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Advanced Optical Sensors for Non-Destructive Monitoring of Fruit Quality Parameters during Growth

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ABSTRACT

A multi-distance continuous wave optical sensor for nondestructive monitoring of fruit quality in the visible and near infrared spectral range has been developed. The sensor has been characterized in terms of sensitivity to changes in the optical properties by means of measurements on solid tissue phantoms. A state-of-the-art technique for characterization of diffusive media, time-resolved reflectance spectroscopy, has been used to assess the optical properties (absorption and reduced scattering coefficients) of the phantoms so as to provide a calibration for the new sensor. Measurements have been also performed on fresh apple to test the correlation between the readings of the two sensors.

Keywords: Optical sensor, light absorption, light scattering, internal quality, Italy.

1. INTRODUCTION

The use of optical sensors in the VIS and NIR spectral region for non-destructively monitoring chemical and structural parameters related to fruit growth (e.g. chlorophyll content, water content, texture) has been recently fostered by the incessant progress in photonic devices and components (Zude, 2012).
Continuous wave (CW) optical sensors with a single source detector pair are relatively easy to build and manage, but they are not able to discriminate between changes in light scattering and light absorption. The use of advanced sensors employing more complex configurations with multiple source detector pairs have been recently proposed to measure photon-path in diffusive samples so to assess influences of fruit varying scattering coefficients on non-destructive pigment.
In this work we present the results obtained by a newly developed multi-path multi-wavelength optical sensor also in comparison with time-resolved reflectance spectroscopy (TRS), a state-of-the-art optical technique for the characterization of diffusive media.

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2. MATERIALS AND METHODS

2.1 Sensors

A multi-path continuous wave optical sensor was designed and built by Sinteleia by properly modifying a DA-meter sensor. It employs a silicon photodiode as detector and LED as light sources operating at 670 nm and 730 nm. Two series of sources, placed at a distance of 0.7 cm and 1.5 cm from the detector allow recording of multi-path information.

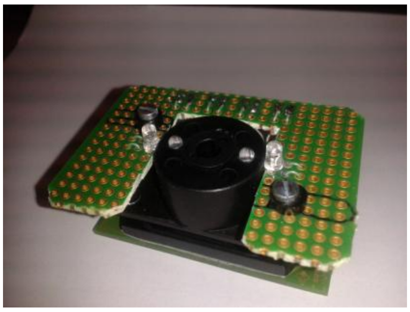

Figure 1. Photo of head of the multi-path CW sensor.

A TRS setup developed at Politecnico di Milano was used as standard reference for diffuse optical measurements. The light source is a fibre laser providing white-light picosecond pulses, adjustable in power by a variable neutral-density attenuator. A filter wheel loaded with 14 band-pass interference filters is used for spectral selection in the range 540-940nm. Light is delivered to the sample by a multimode graded-index fibre. Diffuse remitted light is detected by 1 mm fibre placed at 1.5 cm distance from the source. The light is detected with a photomultiplier and a time-correlated single-photon counting board. A model for photon diffusion in turbid media was used to analyze TRS data to assess the bulk optical properties (absorption coefficient, μ_a, and reduced scattering coefficient, μ_s') of samples (Martelli et al., 2009). Convolution of the photon diffusion model with the IRF is performed before fitting the experimental data (Cubeddu et al., 1996).

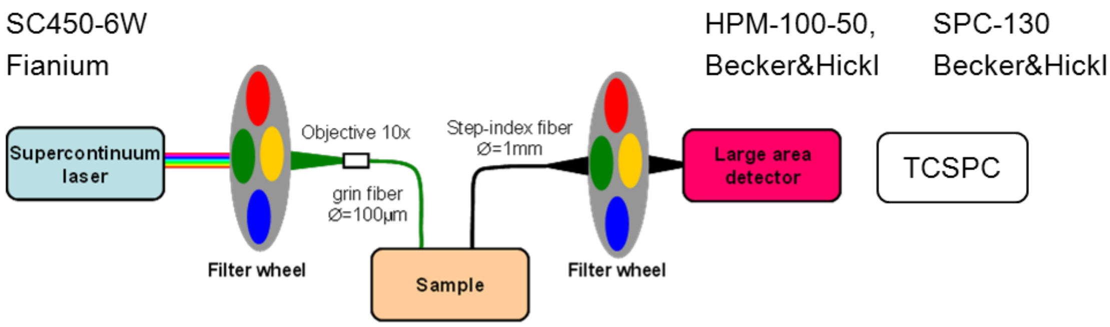

Figure 2. Scheme of the system set-up for TRS. TCSPC: time-correlated single photon counting.

2.2 Measurements

Measurements were performed with the CW sensor and with the TRS setup on a set of calibrated solid phantoms mimicking optical properties of biological media in the VIS and NIR spectral range. A combination of 8 absorption values in the 0-0.5 cm^{-1} range, and of 4 scattering values in the range 5-20 cm^{-1} were considered (Pifferi et al, 2005). Moreover measurements were performed also on a batch of 30 Braeburn apples, grown in Leuven (Belgium), to test the sensor in real life conditions.

3. RESULTS AND DISCUSSION

3.1 Phantoms

Figure 3 shows the absorption and the reduced scattering coefficient spectra as measured by TRS on phantoms A2, B2, C2 and D2 (same absorption coefficient: 0.07 cm^{-1} at 660 nm; different reduced scattering coefficient: 5, 10, 15 and 20 cm^{-1} at 660 nm).

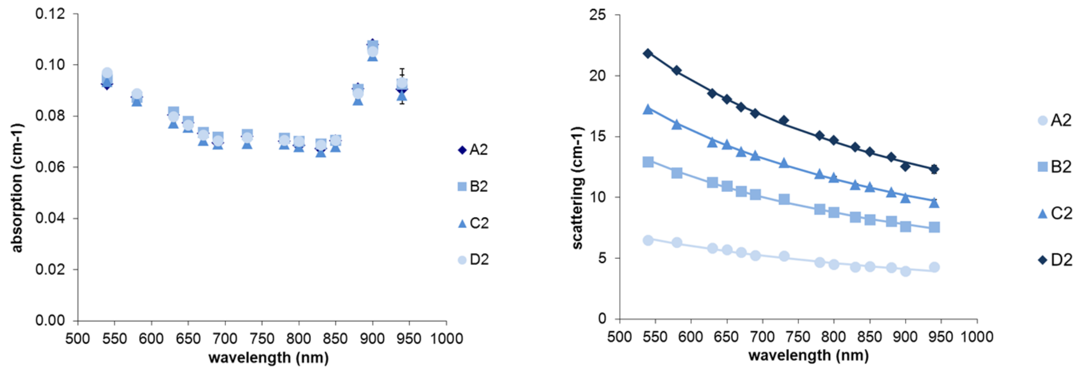

Figure 3. Absorption (left) and reduced scattering (right) spectra of phantoms A2, B2, C2 and D2. The continuous line is the best fit of the reduced scattering spectrum with the Mie approximation (Mourant et al., 1997).

The CW sensor is sensitive to changes in the optical parameters of the phantoms. The measured CW reflectance diminished at both distances as a function of absorption and of scattering coefficients as shown in Figure 4.

3.2 Apples

Measurement on apples showed that the CW sensor was able to sort fruit on the basis of the signal at 670 nm. Good correlation was found between diffuse reflectance readings of the CW sensor and the absorption coefficient measured by TRS (see Figure 5).

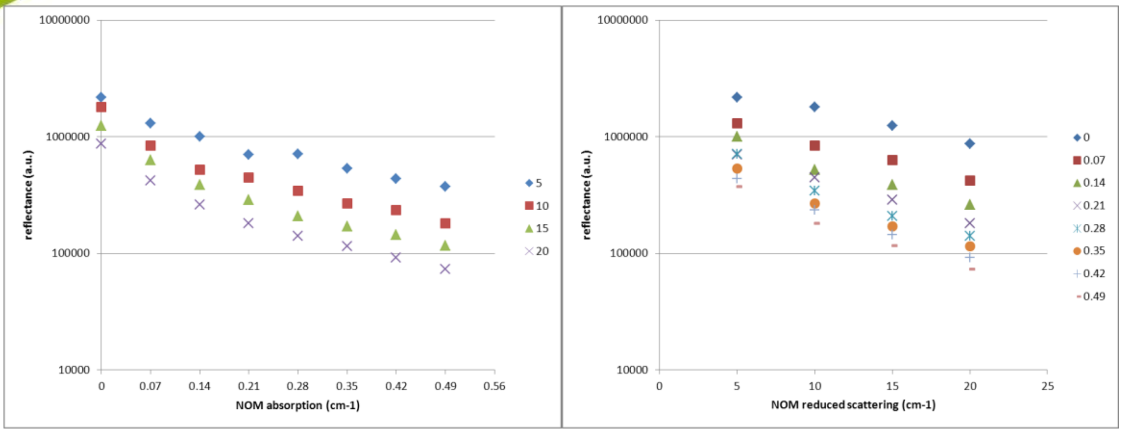

Figure 4. Diffuse reflectance readings from the multipath CW sensor as a function of the absorption coefficient for different values of the scattering coefficient (left) and as a function of the reduced scattering coefficient for different vaues of the absorption coefficient (right).

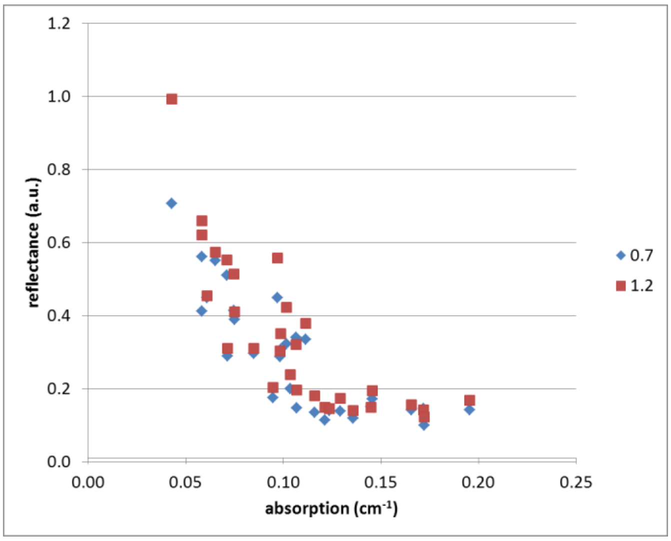

Figure 5. Diffuse reflectance readings with the CW sensor taken on apples at 0.7 and 1.2 cm as a function of the absorption coefficient as measured by TRS.

4. CONCLUSION

The multi-path CW sensor proved sensitive to changes in optical properties in a range of values typical of biological tissues (e.g. fruit). Work is in progress to optimize the CW sensor so as to achieve absolute quantification of the optical properties by exploiting a physical model for photon diffusion to interpret the CW data.

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