2}$$

where Ω refers to a small patch in the image. Then the transmission map can be estimated by

$$\widetilde{t}(x) = D(x) + (1 - \max_x D(x)). \tag{3}$$

Now that the transmission map and the background light are known, for convenience, we can rewrite Eq. (1) as follows:

$$J^c(x) = \frac{I^c(x) - B^c}{\widetilde{t}(x)} + B^c, \quad c \in \{r, g, b\}. \tag{4}$$

For preventing too much noise, we can restrict the value of the estimated transmission map between 0.1 and 0.95. Therefore, the final enhancement of the scene radiance $J(x)$ can be expressed by

$$J^c(x) = \frac{I^c(x) - B^c}{\min\{\max\{\widetilde{t}(x), 0.1\}, 0.95\}} + B^c, \quad c \in \{r, g, b\}. \tag{5}$$

3 Conclusions

Inspired by a biological mechanism that ganglion cells transmit information by receiving input from photoreceptors via bipolar and amacrine cells, we introduce an integrated framework for color correction by simultaneously considering sublayers of cone and rod photoreceptors, bipolar and amacrine cells, and color opponency mechanisms from retina to higher visual cortex. Then we also consider dehazing patterns for further improving contrast, sharpness and visibility of challenging underwater images.

Acknowledgements This work was supported by the Major Innovation Projects for Building First-class Universities in China's Western Region (ZKZD2017006).

References

1. Gao S, Yang K, Li C. Color constancy using double-opponency. IEEE Transactions on Pattern Analysis and Machine Intelligence, 2015, 37(10): 1973–1985
2. Zhang X, Gao S, Li R, Du X, Li C, Li Y. A retinal mechanism inspired color constancy model. IEEE Transactions on Image Processing, 2016, 25(3): 1219–1232
3. Zhang X, Gao S, Li C, Li Y. A retina inspired model for enhancing visibility of hazy images. Frontiers in Computational Neuroscience, 2015, 9: 151
4. Narasimhan S G, Nayar S K. Vision and the atmosphere. International Journal of Computer Vision, 2002, 48(3): 233–254
5. Carlevaris-Bianco N, Mohan A, Eustice R M. Initial results in underwater single image dehazing. In: Proceedings of the OCEANS Conference. 2010, 1–8