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Design of a Low-cost and Compact Radiometer for Spectral Acquisition of Vegetation and Bare Soil

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Abstract

We describe, in this article, the design of a low-cost and compact radiometer with five analog channels for spectral acquisition: four in the visible (blue, green, red and panchromatic) and one channel in the near-infrared. This small embedded system is based on an 8-bit microcontroller for automatic data acquisition, calibrating, storing and serial link processing with a compatible PC, through a C++ application software provided to handle and deal with the mass of data collected and stored in an EEPROM. The acquisition of spectral reflectance measurements of an object for different wavelengths allows the construction of a characteristic curve, named spectral signature of the object. The study of the spectral signatures of different types of surfaces such as water, bare ground or vegetation allows their identification in remote sensing image processing, and consequently, facilitates the interpretation of this kind of data, as, for instance, the AVHRR data of the HRPT images acquired and freely distributed by the satellite NOAA.

Keywords*: radiometer, reflectance, spectral signature, embedded system, 8-bit microcontroller*

1. Introduction

Optical remote sensing devices use visible and infrared sensors to form images of the earth's surface by detecting the solar radiation reflected from targets on the ground. When solar radiation hits a target surface, it may be transmitted, absorbed or reflected. Different materials reflect and absorb differently at different wavelengths. The different types of earth covers (forest, bare soils, water, vegetation, etc ...) are discriminated by the energy that they reflect or emit. These "specters" which characterize the type of observed coverage constitute their spectral signature [1].

Every object on the surface of the earth has its unique spectral reflectance. Figure 1 shows the average spectral reflectance curves for five typical earth's features: clear water, turbid water, bare soil and two types of vegetation. The spectral reflectance curves for type of vegetation manifests the "Peak and valley" configuration [5]. But spectral signature is a set of characteristics by which a material or an object may be identified on any satellite image or photograph within the given range of wavelengths. Sometimes, spectral signatures are used to denote the spectral response of a target.

We have designed a low cost and compact radiometer as an add-on to the instruments already available in our laboratory (LAAR) in order to obtain the characteristics of reflectance spectra of the main types of soil and vegetation existing in the region of our city (ORAN town, north west of Algeria).

2. Principle of the Radiometer

A radiometer (also currently named spectroradiometer) is an electro-optical device for measuring the intensity of the electromagnetic radiation flux in different areas of wavelengths. If the measuring radiation is carried out as a function of the wavelength, the optronic sensor is designed to collect and focus light (optical part) and to convert it into an electrical signal (electronic part). The following Figure 2 shows the block diagram of an optical sensor.

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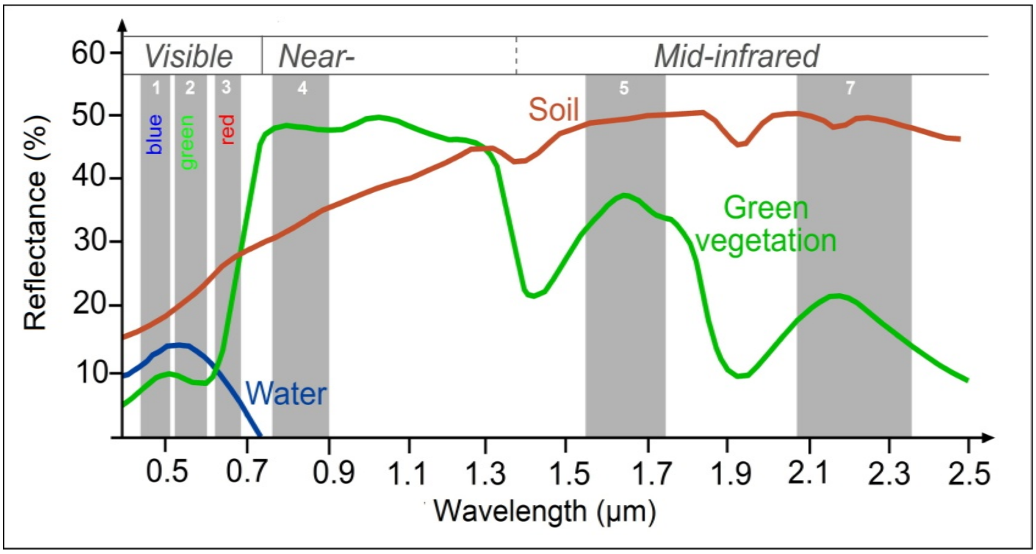

Figure 1. Typical spectral signatures

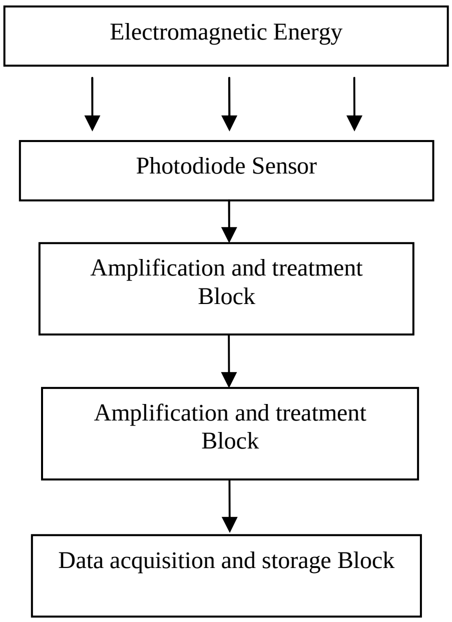

Figure 2. Functional scheme of a radiometer

Each detector receives, through an optic and a number of mechanisms [3], the energy E (ω, t, λ) with measurement spectral response R (λ) and integrated over a solid angle Δω, during an integration time At, and spectral band Δλ. This gives a measure adjusted by a calibration coefficient A:

$$m = \mathrm{A}\int_{\text{solide anqle}}\int_{\text{integration time}}\int_{\text{spectral bande}} \mathrm{E}(\omega,\mathrm{t},\lambda)\ \mathrm{R}(\lambda)\mathrm{d}\omega.dt.d\lambda \qquad (1)$$

3. Description of Our Mini Radiometer

Through the increasing use of microcontrollers in all the domains of modern electronics, we now observe the emergence of very compact devices, with very low power consumption, and a multitude of options available. In the field of instrumentation, the multi-spectral measurement systems, called "radiometers", were highly profitable of this fact. Thus, we can now design a mini radiometer with a small footprint, having an important autonomy, a very big storage capacity (in Gigabytes), multi-channels, and many options easily programmable with a high-level language. The laboratory (LAAR) of the Faculty of Physics (USTO) is equipped with a receiving station for satellites images NOAA and METEOSAT. In parallel to the acquisition of these satellite images and their involved data processing, several electronic devices have been designed to improve this local station, in particular, an automatic tracker for polar satellites based on the SGP4 algorithm of the NASA [7], another tracker device for the Sun based on an ephemeris algorithm [8], and an APT datalogger for the automatic acquisition and archiving of APT NOAA images.

The following mini-radiometer is based on a microcontroller PIC16F887. It is an 8-bit mid-range microcontroller from Microchip, which became the world leader in this category of components since 2002. Figure 3 and Figure 4 show the main parts and components in the conception of this device.

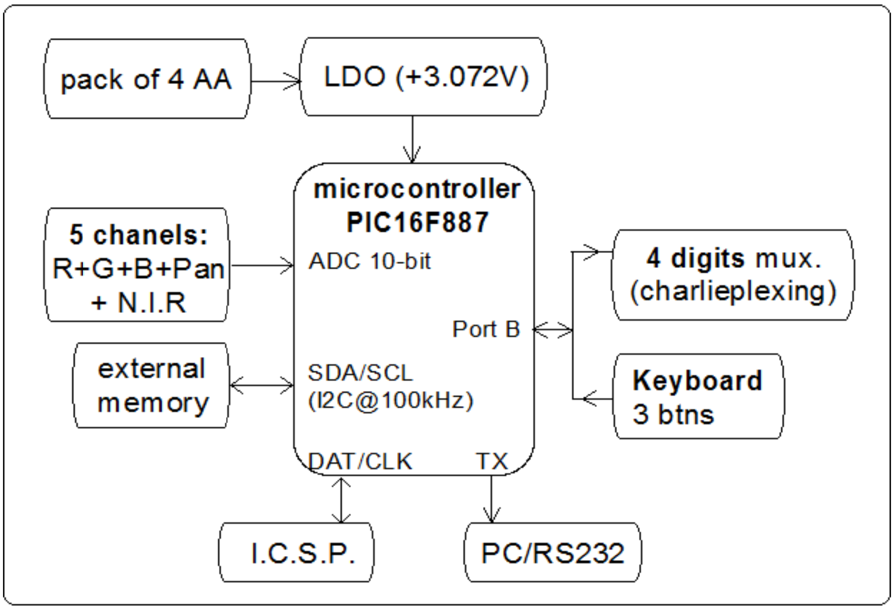

Figure 3. Diagram of the mini-radiometer, based on a microcontroller PIC16F877

BPW21 PIC16F887 24CL64

Figure 4. Main components used in this design

This low power consumption device is fed with a battery pack of four AA, followed with a micro power LDO regulator to provide a stable and precise +3.0V, as this voltage value serves also as a reference voltage for the microcontroller during the analog measures from its internal 10-bit resolution ADC module. This regulator circuit has superior performances, compared to classical bipolar regulators, as the typical LM78xx series. It is based on the MCP1702 characterized with a very low quiescent current of 2 μA and a voltage drop (input output) lower than 0.6V, against 3 to 5 mA and 2.5V to 3V for a classic LM78xx, as Figure 5.

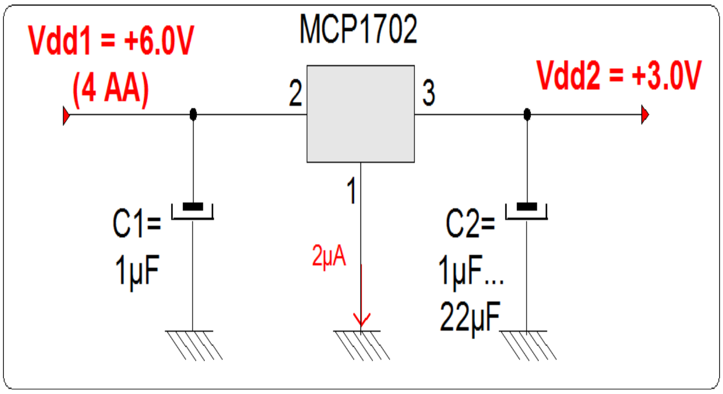

Figure 5. A very low quiescent current and low voltage drop out regulator circuit

The microcontroller PIC16F887 is internally clocked at 4MHz which is the system clock (execution of each RISC instructions in 1 microsecond, except for branch) and an external quartz of 32.768 Hz which pilots a real-time clock RTC. The 10-bit internal analog to digital converter (ADC) is used to handle measurements from diverse lights sensors (visible and near infrared) and stored in an external EEPROM memory. A small keyboard of only 3 buttons is multiplexed with a 4 digits 7-segments LED display, using the charlieplexing mode [4]. This mode allows a microcontroller to be connected to a limit of 8 digits (7-segments LED display) with only 8 I/O lines (our design would have required 12 I/O lines with a classical 4 digits 7-segments LED display circuit).

In order to reduce current consumption of this LED display, a technique of double multiplexing [5] was used: while one digit is fed at a moment, only one segment is activated; this fact allow us to reduce the current as low as 2 mA (instead of 16 mA for a classic multiplexing). Finally, to increase even more the autonomy of this device and the longevity of the battery, a parallel study on the retinal persistence allowed us to adjust the visibility of this LED display to about 0.3s in a period of blinking of 1s; the dead time duration of 0.7s was used to scan the 3 buttons of the small keyboard. This device can be connected to any PC through the serial port [6] by using the RS232 protocol (8N1 at 115200 bauds), but without using the typical conversion circuit MAX232. As noticed in a modern PC, the serial port is sensitive to level voltages as low as 3V (in absolute value). A software application in C++builder was developed to visualize the acquisition of the measures through this connection. Figure 6 shows the detailed circuit of the mini-radiometer; whereas Figure 7 and Figure 8 show the view of the mini-radiometer and graphical user interface of the software application, respectively.

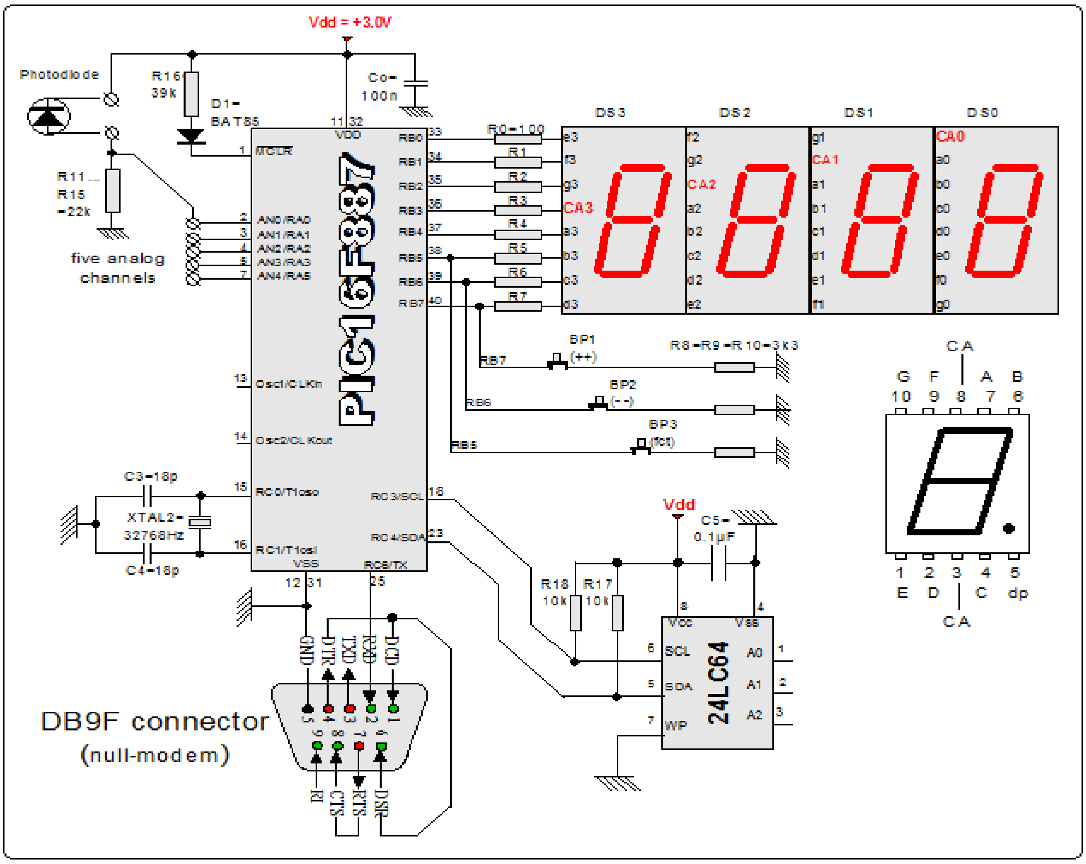

Figure 6. Detailed circuit of the mini-radiometer based on a PIC16F887

Figure 7. A view of the mini-radiometer

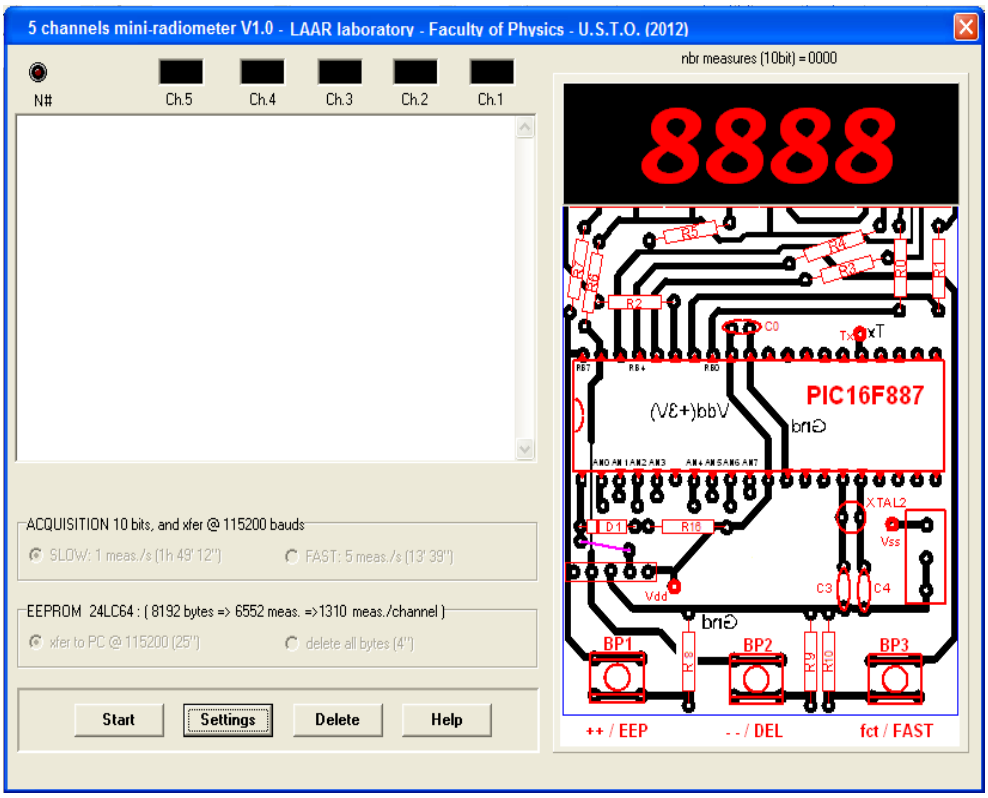

Figure 8. The graphical user interface to monitor the reception of the measures through the PC serial port

4. Study of the Reflectance R

4.1. Theoretical Foundations

The reflectance R of a surface is defined as the quotient between the reflected radiation and the total radiation received:

$$R = \frac{\text{reflected Energy}}{\text{incide nt Energy}} \quad (2)$$

As the amount of radiation reflected from the surface will always be less than or equal to the received energy, R has values between 0 and 1. We will express the reflectance value as a percentage (%).

$$R\% = \frac{\text{reflected Energy}}{\text{incident Energy}} * 100 \quad (3)$$

R is a characteristic of the medium, which we use as a basis for the recognition of different materials. It depends on the wavelength R (λ) [2].

4.2. Measuring the Reflectance of Different Materials

This radiometer is used to evaluate the energy reflected or radiated by an object on different wavelength between 4700nm (electromagnetic radiation "blue") and 1100 nm (radiation "near infrared"), as shown in Figure 9. This energy is first measured as a voltage, after converting the digital count (between 0 and 1023) indicated by the microcontroller [9].

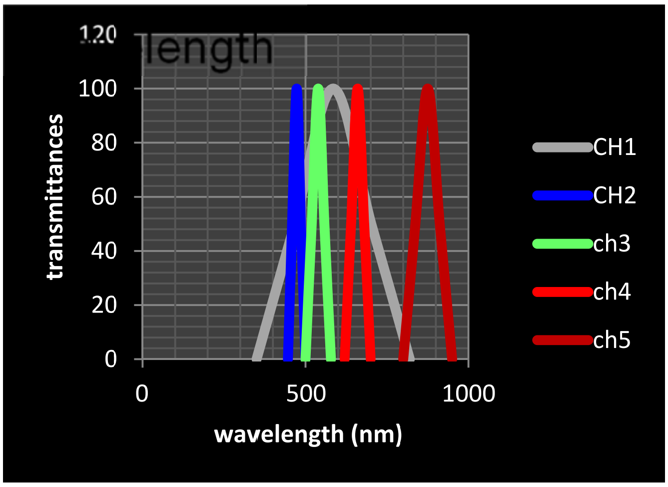

Figure 9. Spectral Channels

The experiment as Figure 10 consists in evaluating the incident energy with a clear target reference and luminance for different plant species, for bare soil or mixed objects (vegetation / soil), in the blue, green, red and near infrared spectrum. The ratio of two measures used to assess the reflectance (%) of objects studied for the wavelengths considered.

Figure 10. A view of the test held in the laboratory

This radiometer as Figure 11 was built to achieve measurements through 5 channels simultaneously, in order to enhance a simpler similar design [10] previously used in our laboratory.

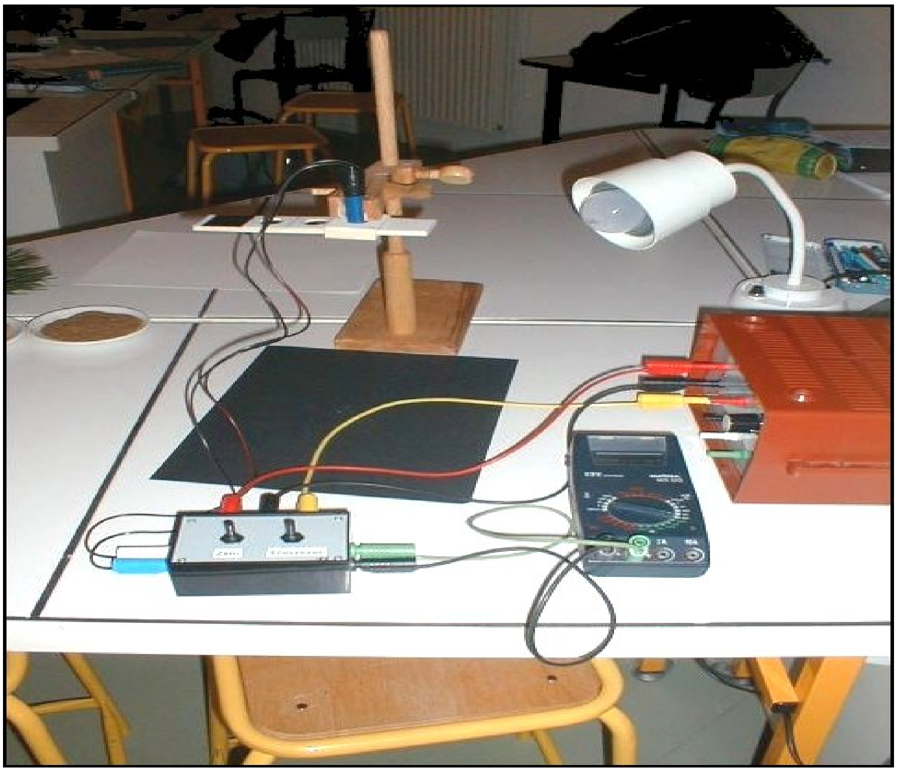

Figure 11. A manipulation with a very simpler similar radiometer

The operation has been repeated for different samples as Figure 12; each spectral signature is represented in the following chart with a different color:

- dry sand
- humid sand
- green leaves
- dead leaves

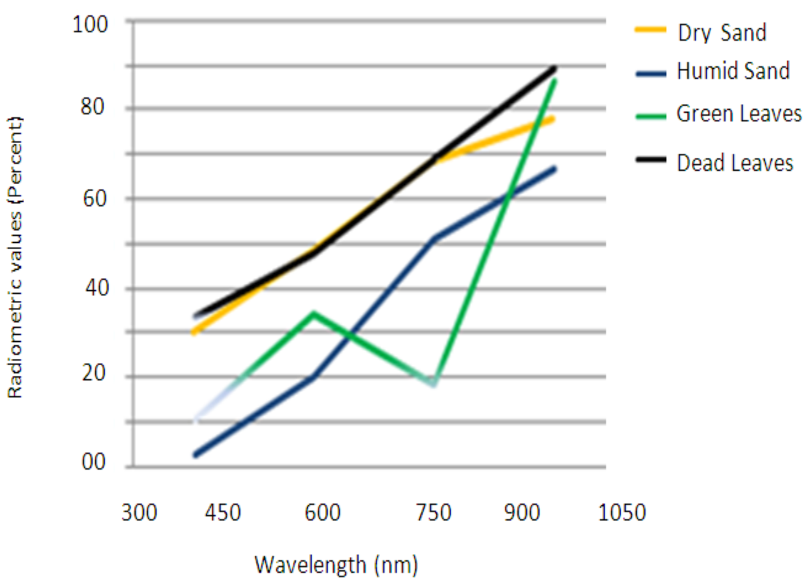

Figure 12. Reflectance measurements

5. Conclusion

The realization of a device for measuring reflected or emitted radiation by any natural object requires the use of specialized sensors and an electronic circuit with a high performance. In this research, we have described a simple circuit based on microcontroller. The mini-radiometer realized can measure the reflected or emitted light from a target sample with a significant radiative response. Before this achievement, we have studied the properties of some thematic products (sand and vegetation) to validate the functionality of our device. We have been particularly interested by the visible and near infrared spectrum.These features are: (1) Excellent five channels spectral response. (2) Measurement insensitivity to variations in ambient temperature. (3) Embedded prototype, integrating all necessary functions into one device only, (4) low power supply required. (5) RS232 serial output for connectivity to a PC.

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