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Portable multispectral imaging system based on Raspberry Pi

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Abstract

Purpose In this work, the authors aim to present a compact low-cost and portable spectral imaging system for general purposes. The developed system provides information that can be used for a fast *in situ* identification and classification of samples based on the analysis of captured images. The connectivity of the instrument allows a deeper analysis of the images in an external computer.

Design/methodology/approach The wavelength selection of the system is carried out by light multiplexing through a light-emitting diode panel where eight wavelengths covering the spectrum from ultraviolet (UV) to near-infrared region (NIR) have been included. The image sensor used is a red green blue – infrared (RGB-IR) micro-camera controlled by a Raspberry Pi board where a basic image processing algorithm has been programmed. It allows the visualization in an integrated display of the reflectance and the histogram of the images at each wavelength, including UV and NIRs.

Findings The prototype has been tested by analyzing several samples in a variety of applications such as detection of damaged, over-ripe and sprayed fruit, classification of different type of plastic materials and determination of properties of water.

Originality/value The designed system presents some advantages as being non-expensive and portable in comparison to other multispectral imaging systems. The low-cost and size of the camera module connected to the Raspberry Pi provides a compact instrument for general purposes.

Keywords LED, Raspberry Pi, Micro-camera, Multispectral imaging

Paper type Research paper

1. Introduction

In this work, we propose a low-cost compact multispectral system for general purposes where the illumination is carried out by means of a light-emitting diode (LED) panel with multiplexed wavelengths from 385 to 970 nm. The data collection and processing are accomplished by a commercial Raspberry Pi board, thus presenting some advantages, such as reduced dimensions, portability and being non-expensive. This board allows the use of a micro-camera as image sensor, which also includes the focusing optics. The low cost and size of this camera module, compared to others in the market, as well as the high processing capacity of this compact instrument, make this novel system suitable for being useful in a variety of applications.

Multispectral and hyperspectral imaging are analysis techniques based on the acquisition of the same image in different wavelength regions from which spectrally resolved information at each pixel of the imaged scene is generated (Levenson *et al.*, 2006; Wolfe, 1997; Salzer and Siesler, 2014). In multispectral imaging, images are acquired at several discrete wavelengths, usually 6 to 10 or even less, in the considered range of the spectrum (Xing and De Baerdemaeker, 2005; Huang *et al.*, 2015). In the hyperspectral approach, a very high number of close wavelengths are used, usually more than 100, thus obtaining a huge amount of data (Nansen *et al.*, 2008; Geladi *et al.*, 2004).

Spectral imaging combines two methodologies, spectroscopy and imaging. Whereas imaging provides the intensity of every pixel of the image and a typical spectrometer provides a single spectrum, a spectral image provides a spectrum at each pixel, which is seen as a cube of information (Garini *et al.*, 2006). The data of this cube are processed (Shen *et al.*, 2007; Goetz, 2009; Burns and Berns, 1996), and the spectral characteristics allow to distinguish spectral differences in an object, which can be used to detect changes in the surface, structure or composition of the sample (Xia *et al.*, 2016; Zhao *et al.*, 2016).

Spectral imaging was introduced for the first time in 1985 as a technique for remote sensing (Goetz *et al.*, 1985). From that year, this analysis technique has been gaining more and more acceptance, and its application fields now comprise a diversity of areas such as agriculture, armed forces, environment, geography, medicine, nutrition, etc. (Zhao *et al.*, 2016).

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A spectral imaging system is formed by the basic components: lighting, focusing optics, detector and a wavelength selector system. There is a diverse range of methods for wavelength selection which determines the design. In the first multispectral imaging systems, it was accomplished through filtering the illumination and using a monochrome digital camera to collect the reflected light. Alternatively, wavelength selection can be achieved through either filtering or dispersing the reflected light (Liang, 2012).

In more recent spectral imaging systems, the wavelength selection is carried out directly in the illumination source, that is, the sample is illuminated with a monochrome light. For this purpose, programmable light sources are used (Tominaga, 2012). In the past years, thanks to the development of very effective LEDs, the illumination of the samples or scenes in spectral imaging is being accomplished by the use of LEDs with very narrow wavelength spectrum (Xia *et al.*, 2016; Shrestha and Hardeberg, 2013; Park *et al.*, 2007). LEDs are found to be invariant compared to white lights, and, hence, they are recommended for multispectral systems.

Traditional spectral imaging systems are expensive and delicate laboratory instruments because they include complex illumination sources, optics and high-resolution cameras (Tominaga and Horiuchi, 2012; Kim *et al.*, 2010). In addition, an external computer is required for data processing and system controlling.

The instrument presented here solves these disadvantages making use of compact and low-cost commercial devices: a Raspberry board for control and image processing, a micro-camera module with integrated focusing optics for image acquisition and a set of LEDs for illumination and wavelength selection.

2. System description

As explained above, the developed instrument has been conceived to be a low-cost portable system based on non-expensive commercial devices that allow an easy use in a variety of applications. The data processing is carried out with simple algorithms based on the detection of the intensity of the light captured by the camera. In the following sections, the system is exposed in detail.

2.1 Instrument design

The scheme of the proposed multispectral imaging prototype is presented in Figure 1. The core of the instrument is the commercial platform Raspberry Pi 3 model B (Raspberry Pi Foundation, UK). It is a low-cost device of small dimensions (8.5×5.6 cm^2) with high processing capabilities thanks to the included 1.2 GHz 64-bit Quad-Core ARMv8 Cortex-A53 with 1GB RAM, thus making it appropriate for image processing. In addition, it supports a variety of connectivity protocols such as Wi-Fi 802.11 b/g/n, classic and low-energy Bluetooth, USB, etc., allowing data transmission between the instrument and an external computer for further data processing or storage.

The user interface is implemented by a touch screen model Adafruit PiTFT – 320 × 240 2.8“ (Adafruit, USA) designed for operation along with Raspberry Pi platforms. Through this LCD, the user can initiate the operation of the system, being the results displayed on it. No other device is required for configuration, interfacing or images visualization.

The image of the sample or scene is acquired through the micro-camera Raspberry Pi NoIR (Raspberry Pi foundation), a RGB camera add-on for Raspberry Pi that does not have any IR cut filter installed. This device is based on the image sensor OV5647 (OmniVision Technologies, USA), which is sensitive to near ultraviolet (UV), visible and near-infrared radiation up to a wavelength of about 1,000 nm. Figure 2 shows the spectral sensitivity of this sensor. The resolution of the micro-camera is 5 megapixels, and the dimensions are 2.5×2.4 mm^2. This device has a fixed focus lens onboard, i.e. no other focusing system is required. Nevertheless, the sample must always be placed at the same distance from the camera. This device is directly connected to the Raspberry Pi via a camera serial interface bus. The use of this low-size and low-cost camera allows the design of a compact instrument

Figure 1 Block diagram of the instrument

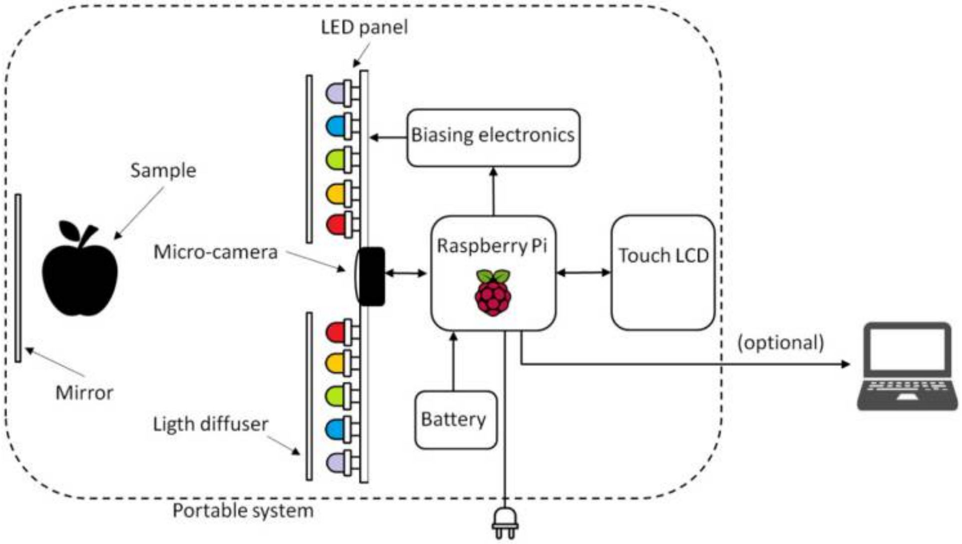


Figure 2 Spectral sensitivity of the sensor OV5647

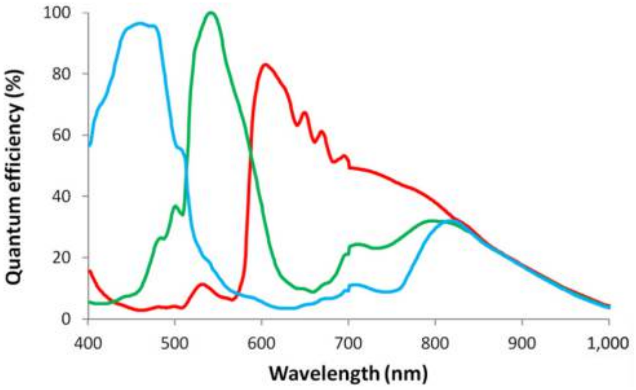
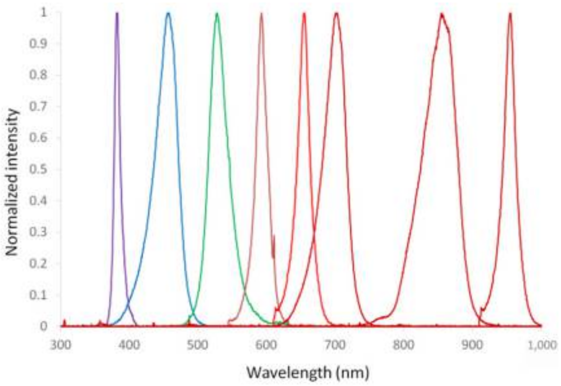


Figure 3 Normalized spectra of the LEDs



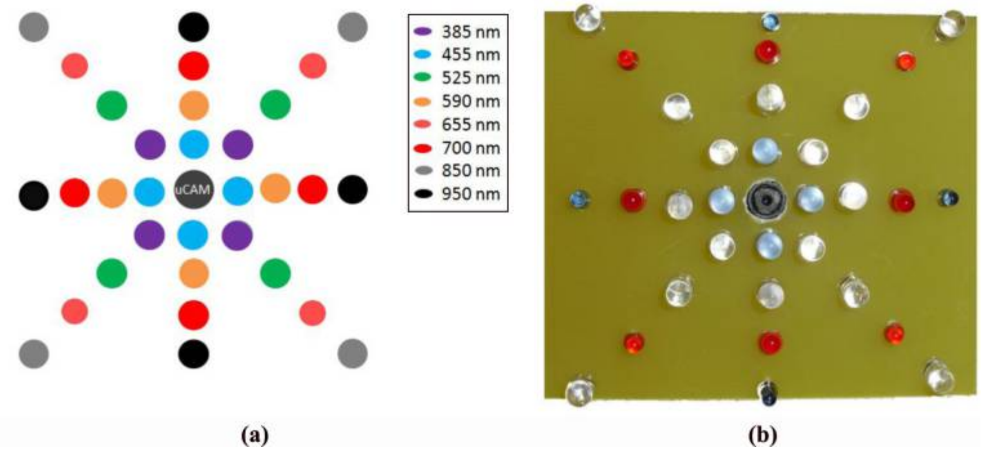
because it avoids the necessity of larger and more complex cameras for image acquisition, as it happens in other reported systems for multispectral imaging (Xing and De Baerdemaeker, 2005; Huang *et al.*, 2015).

The illumination of the sample is carried out by means of a LED panel which contains four LEDs for each one of the eight different wavelengths used, giving a total of 32 LEDs. Because the objective of the work is the development of a portable multispectral system for general purpose, the wavelengths are selected to cover the full range NUV-vis-NIR (NIR – near-infrared region). The selected wavelengths are 385, 455, 525, 590, 655, 700, 850 and 950 nm. Although only eight wavelengths are available in this prototype, this number can be easily expanded. As said, to obtain these wavelengths, appropriate low-cost LEDs are included in the panel following a specific pattern. The LEDs used are, in growing peak-wavelength order, the models VAOL-5EUV8T4 (Visual Communications, USA), L-53MBC (Kingbright Electronic, Taiwan), C503B-GAN-CC0D0782 (Cree, USA), HLMP-EL08-VY000 (Avago Technologies, USA), L07R3000G1EP4 (Ledtech Electronics, Taiwan), LN29RPX (Panasonic, Japan), TSHG6210 (Vishay Intertechnology, USA) and L-34F3BT (Kingbright Electronic). The spectra of the LEDs have been characterized through a spectrometer, obtaining the normalized distributions presented in Figure 3.

The LEDs are placed in a panel surrounding the micro-camera, as it is shown in the Figure 4. Four LEDs are used for each wavelength, disposed in a cross shape equidistant to the center. The main objective of this scheme is to avoid shadows in the pictures where samples are illuminated for each wavelength alternatively (Moreno *et al.*, 2006; Jong-Woei Whang *et al.*, 2009). To eliminate the directivity of the emitted light of the LEDs, a light diffuser is placed as indicated in Figure 1. It consists of a simply translucent plastic, with an aperture in the center for the micro-camera.

To obtain a stable illumination, the LEDs are biased by means of a current source. The scheme of the biasing electronics is presented in Figure 5. The current source design is based on an operational amplifier model LT1366 (Linear Technology, USA) which can drive a high output current up to 30 mA. A Zener diode model LM385-2.5 (Texas Instruments, USA) is used to force a voltage drop of 2.5 V in the negative feedback loop. With this configuration, a biasing current I_{bias} = 5 mA is generated. The LEDs of the same wavelength are serially arranged, being switched on at the same time, whereas the others remain unbiased. The selection of the LED-branch to be biased is carried out by using an analog multiplexer model ADG408 (Analog Devices, USA), controlled by the Raspberry Pi through three digital input signals.

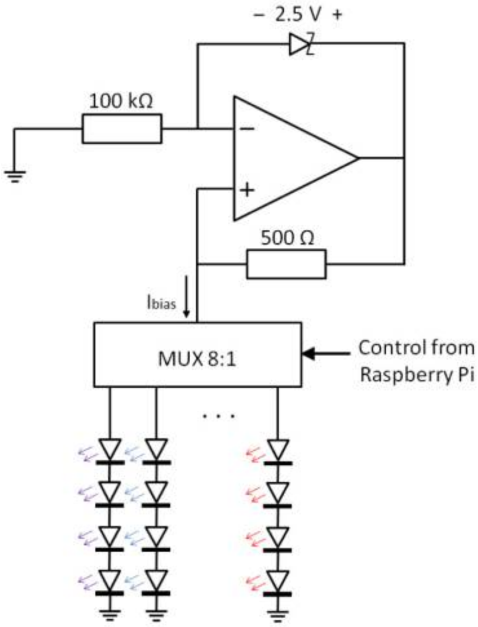
Figure 4 LED panel and micro-camera disposition scheme (a) and photograph (b)



(a)

(b)

Figure 5 LEDs biasing electronics



The power supply of the instrument can be obtained from batteries or from an AC/DC converter connected to the mains. The whole system is enclosed in a dark box in which the sample is situated for its analysis. A small mirror is placed behind the sample for trans-reflectance measurements of transparent samples.

2.2 Image processing

When the sample is situated in the corresponding position inside the prototype, the system takes a photograph at each available wavelength sequentially. These images are stored in the memory of the Raspberry Pi and processed to obtain some parameters that can be related to the properties of the sample. The usual analysis in spectral imaging consists in the evaluation of the reflectance of the light from the sample, obtained from the acquired images, for the considered wavelengths (Burns and Berns, 1996; Shen *et al.*, 2007). In other approaches, the intensity of the incident light is considered instead (Kim *et al.*, 2010; Descour *et al.*, 1997).

In this work, the image processing is carried out in the Raspberry Pi, which has computation capacity enough for this purpose, using the OpenCV library for real-time processing. Two analysis techniques have been implemented although any other scheme can be added to the code.

In the first technique, the image at each wavelength is characterized by the intensity of the reflected light collected by the micro-camera, in a similar approach to the conversion of the color image to the luminance image (Liu *et al.*, 2011). The intensity of the image is defined as the sum of the individual intensities of every pixel in the image, which are calculated from its RGB coordinates as (Escobedo *et al.*, 2016):

$$I_{pixel} = \sqrt{R_{pixel}^2 + G_{pixel}^2 + B_{pixel}^2} \rightarrow I_{image} = \sum I_{pixel} \qquad (1)$$

The evaluation of the image intensity I_{image} through the considered range of the spectrum allows to characterize a sample by means of its reflectance, and the alteration of this parameter at certain wavelengths might provide information about some change in the properties of the sample.

The second implemented analysis technique consists of the generation of a histogram of the image, where a representation of the occurrence of the intensity of every pixel is displayed for each wavelength. This approach provides more detailed information about the intensity distribution of the image, and it allows the detection of slight differences of the images when some alteration of the sample occurs (Kim *et al.*, 2001, 2015).

3. Results and discussion

As previously stated, the goal of this work is the development of a low-cost, easy-to-use, portable multispectral imaging system for general purposes. The instrument is intended to be suitable for basic applications such as the detection of rottenness in food, materials classification, sample surface examination, etc. In this section, some examples of these applications will be exposed.

3.1 Detection of damaged apples

Specific spectral imaging systems have been developed and reported in the literature for the detection of bruises in apples (Baranowski *et al.*, 2012). With this application, we show the feasibility of the developed general purpose instrument to detect damage on fruits, in particular on apples.

Figure 6 presents the photographs of a damaged sample at the eight different wavelengths. As it can be seen from the figure, there are some wavelengths at which damages are more perceptible than others.

These images have been processed to visualize the change in the histogram at these wavelengths when the fruit shows these imperfections (Huang *et al.*, 2015). Figure 7 shows the comparison between the histograms of damaged and undamaged apples at the wavelengths 455, 525, 660 and 870 nm. As it is observed, there is a shift of the histogram to lower intensity values when the apple is damaged because of the

Figure 6 Photographs of a damaged apple

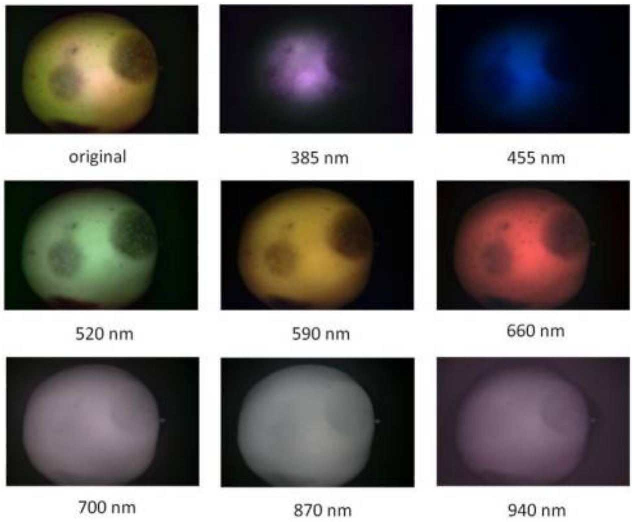
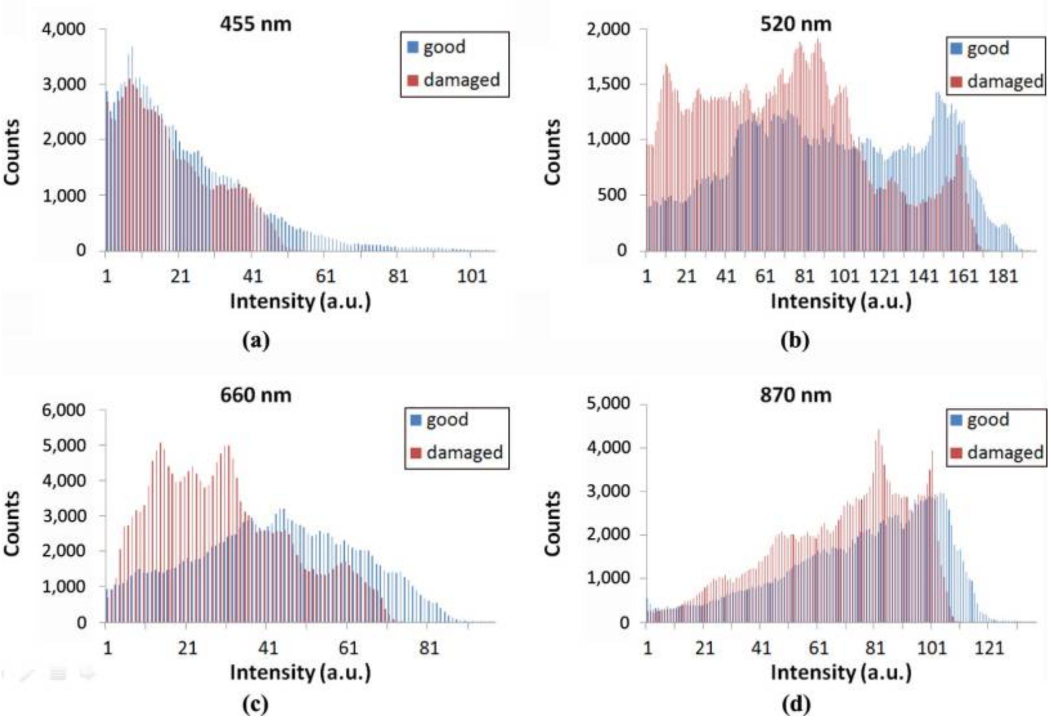

original
385 nm
455 nm
520 nm
590 nm
660 nm
700 nm
870 nm
940 nm

Figure 7 Histograms of the images of the apple



presence of dark areas where the damage appear (Figure 5). This shift is more evident in the images taken at 525 and 660 nm in which these dark areas shows a deeper contrast.

3.2 Peach ripeness monitoring

Spectral imaging analysis has also been widely applied to the monitoring of the state of food, particularly the properties of fruits, including ripeness, firmness, acidity, etc. (Wang *et al.*, 2015; Lu and Peng, 2006). In this case, the presented system is applied to the detection of over-ripe peach fruit. Figure 8(a) displays the comparison of the images of a good peach and an over-ripe peach at the wavelength of 590 nm. The images at every wavelength have been processed to obtain the reflected intensity received by the micro-camera and, therefore, the reflectance. The representation of this parameter is shown in the Figure 8(b). As it can be appreciated, there is a shift of the curve at high wavelengths that can be useful for the discrimination between pieces of peach fruit.

3.3 Detection of sprayed cherries

In this case, the instrument is used for the detection of cherries sprayed with pesticide. This substance remains in the surface of the fruit until it is well washed. In Figure 9(a), the reflectance analysis is presented. As it can be seen, only a slight variation in the curve at UV and IR wavelengths differences the graphics. A detailed analysis of the images at 940 nm is presented in Figure 9(b) as a comparison of the histograms. This result confirms the shift of the intensity of the image at this wavelength when the cherry is sprayed with pesticide.

3.4 Plastics classification

The analysis techniques based on spectral imaging is widely applied for discrimination and classification of plastic materials such as PolyEthylene Terephthalate (PET), Polyvinyl Chloride, low-density PolyEthylene (LDPE), high-density PolyEthylene (HDPE), PolyPropylene and PolyStyrene (Moroni *et al.*, 2015;

Figure 8 Images at 590 nm (a) and reflectance spectra (b) of good and over-ripe peaches

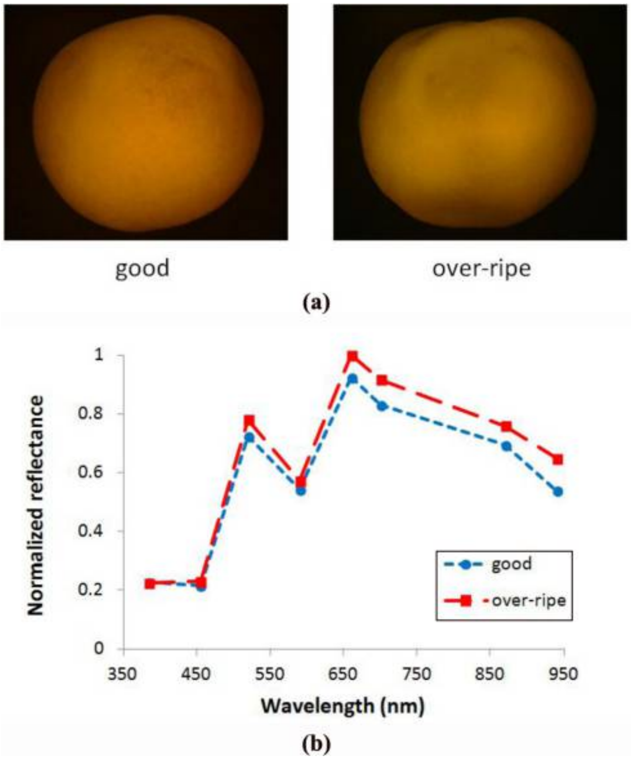
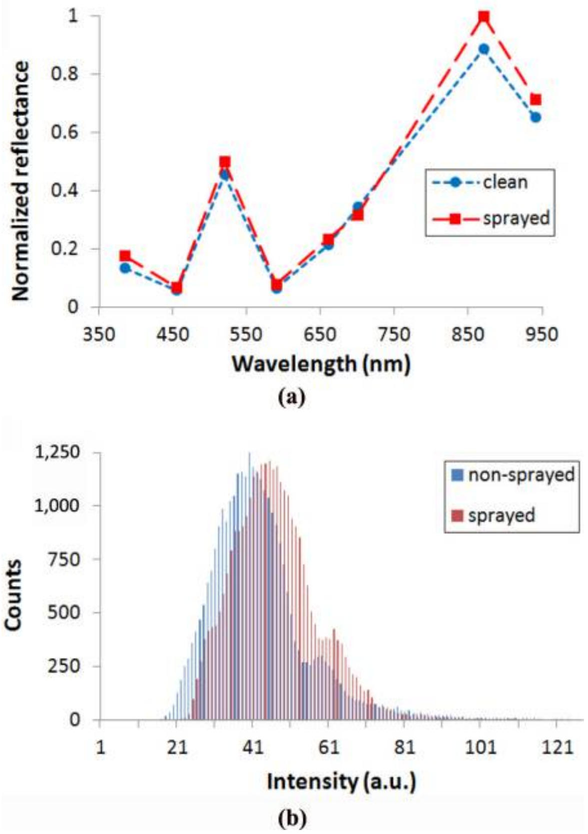


Figure 9 Reflectance spectra (a) and histograms at 940 nm (b) of sprayed and clean cherries



(a)

(b)

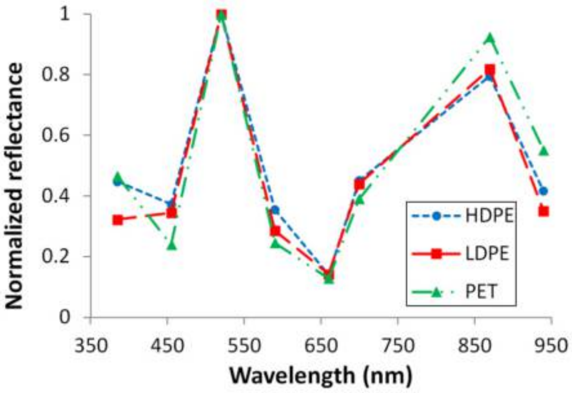
Vidal *et al.*, 2012). Here, we have applied the instrument for the classification of three plastics: LDPE, HDPE and PET. In Figure 10, the reflectance spectra for three samples of these materials are shown.

From this figure, it is clear that the shapes of the spectra are quite similar in the visible region of the spectrum. In high wavelengths corresponding to IR, some differences allow to discriminate the materials.

3.5 Water classification

The monitoring of water properties is also a field of application of spectral imaging (Cattaneo *et al.*, 2015; Fichot *et al.*, 2016). The presented prototype is also applicable to the analysis of water samples thanks to the included mirror that allows trans-reflectance measurements. In this study, three different water samples have been considered: unchlorinated water, chlorinated drinking water and chlorinated non-drinking water. Figure 11(a) shows the obtained reflectance spectra for these samples. As it can be seen, the curves are clearly distinguishable, being the recognition of the samples suitable. Figure 11(b) shows an example of the histograms obtained at 385 nm for two of the samples.

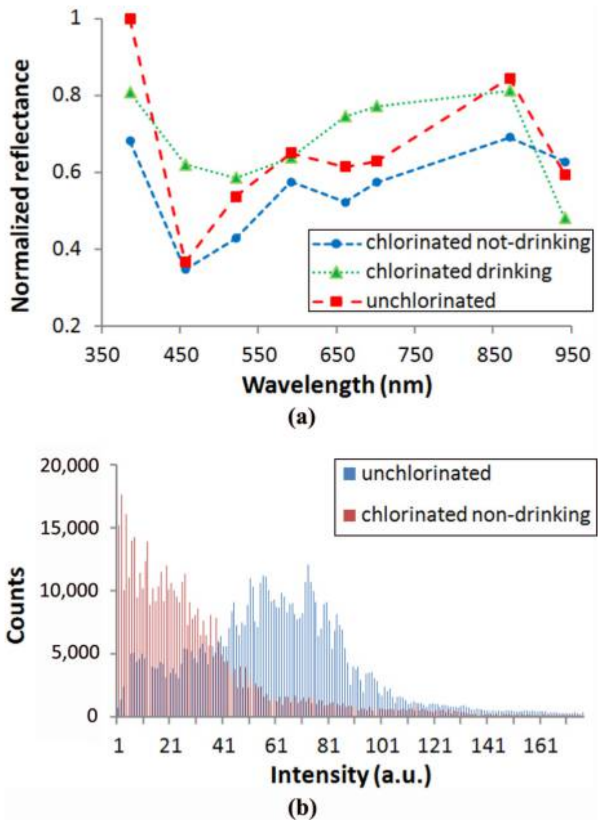
Figure 10 Reflectance of HDPE, LDPE and PET



4. Conclusions

We have presented a prototype of a multispectral imaging system for general purposes. The advantages of this instrument regarding other systems previously reported reside in its portability, low cost and easy use. The wavelength selection has been carried out by light multiplexing through an LED panel and the image acquisition by means of an integrated micro-camera, which is the key design point that allows the development of a compact and portable system. The core of the instrument consists of a Raspberry Pi board. The use of commercial boards in custom-developed instruments for research is promising via for fast design of advanced instrumentation because it allows fast evolution of the prototypes with few redesign stages. A basic image processing algorithm has been implemented in the Raspberry Pi that allows to obtain both the reflectance of the image through the evaluated spectrum and the histograms of each

Figure 11 Reflectance (a) and histograms at 385 nm (b) of the water samples



(a)

(b)

image. This analysis allows an in-situ fast classification or identification of the samples. Further processing of the images can be carried out with more advanced techniques such as principal components analysis implemented in the Raspberry Pi or in an external computer to which the instrument can be connected. Thanks to this connectivity the instrument is fully compatible with other custom-designed image processing algorithms without the necessity of reprogramming the core. Nevertheless, this is also possible with little effort because the computation capability of the Raspberry Pi board is still high enough to support additional code.

The feasibility of the prototype has been proved by the analysis of different samples: fruits, plastics and water. In all cases, the inspection of the intensity spectra or the histograms at certain wavelengths allows a first determination of the samples, which proves the variability of scenarios suitable to be analyzed with the presented system.

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