Multispectral imaging system for detection of small vertebrate fossils

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Abstract

Paleontology studies the evolution of life on Earth, ancient plants and animals, based on the fossil record. One of the main applications of fossils is dating sedimentary layers, which is nowadays made through the detection and posterior identification of tiny dental or skeletal remains of small mammals included in the sediment. Unfortunately, the process of separation of fossils from sediment is carried out only by hand and it is mainly based on morphological features, which leads to a remarkable waste of time and its subsequent economic impact. For this reason, this study proposes a new tool based on a multispectral system for the identification of fossil remains of small vertebrates based on the analysis of spectral characteristics. Specifically, a multispectral system with a CCD camera attached to a liquid crystal tunable filter was used in combination with daylight and ultraviolet light sources in order to discriminate the microfossils from the sediment. In this preliminary study, it is shown that the reflectance of bones and teeth is higher than the sediment, especially at wavelengths above 600nm. Moreover, a higher fluorescent emission of the paleontological remains is also observed around 550 nm. Therefore, these spectral differences can be successfully used by multispectral imaging systems to enhance the contrast between fossils and sediments, making easier their spatial detection and posterior separation.

Introduction

A large number of paleontological excavations are being carried out every year all over the world. The study of fossils sheds new light on how life was in the past. One of the key aspects in the analysis of fossils is dating sedimentary layers, which in most Cenozoic sediments is made through the taxonomic identification of dental or skeletal remains of small mammals. Such tiny fossils included in the sediment are crucial in order to later establish stratigraphic correlations and determine the age of geological layers with high accuracy (López Martínez 1992 [345:365]).

Unfortunately, the task of separation of fossils from sediment is currently done completely manually and according to external morphological criteria, which leads to a waste of time with the subsequent significant economic impact. Moreover, a previous chemical treatment and/or a process of wet sieving with high-pressure water is also necessary to obtain a first separation of the fossils of bones and teeth from sand and gravel. The particles obtained with this technique are 2 mm in size approximately. Afterwards a trained specialist will further classify these particles with an exhaustive visual recognition process and the help of a binocular microscope (Daams 1988 [3:18]) (Figure 1).

The sieving system, which was developed in the mid-1950s by specialist paleontologists in microfossils, remains practically unchanged since its origin. Actually, it was inspired by the gold-seekers method used in United States in the 19th century. Only the incorporation of a variety of mesh sizes in the nets by the 1970s improved this technique, which allowed reducing the separation time of the material and diminishing its loss. The consequence of this methodological improvement was a considerable advance in the number of paleontological treatable sites, but it was not accompanied by a progress in detection techniques and physical separation of the small fossils (Daams 1988 [3:18]). Consequently, nowadays the visual recognition process and manual separation is still limiting the process because of the high amount of time and human resources needed.

a) b)

Figure 1. a) Wet sieving process of paleontological samples using Freudenthal's technique. b) Visual recognition of teeth and bones using a binocular microscope.

In order to improve the former procedure, some preliminary attempts have been made using properties of fluorescence of fossils, which they exhibit when exposed to ultraviolet light (UV). In some cases this might help in distinguishing bones and teeth from other components like sand and gravel (Croft 2004 [795-800]). Nevertheless, this method cannot be used in a generalized form as properties of fluorescence depend on the type of fossils analyzed and there are also limits of light exposure linked to the conservation of paleontological remains.

On the other hand, there is a lack of information regarding the spectral features of different types of fossils and this opens new fields of research which might be useful to overcome some of the former limitations. One of the major difficulties that arise from this study is to accurately measure the spectral properties of samples to be analyzed as they are below 2 mm in size and not uniform at all. Therefore, for this purpose the use of standard instrumentation is not very advisable.

In this context, multispectral imaging systems, which use a spectral sampling technique together with a digital imaging sensor, can provide a better insight in this matter. There are several spectral sampling techniques such as single point spectrometers with 2-D scanning systems (Bonifazzi 2008), digital cameras combined with line-scan spectrographs (Barbin 2012 [30-42]), color filter wheels (Vilaseca 2006 [4241-4253]), and tunable filters of liquid crystal or acousto-optic technology (Harderberg 2002 [2532], Tran 2005 [735-752]). Multispectral imaging is a rather new field of research with many applications such as remote sensing (Weng 2011 [610]), color imaging (Shresta 2011), biometrics and medicine (Everdell 2010, Bouchard 2009 [15670-15678], Vilaseca 2008 [5622-5630], Basiri 2010, Paquit 2009), cultural heritage and art work studies (Kubik 2007 [199-529], Padoan 2008 [25-30], Marengo 2011 [6609-6618], Herrera-Ramírez 2014 [3131-3141]). However, up to our knowledge it has not yet been used in paleontology.

For all these reasons the main objective of this project is to study the feasibility of using a new method based on the spectral features measured by means of a multispectral imaging system to separate paleontological remains from sediment. The multispectral system used in this study consists of a monochromatic CCD camera and a liquid crystal tunable filter (LCTF) that allows us to obtain a set of images of the microfossils through many spectral bands. This might help in decreasing the time needed and reducing the important economic impact that exists at present.

Method

Paleontological remains found in Abocador de Can Mata C5-D1 (Hostalets de Pierola, Barcelona - Catalonia, Spain) of 11.6 million years were analyzed in this study. These fossils are only a small representation of all those recovered after water-screening a total amount of about 10 tons of sediment.

As formerly mentioned, a multispectral imaging system comprising a 12 bit-depth monochromatic camera (QImaging QICAM Fast 1394) with a LCTF (Varispec filter model #VIS-07-HC-20-1012) was used to acquire spectral images of fossils (bones and teeth) and sediment (sand and gravel) under daylight (D65) (SpectraLight III overhead luminaire). The system allowed obtaining images in 33 different spectral bands (from 400 nm to 720 nm with a 10 nm-step). Each spectral image was obtained by calibrating the exposure time in order to optimize the dynamic range of the camera.

Samples including only microfossils (bones and teeth) or sand-gravel, which were firstly separated by a trained paleontologist, were captured. These individual samples were also characterized by means of a commercial spectrometer (Instrument Systems® Spectro 320 Scanning) with a telescopic optical probe for radiance and luminance measurements (Top100 accessory).

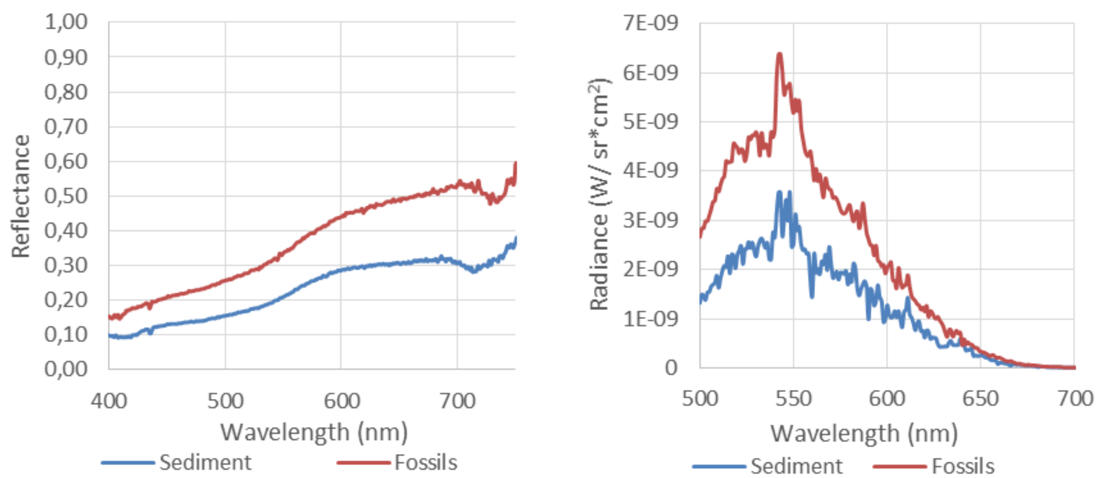
These images and spectral measurements allowed us to know if there were any spectral differences between the microfossils and the sand-gravel, highlighting any wavelength peak at a specific location that could help us to differentiate between them.

After that, images from samples containing a mixture of microfossils and sand-gravel were also taken under D65 and UV light, as a means of studying different strategies to allow a fast and automated detection and later separation.

Results

Figure 2(a) shows the mean spectral reflectances of the microfossils and the sand–gravel samples in the visible range of the electromagnetic spectrum. Figure 2(b) shows the fluorescence emission of the same samples measured when they are illuminated with UV light. As it can be seen, in general bones and teeth have a higher reflectance values and this difference increases from 600 nm on. Despite the fact that microfossils have higher reflectance than the sand and gravel at longer wavelengths, there are not specific wavelength peaks that permit distinguishing between them. On the other hand, microfossils also show a more marked fluorescence rather than sand-gravel samples, basically around 550 nm.

The increased difference in reflectance at long wavelengths can be also observed in Figure 3, where some of the spectral images taken with the multispectral system under D65 illumination are provided.



a) b)

*Figure 2. a) Reflectance of sand and bones-teeth samples. b) Emission spectra (Radiance in W/sr*cm^2) of sand and bones-teeth under ultraviolet light.*

As can be seen, more marked luminous differences between samples are obtained in spectral bands higher than 600 nm, making them more suitable to detect the fossil remains. Another point to highlight is that the color sRGB image does not provide a so marked difference between samples as the spectral images at long wavelengths do. Taking into account that the sRGB image is similar to what the naked eye sees, it can be suggested that the use of spectral images at specific wavelengths could make much easier the detection and later separation of samples.

As stated in the methodology section, images of the paleontological remains including mixed samples, i.e. with microfossils and sand-gravel together, were also photographed. Figure 4 provides sRGB images under D65 and UV illumination conditions. The UV source was used to enhance the contrast between teeth and bones with respect to the sediment, due to their different spectral features in terms of fluorescence.

As it is shown, it is almost impossible to differentiate between samples by using the daylight image while bones and teeth are highlighted and easier to discriminate with UV light. Making use of the green component of the sRGB image under UV light, the bones and teeth are more contrasted as they present a higher fluorescence peak at 550 nm approximately. Finally, a posterior image processing procedure applied to this green component also provides a greyscale image in which a segmentation algorithm is carried out. The results obtained suggest that this would be a very helpful procedure to detect the bones and teeth and to later separate them from the sand and gravel.

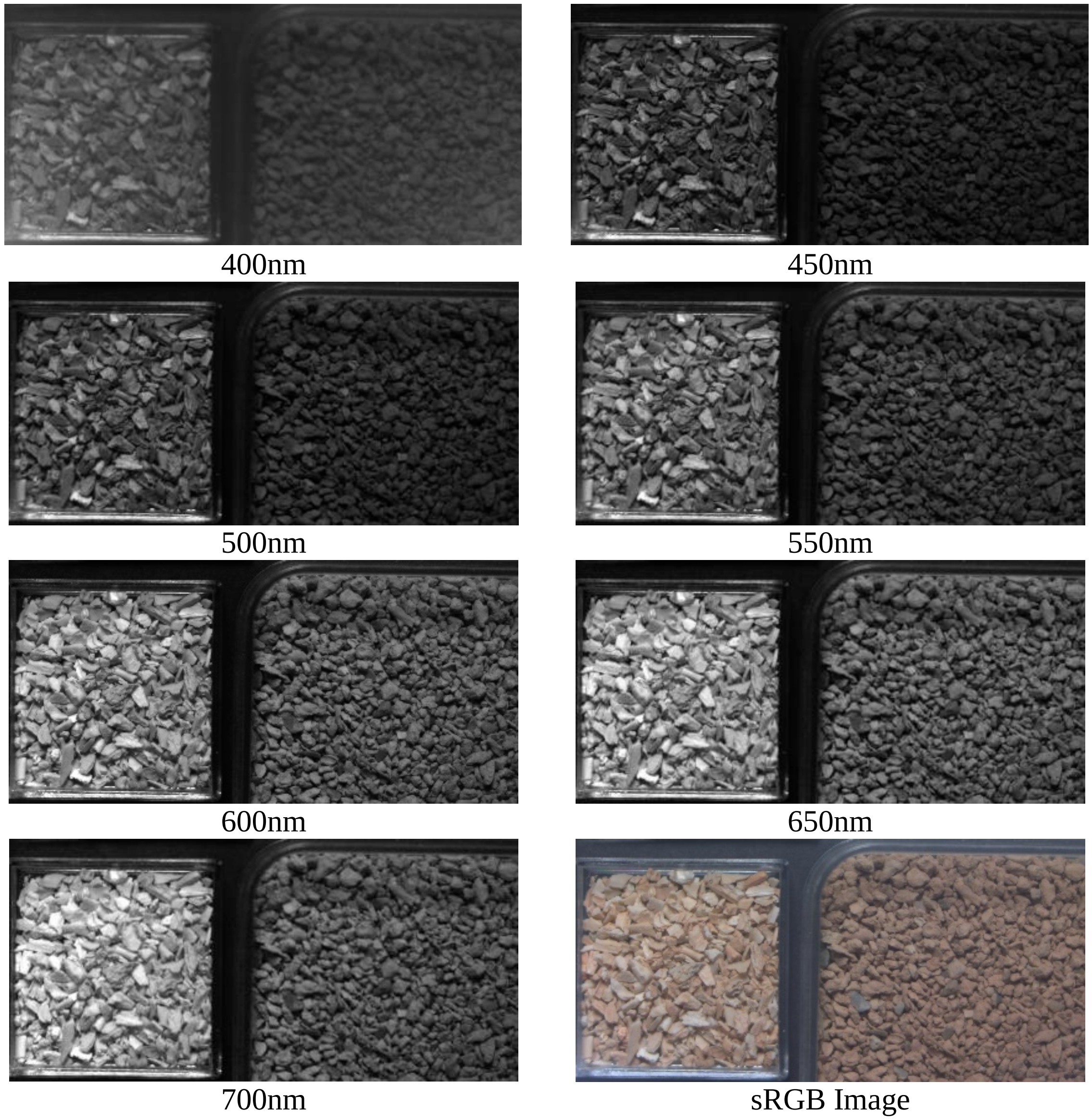


Figure 3. Examples of images of the paleontological sample obtained with the multispectral system under daylight light. A simulated sRGB image is also provided. The left sample correspond to microfossils (bones-teeth) and the right sample to sand and gravel. It is easy to perceive that luminous differences between samples increase with wavelength and that a sRGB image does not allow a rather good discrimination.

Conclusion

In this study, the feasibility of using a multispectral imaging system was tested as a means of detecting paleontological remains such as microfossils from sediment. For this purpose, a multispectral imaging system consisting of a digital CCD camera and a LCTF were used. Daylight and UV light sources from an overhead luminaire were used to light samples containing both microfossils (bones and teeth) as well as sediment (sand and gravel).

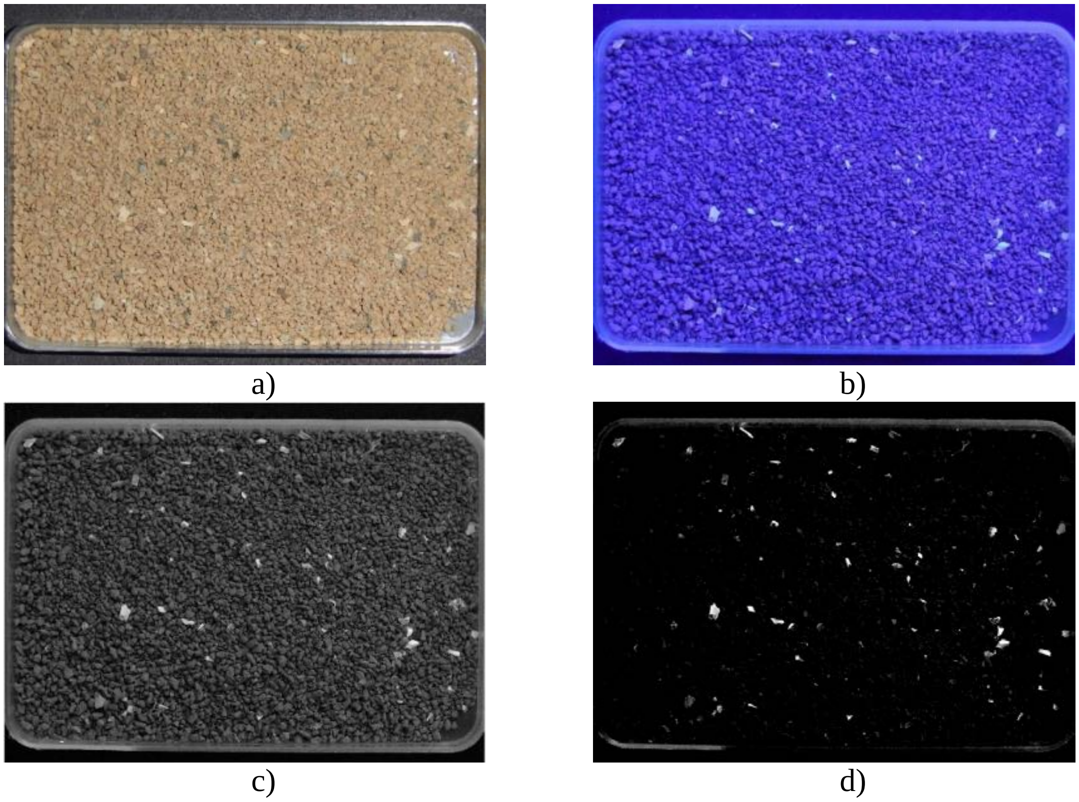


Figure 4. Images of paleontological remains without separation of bones-teeth and sand-gravel. a) sRGB image illuminated with a daylight source. b) sRGB image illuminated with UV source. c) Green component of the image under UV light. d) Greyscale segmentation of the green image (c).

The results suggest that both kinds of samples have a different spectral reflectance in the visible range, mainly above 600 nm where bones and teeth have higher values. The fluorescence emission of microfossils is also higher than the sediment, especially around 550nm. Furthermore, a segmentation algorithm is used to highlight fossils from sediments when the green component of the sRGB image under UV light is considered.

Accordingly, we show that these differences can be successfully used by multispectral imaging systems to enhance the contrast between fossils and sediments, making easier their spatial detection and posterior separation. Therefore, using spectral information besides morphological criteria, would lead to a significant decrease in time and economic costs.

Nevertheless, further research is still needed in order to establish which type of paleontological remains can be separated by this method and studying the specific spectral features of samples coming from different paleontological excavations.

This new method represents a clear innovation in the field of paleontology, and it will be very helpful to overcome limitations of currently used techniques for fossil recovery.

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