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Research article

Retinal model-based visual perception: Applied for medical image processing

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ABSTRACT

The Human Visual System (HVS) model based image quality metrics, correlates strongly with the evaluations of image quality as well as with human observer performance in the visual recognition process. Physiological modeling of retina plays a vital role in the development of high-performance image processing methods for better visual perception. For image processing in medical diagnosis, one has to follow several steps like image preprocessing, image segmentation, feature extraction, image recognition, and interpretation. This work aims at developing human visual system based image processing which stands advantageous when compared with the conventional processing methods. The main aim of this work is to develop a model for retina, which has complex neural structure, capable of detecting the incoming light signal and transforms the signal before transmitting it through the optic nerve. This retinal model comprises of the photoreceptor, outer-plexiform and inner-plexiform layers exhibiting the properties of compression and spatiotemporal filtering in the processing of visual information. The spatial frequency value is evaluated using Discrete Cosine Transform (DCT) technique thereby enhancing the contrast visibility in the dark area and maintaining the same in the bright area using photoreceptor layer of the retina. Contour contrast enhancement is achieved by modeling outer- plexiform layer of retina and parvo channel of the inner-plexiform layer is modeled to extract finer details of the image. The properties like luminance, spatial and temporal frequencies were considered to develop the human visual system based retinal model. The proposed model is applied to a wide variety of medical images and with simulated results it has been proved that the texture feature values of the processed image are found to be higher than the original input image. Further, this method proves to be more flexible which enables easier practical implementation when compared to that of generic medical image processing techniques.

Introduction

Imaging modalities like X-rays, Computed Tomograms, Ultrasound, and Magnetic Resonance Imaging are used to assess the condition of an organ/full body. Proper diagnosis and treatment are aided by monitoring the physiological condition over an observation period. To make diagnosis simpler and accurate, the images obtained through the scanning modalities are subjected to processing. Medical image processing technique go through the following steps for disease diagnosis and to check for normal and abnormal conditions, (i) The first step is image preprocessing to filter noise and to enhance image quality. (ii) The next step is image segmentation where the region of interest is segmented using different segmentation algorithms. (iii) The third step is feature extraction, where different textures and statistical features are extracted to analyze the morphological behavior of the image. (iv) The final step is classification, where the image is classified as normal and abnormal image by comparing the values of the extracted features. The software can be used for simulation to evaluate strategies and to perform planned treatments (Costin, 2014). To extract the finer details of the image, the acquired image is subjected to several step by step processing, like image pre-processing, image segmentation, feature extraction, image recognition, and interpretation. Algorithms are written to process the image which makes the system more complex.

The main scope of these algorithms is fairly expansive, ranging from automatically extracting Region of Interest (ROI) as in the case of segmentation thereby improving the quality of perceived image using image enhancement. Algorithm testing for image processing applications is carried out to check whether the particular

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algorithm satisfies its specification relating to criteria such as accuracy and robustness. Testing an algorithm helps to analyze the algorithm both qualitatively and quantitatively. Performance metrics is a meaningful and computable measure used for quantitatively evaluating the performance of any algorithm. For accessing image quality, there is no single quantitative metrics which correlates well with image quality as perceived by the human visual system. Image quality measurement is important in many image processing applications. Quality assessment methods have been carried out in the literature to assess the characteristics of the human visual system (Wang, Bovik, Sheikh, & Simoncelli, 2004). Gao, Lu, Tao, and Li (2010) in his study proposed image quality assessment technique using human visual system model to provide a better understanding of image using two methods namely bionic and engineering methods. But the main issue in their study was the metrics not extended for chromatic image quality assessment. Pei and Qiao (2010) proposed a cascade model of the retina to gain the output image of bipolar cell layer and spike trains of ganglion cells. The model proposed by the author was further extended to develop artificial retina prosthesis. In his work, the author did not consider contrast gain, the translation equation between cell layers was not accurate, and the connectivity between cell layers was considered neglecting the effect between the cells. Hui, Xu-Dong, and Song (2010) proposed retina model to stimulate complex structure of retina covering main information processing pathway.

Mantiuk, Myszkowski, and Seidel (2006) proposed a framework for image processing application that works in the visual response space. The author in his work developed tone mapping algorithm to produce sharper images, but the accuracy was not too good. Hafiz, Alnajjar, and Alnajjar (2010) proposed a model from mammalian retina based on dynamic mask inspired by the neuron connection of retina towards better robotic vision Senan, Saadane, and Barba (2001) developed an HVS model for information coding application. The study involved modeling of visual cortex that is subjected to the high-level information processing and did not concentrate on what happens at the retina level, i.e., low-level processing. Physiological modeling of the retina was carried out including functionalities like luminance, compression properties, spatial and temporal frequencies for better visual perception. Hérault and Durette (2007) developed a model of the retina for processing visual information which includes functionalities like sampling, spatiotemporal, nonlinearity, and color coding. In their work authors have not illustrated much on compression properties of the retina. In the proposed retinal model study on detecting the perception on various layers of retina based on compression, properties are carried out. A lot of works has been carried out to understand the functionalities of HVS and further to apply this knowledge in various image processing applications.

A model for processing color was proposed by Herault (1996). In their work, the authors have presented a detailed biological perspective of the interactions taking place in the different layers of the retina. These perspectives have helped in understanding the cellular interactions taking place in the retina and design filter models accordingly. Benoit, Caplier, Durette, and Herault (2010) have proposed a model for different layers of the retina and the processing that occurs in the primary visual cortex of the brain. The image acquisition property of the photoreceptors was modeled on an enzyme relationship called the Michaelis-Menten relationship (Beaudot, 1994, 1996). The subsequent layers have been modeled as low pass spatiotemporal filters which interact to give band-pass spatiotemporal effects, retaining spatial frequencies in a particular band only (Benoit et al., 2010).

A study by Ravikumar and Rattan (2012) on analysis of various quality metrics for medical image processing showed that on enhancing the contrast value of an image by increasing the variance, image quality metrics like mean square error (MSE) value increases and the peak signal to noise ratio (PSNR) value decreases. This paper presents the comparative study of various quality metrics for medical image processing application. The proposed work is based on Benoit et al. (2010) but modified regarding spatial and temporal frequencies. The development of such retina model allows the extraction of finer details of the image. The purpose of this work is to address the importance of applying the HVS model to image processing. Physiological-based HVS model considering image compression properties is incorporated to obtain good image quality at low bandwidth. The main aim of this study is to develop a mathematical model of the retinal layer to extract the finer details of the image thereby reducing the complexity involved in generic image processing techniques. Retinal structure details are given in Section "Retinal structure", followed by mathematical modeling of retinal layers in Section "Mathematical modeling of retinal layers".

Retinal structure

Human retina contains nearly about 200 million nerve cells; it is less than a millimeter thick over most of its extent (Kaiser & Boynton, 1996). The retina detects light falling on it, and then converts the incoming light into its equivalent electrical signal and later performs initial processing of signal and finally the processed information is sent to the brain through optic nerve where this information is perceived as an image. Human retina acquires information from the outside world, performs sampling, compresses the information and sends the information to the brain.

Path of information flow from the light source to the optic nerve fiber is derived from a three neuron chain which starts from the photoreceptor layer to bipolar cells to ganglion cells Fig. 1. The first and foremost layer of the retina is the photoreceptor layer which is responsible for visual data acquisition; this layer is also associated with local logarithmic compression of the image luminance. Photoreceptor layer is in-turn connected to the ganglion cell layer through a series of neurons. There are two main receptors in the photoreceptor layer namely, the cones responsible for color vision processing and are color sensitive. The rods are even more sensitive than cones and are responsible for dim light vision. Rods are responsible for producing low-level illumination that gives rise to scotopic vision. Rods and cones, in general, produce a nonlinear response. The retina cells are connected to each other for better visual perception, thereby forming two main layers namely, the Outer-Plexiform Layer (OPL) and the Inner-Plexiform Layer (IPL). In the Outer-Plexiform Layer (OPL), the signals are transmitted from the photoreceptors layer to two kinds of cells namely, the bipolar cells and the horizontal cells through a junction called synaptic triad. Connections between cones and bipolar cells are of a one-to-one type in the fovea region; several bipolar cells may be connected to the same cone (Yang et al., 2004). If a cone is excitatory to a bipolar cell, it is also excitatory to a horizontal cell, and this horizontal cell is, in turn, inhibitory to the bipolar one. In the Inner-Plexiform Layer (IPL), the bipolar cells are connected to ganglion cells and the amacrine cells, the axons of the ganglion cell constitute the optic nerve, and the amacrine cells play a similar role as the horizontal cells in the OPL.

Retinal layer based HVS model

An understanding of the human visual system plays a very crucial role in the design of image processing system. The block diagram of the proposed retinal layer model is shown in Fig. 2.

Photoreceptor acts as a sensor of the human visual system which is responsible for converting a photon into a nerve signal.