Underwater Image Brightness Enhancement based on the DCT Coefficient Model using Genetic Algorithm

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Abstract

Nowadays underwater image process gains more and more attention, as an increasing number of researchers and companies showing interest in ocean engineering, underwater archaeology, mining *etc.* The uneven illumination in water brings image analysis a challenge. This paper introduces a new method to optimize brightness based on the DCT coefficient. The statistical model of image DCT coefficients changes with operations on image. Our method is used to enhance the under-exposed and over-exposed regions of images by regulating the low-frequency part of the image DCT coefficients using genetic algorithm.

Keywords: underwater image process, DCT coefficients, genetic algorithm, brightness enhancement.

1. Introduction

Nowadays, with the rapid development of science and technology, marine resource and marine habitat has become hot topics. Due to the fast-rising of deep-sea work, underwater image process has attracted more and more attention, especially in the field of ocean engineering, aquatic species counting, underwater archaeology, mining and robotics ^(1, 2). As sunlight drops off within a certain distance and blue-green color dominates underwater images, artificial lighting is employed for capturing images ⁽³⁾. The uneven illumination in deep sea brings image analysis challenges.

Image enhancement can be achieved differently by processing from spatial domain or frequency domain. The spatial domain refers to the image plane itself, and methods in this category are based on direct manipulation of pixels

in an image ⁽⁴⁾. As to the latter, the image is firstly changed to transformation domain and then inverse transformed to spatial domain after processing in transformation domain. Histogram Equalization (HE) is a very common method used to enhance image in spatial domain ⁽⁵⁾. While in transformation domain, Discrete Cosine Transform (DCT) is usually applied in image compression ⁽⁶⁾. This paper proposed a new method to enhance the brightness of underwater images based on the DCT coefficient.

2. Method

Color images are now in widespread use. However, noticeable differences often exist between the observed scene and the captured image, especially in deep sea. The captured image may appear to be too darkened (under-exposure) or overly brightened (over-exposure) ⁽⁷⁾. To equalize brightness of underwater images, the process of proposed method is shown in Fig. 1.

Fig. 1. The proposed method process

2.1 YCbCr Color Space

YCbCr color space is widely used for video and digital

photography system. While RGB represents color as red, green and blue components, YCbCr represents as brightness and color different signals. In YCbCr, Y is luminance, and Cb and Cr are the blue-difference and red-difference components⁽⁸⁾. The transformation from RGB to YCbCr is as follows:

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.257 & 0.564 & 0.098 \\ -0.148 & -0.368 & -0.071 \\ 0.439 & -0.291 & 0.439 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix} \quad (1)$$

After the transformation, Y channel is extracted to perform the following Discrete Fourier Transformation.

2.2 Discrete Cosine Transform (DCT)

Discrete Cosine Transform (DCT) is often used in signal and image processing, especially for lossy compression because of its strong energy compaction property^(9, 10). The DCT and inverse DCT equation of an image is as follows:

$$F(i, j) = c(u)c(v) \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} \cos \left[\frac{(i+0.5)\pi}{N} u \right] \cos \left[\frac{(j+0.5)\pi}{N} v \right] \quad (2)$$

$$f(i, j) = \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} c(u)c(v) F(u, v) \cos \left[\frac{(i+0.5)\pi}{N} u \right] \cos \left[\frac{(j+0.5)\pi}{N} v \right] \quad (3)$$

Where:

$$c(u) = \begin{cases} \sqrt{\frac{1}{N}}, & u = 0 \\ \sqrt{\frac{2}{N}}, & u \neq 0 \end{cases} \quad (4)$$

After an image is transformed by DCT, in the output DCT matrix, the larger values of coefficients are concentrated mostly in the upper left corner of the matrix (low-frequency components), while values of coefficients tend to become smaller and smaller in the low right corner of the matrix (high-frequency). Since F(0, 0) as direct current(DC) coefficients do not exist significant statistical regularity, this paper discusses statistical model of the AC coefficients. Fig. 2 shows the Y channel of an YCbCr image and its DCT matrix.

The point of doing it is that now high and low-frequency brightness information have been separated out. The proposed method achieves brightness equalization by regulating the low frequency coefficients to small values. And genetic algorithm is employed to find a relatively optimal DCT matrix to get ideal results.

Fig. 2. (a) Y channel of an image. (b) DCT matrix of a

2.3 Genetic Algorithm

Generation algorithm (GA) is a metaheuristic inspired by the process of natural selection that belongs to the larger class of evolutionary algorithms (EA). The concept of GA was first proposed by Charles Darwin. GA is a stochastic searching algorithm and could find out optimal search by itself and restore the search direction adaptively not bounded with predictive factors⁽¹¹⁾. Now GA is widely applied in many optimization problems in the field of, machine learning, artificial intelligence, signal and image processing, etc⁽¹²⁻¹⁴⁾.

Generation algorithms are commonly used to generate high-quality solution to optimization by relying on bio-inspired operators such as crossover, mutation and selection, the process of GA is shown in Fig. 3. In this paper, the fitness function is determined as mean luminance error of the regulated image.

Fig. 3. Flowchart of GA

(a) Selection

In genetic algorithm, selection of gene is a crucial step

in which individual that has better fitness value are chosen for next-generation reproduction. There are various selection operators, including roulette-wheel selection, truncation selection, stochastic universal sampling and so on. We choose tournament selection, which involves running several “tournaments” among a few individuals chosen at random from the population, and then the one with the best fitness is selected for crossover.

(b) Crossover

Cross operator varies the programming of an individual from one generation to the next. Crossover is a process of taking more than one parent organism and producing a child organism from them. Crossover is primarily sorted in accordance with application and there are various types of encoding like single point, two point, uniform and arithmetic crossover, *etc* ⁽⁶⁾. In this paper, two-point crossover is applied so that coefficients between the two points are swapped between the parent organisms, rendering two child organisms.

(c) Mutation

Mutation operator is used to maintain the genetic diversity of a population to the next by modifying one or more gene values with some probability. For different individual types, different mutation types are suitable, such as bit-string mutation, flip-bit mutation, uniform mutation, *etc*. In this study, we use Gaussian mutation which adds a unit Gaussian distributed random value to the chosen gene.

3. Results and Discussion

After the implementation of GA, an optimum fitness will be obtained. Since we set the fitness function as mean luminance error of the regulated image, the smaller the value is, the better result is displayed as shown in Fig. 4.

Fig. 4. (a) Fitness=237 (b) Fitness=51 (c) Fitness=28

Histogram equalization is a popular method for image enhancement. It implies mapping one distribution of gray level to another distribution of gray level ⁽¹⁴⁾. Different color

images are used to evaluate the results of the proposed method and histogram equalization. The results are shown in Fig. 5. It is clear that the proposed method performs better in enhancing the brightness of underwater images.

Fig. 5. (a) Original image (b) Enhanced by proposed method (c) Enhanced by histogram equalization

4. Conclusions

The uneven illumination in deep sea brings underwater image process challenges. In this paper, a new method for optimizing underwater image brightness has been presented. Our method is used to enhance the too darkened or overly brightened regions of images by regulating the low-frequency part of image DCT coefficients. And genetic algorithm has been applied in DCT coefficients adjustment to achieve better results. From the experiments and results, the proposed method is proved to be a more effective and convenient way to enhance the underwater images.

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