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Reconstruction of hyperspectral cutaneous data from an artificial neural network-based multispectral imaging system

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ABSTRACT

The development of an integrated *MultiSpectral Imaging* (*MSI*) *system* yielding hyperspectral cubes by means of artificial neural networks is described. The *MSI system* is based on a CCD camera, a rotating wheel bearing a set of seven interference filters, a light source and a computer. The resulting device has been elaborated for *in vivo* imaging of skin lesions. It provides multispectral images and is coupled with a software reconstructing hyperspectral cubes from multispectral images. Reconstruction is performed by a neural network-based algorithm using heteroassociative memories. The resulting hyperspectral cube provides skin optical reflectance spectral data combined with bidimensional spatial information. This combined information will hopefully improve diagnosis and follow-up in a range of skin disorders from skin cancer to inflammatory diseases.

1. Introduction

Early melanoma detection has gained major attention for the development of non-invasive imaging techniques [1,2] and computer-based solution [3,4]. Those efforts try to bring objective measurement of skin lesions. The use of skin colour in dermatological diagnosis relies mainly on direct visual analysis and/or RGB (red, green, blue) colour photography. This approach has limits due to the poor colour discrimination of the human eye and brain, and their inability for comparisons at different times. In order to overcome such limitations, measurement of optical reflectance from skin lesions can provide valuable spectral information, potentially useful for diagnosis. This can be achieved by combining advantages of spectrophotometers (spectral resolution) and digital cameras (spatial resolution), in MultiSpectral (MSI) and HyperSpectral (HSI) Imaging systems. MSI and HSI systems have the capacity to acquire images at different short spectral bands, including wavelengths which the human eye is unable to capture. Therefore, it is possible to extract extra information about light-matter interaction that is usually concealed within RGB images. Some skin diseases appear to exhibit specific reflectance properties. For instance, according to Tomatis et al. [5], cutaneous melanoma may have different variegations above specific wavelength values as compared to non-melanoma lesions. Currently, the use of MSI devices in dermatology is limited to few devices [5–7]. A new category, consisting of HSI systems is currently under investigation in several research groups, in microscopy [8,9] and for *in vivo* optical diagnosis [10] but limitations of HSI are generally their complexity and cost [11]. MSI usually involved 4–16 spectral bands when HSI is able to record a much higher number of very narrow bands (20–200). HSI provides a hyperspectral cube (HC) which contains contiguous spectra. In contrast, multispectral images should be considered as discrete spectra.

In this contribution, the development of an integrated MSI system, composed of a CCD camera, a rotating wheel and a set of interference filters, is described. The MSI is coupled with software that reconstructs hyperspectral cubes from acquired multispectral images. Our system is innovative since it evolves from a MSI into a HSI system without the need for an increased number of filters.

In this article, the following section presents the MSI systems. Then, the hyperspectral cube reconstruction method is detailed. Finally, preceding the discussion, results of cube reconstruction are presented.

2. Materials and methods

2.1. Acquisition system of multispectral images

The multispectral imaging system is called ASCLEPIOS standing for Analysis of Skin Characteristics by Light Emission and Processing of Images Of Spectrum. For ergonomic purpose, the acquisition system (Fig. 1) is divided in two parts, a light source compartment and a hand-held device.

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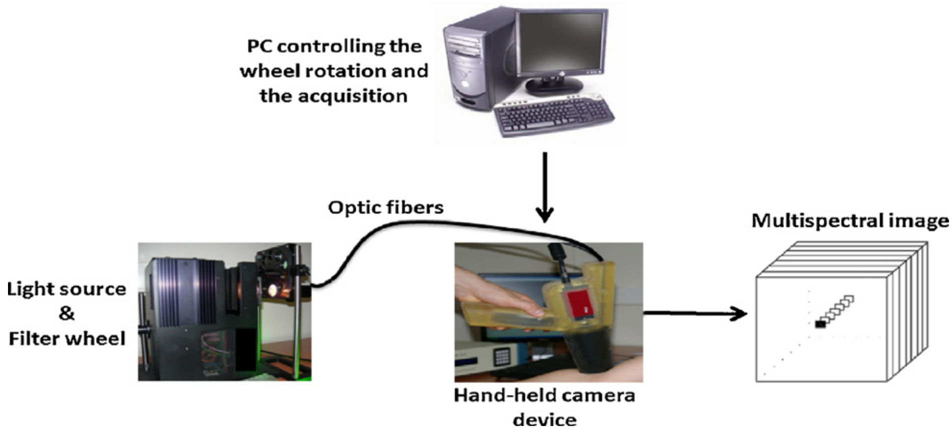

Fig. 1. ASCLEPIOS system description.

The light source compartment houses the illumination device, the rotating wheel and the set of interference filters. A xenon light source (175 W) with light spectrum in the range of 380–1000 nm is employed. The filter wheel holds the set of interference filters and gradually rotates to position each filter in front of the light source yielding a light source of a specific waveband. Seven interference filters fully cover the visible domain from 400 to 800 nm. The set of filters sample the chosen domain into equal spectral bands (bandwidth of approximately 60 nm). The filters have peak transmittance that range from 60 to 80%. The light at a specific waveband is carried out by optic fibres to the back of hand-held device. The back of the hand-held device also houses the camera. The use of a filter wheel in comparison to other system was motivated by a flexibility offered by the different widths and transmittance selection of commercial filters.

Considering this configuration, the camera and the illuminating optics fibres, both oriented toward the skin, are enclosed in a hand-held device protecting the acquisition of external light. Thus, the skin is only illuminated with light of specific wavebands. The extremity of the hand-held device includes a nozzle which sets a constant distance of 10 cm between the skin area and the camera. For each spectral band illumination, the system acquires Images 1280 × 960 pixel images coded in 16 bits using a single monochrome CCD-based camera. The monochrome camera is based on the IEEE-1394 data transferring protocol, with acquisition rate capacity of 30 frames s^{-1} at full resolution. A magnifying lens is mounted in front of the camera which provides an useful area of 2.85 cm × 2.2 cm, yielding a spatial resolution of 45 pixels mm^{-1}. The spectral sensitivity range of the CCD image sensor matches with the set of interference filters and the light source spectral range.

After positioning the hand-held device nozzle on the skin area under study, the user presses a wireless remote control located in the handle of the hand-held device. The pressure triggers the acquisition which is performed in less than 1 s. The system yields seven monoband images which compose one multispectral image.

2.2. Hypersectral cube reconstruction

The aim of hyperspectral cube reconstruction is to retrieve, from the camera signal, the reflectance spectrum in each pixel (linked to the physical property of the skin element) but also to increase the number of bands within the same spectral range. The reconstructed spectral volume of cutaneous data, also called hyperspectral cube (HC), provides a 3-dimensional volume (x, y, z) where x and y are for spatial dimensions and z for spectral dimension.

The HC is reconstructed using a neural network-based algorithm proposed by Mansouri et al. [12]. The artificial neural networks (ANN) are composed of two steps, learning and reconstruction [13]. In order to reconstruct spectra linked to the physical properties of the skin element, the proposed method takes into account a model of light propagation, used to extract the reflectance information.

Fig. 2 presents the model we used with the spectral response of all the elements involved in the acquisition process. Such a model aims at separating each element of the acquisition process to retain the reflectance information $r(\lambda)$ only.

By using this model and by considering a linear optoelectronic transfer function, $I(\lambda)$, $\Phi_k(\lambda)$, $O(\lambda)$ and $\alpha(\lambda)$ can be substituted by the spectral sensitivity S_k (λ) of the kth filter. Therefore, the reflectance spectra r needs to be estimated from the known camera response and the spectral sensitivity leading to an inverse problem.

Artificial neural networks are modelled on the human brain and aim to mimic the function of biological neural networks. ANN are composed of neurons link to each other by synapses. These synapses have coefficients which correspond to the weight of the connection. ANN have to be configured, meaning that the weights of the synapses have to be set to produce desired output from specific input during the learning process. A self-supervised learning method is chosen to determine the correct weight of the different connections. Perceptron is a basic model of neural networks. It is a binary classifier where the output, which is function of the neuron activation, is either 0 or 1 for deterministic perceptron. This limits the generalisation capacity. Knowing that perceptrons give same response to same stimulus after training, the function that converts the activation into a response is modified. It is changed to give probabilistic response using the Boltzmann distribution. Rather than outputting 0 or 1, this distribution delivers proportional response (restricted into [1 0]). Such perceptrons lead to the creation of associative memories (in our case heteroassociative). Heteroassociative memories is used due to its modularity in regards to the different sizes of the input and output vectors. Such

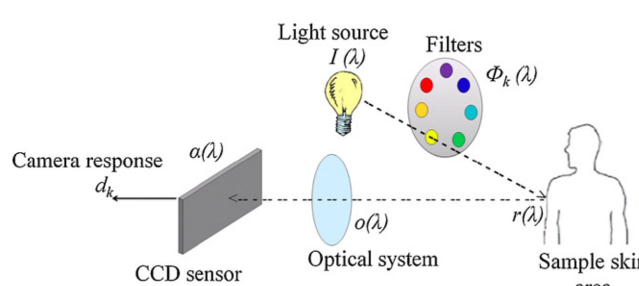

Fig. 2. Synopsis of the spectral model of the acquisition process in a multispectral system.