

# Study on non-destructive measurement of sugar content of peach fruit utilizing photonic crystal-type NIR spectroscopic camera

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**Abstract**— Near infrared (NIR) spectroscopy is a versatile method for non-contact and non-destructive measurement of agricultural products such as fruits, and has been nowadays widely used in practical production fields. As a next stage of the method, imaging functionality has been demanded, to help optimizing growth process, finding best picking up date, or providing detailed quality data to consumers. Multispectral imaging (MSI) camera, which acquires multiple wavelength images in NIR, can be a promising candidate for this purpose. For the on-site measurement synchronous capturing capability of all the wavelength images are critically important. To meet this requirement we have been trying to develop a snapshot-type MSI sensor mounted with patterned photonic crystal wavelength filters (PhCF). In this study we first describe the procedure to estimate sugar contents utilizing a set of NIR spectra. Then we will report the result of preliminary imaging experiments of peach fruits utilizing PhCF-MSI camera.

**Keywords**- *Non-destructive measurement; Near infrared spectroscopy; Multispectral imaging; Photonic Crystal*

## I. INTRODUCTION

Application of near infrared spectroscopy (NIRS) [1] into post-harvest quality assessment of agricultural products has been rapidly progressed. NIRS is a method to extract various quality information of by applying statistical processing on transmittance or diffuse reflectance spectra of the target product. Because the optical absorbance in the NIR region is much smaller than those in visible and infrared region, probe light can penetrate deep into the target body. During the diffuse reflection process the spectrum of back-scattered light is modified by the influence of the status of molecular species in the target. This is the reason why NIRS is recognized as a powerful tool for collecting interior information without destructing the sample.

Nowadays NIRS has also been widely used to estimate sugar content (SC) and water content of various fruits in grading process. Almost all the conventional NIRS instruments measure the SC etc. as a body average [2, 3, 4]. On the other hand, recently there is a growing demand from fruit farmers on visualizing the SC distribution of individual fruits on-tree, to determine the best timing for harvesting.

In this study we tried to construct camera-type NIRS imaging system that can visualize two-dimensional distribution of SCs of fruits. We chose peach as a target of measurement, as peach is one of the important local product in Tohoku area. To estimate SC with sufficient accuracy, fine resolution is required for wavelength selective elements in the system. In addition, to be able to capture images in outdoor environment, spectral images have to be acquired with a single shot picturing. To meet these requirements we focused on a snapshot-type camera configuration, which is composed by a CCD image sensor and a photonic crystal wavelength filter (PhCF) [5, 6].

In the following we first describe the standard procedure of constructing a calibration curve for SC. Then the result of preliminary multispectral imaging experiment of a peach utilizing PhCF mounted NIR camera.

## II. STANDARD PROCEDURE OF SC ESTIMATION

Standard procedure of estimating SC, using NIRS is as follows. In the first step optical absorption spectra are measured using reflectance or interactance method. Original spectrum data is then passed to preprocessing such as SNV (Standard Normal Variate) conversion or SG (Savitzky-Golay) method [7], to remove noise, baseline shift, etc. Then, part of the fruit body, which corresponds to the area of optical measurement, is squeezed to obtain juice. Its Brix index (measure of sucrose concentration in water) is measured by a refractometer. A calibration curve is then obtained by multiple regression analysis using the above set of spectra and Brix indices. Brix index of a test fruit can now be predictable by applying its measured NIRS spectrum on the calibration curve.

## III. CONSTRUCTION OF CALIBRATION CURVE USING THE INTERACTANCE METHOD

### A. Outline of the interactance method

Interactance (interaction + reflectance) [8] is one of the methods to obtain diffuse reflection spectra. Probe fibers for illumination and collection are attached on different points on the surface of the target. By doing so, the surface reflection, which contains little information about the internal body can be suppressed. This method has been widely utilized for grading instruments for post harvesting fruits [9]. In this study, prior to the development of PhCF imaging camera we tried to create a

calibration curve of Brix values of peach utilizing interactance spectra and Brix measurement by refractometer.

### B. Measurement of absorption spectra

Experimental setup for the interactance measurement of a peach is shown in Fig. 1. The fruit sample is illuminated by a ring light guide (20mm diam.). The guide is directly attached to the surface of the fruit to avoid leakage of light. Another end of the guide (fiber bundle) is illuminated by a halogen lamp through a long wave pass wavelength filter (cutoff wavelength: 800nm). Diffuse reflected light is collected by a collimate lens and optical fiber (core diam.:1mm) placed at the center of the ring guide, and passed to a multichannel spectrometer (Ocean Optics Inc., USB-4000). We used “Date-Hakutou” peaches and “Sakura-Hakutou” peaches as test samples.

For each sample we measured spectra at four points by an equal angular spacing on the equator. We measured 43 samples, thus total number of spectra is 172. We applied SG method to remove spectral noise and SNV conversion to normalize baseline. Example of the preprocessed spectra is shown in Fig. 2 (172 spectra are overlaid). Note that we used the interactance spectrum of a Teflon block as a reference of the zero absorption line [2]. In the figure we can see difference of spectrum between 840nm~950nm, where absorption band of sugars and water exist.

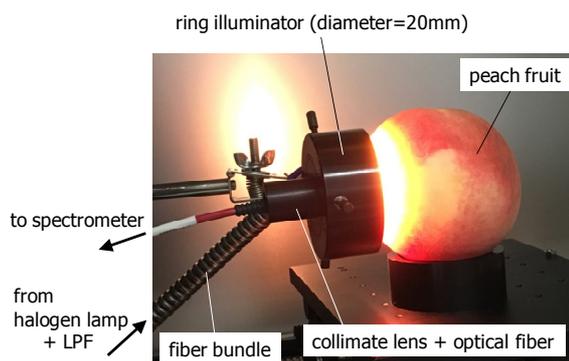


Fig. 1. Experimental setup for the absorbance measurement by the interactance method

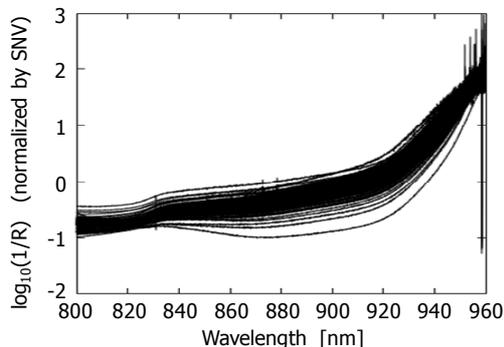


Fig. 2. Example of the interaction spectra (172 lines are overlaid). Preprocessed by SG+SNV

### C. SC measurement by refractometer

Next, we squeezed each part of the optical measurement of the fruits to get a juice, and measured their Brix by a refractometer (ATAGO PEN-1st). We found that dry matter in the juice deteriorates the reproducibility of Brix values. Thus we first roughly removed solid particles by using a polyester tea filter, and then separated remaining dry matters by centrifuge. Brix was measured using the final clear liquid.

### D. Construction of a calibration curve

Multiple regression analysis was applied to the above interactance spectra and Brix values to obtain a calibration curve. Result is shown in Fig. 3.

Correlation coefficient, which denotes the quality of the agreement of the measured and predicted Brix, was calculated as 0.71. General criteria for the correlation coefficient is “good” if larger than 0.5, “very good” if larger than 0.8. The present result indicates potential capability of Brix prediction by NIRS measurement, by selectively collecting light which interacted with fruit body. Knowledge through this experiment was used for the designing a setup of PhCF camera system.

## IV. ACQUISITION OF SPECTRAL INFORMATION UTILIZING PHCF MULTISPECTRAL CAMERA

### A. Photonic crystal wavelength filters

Schematic view, pixel layout, and the picture of the PhCF-integrated CCD are shown in Fig. 4. We have so far studied multilayer-type photonic crystal (PhC) as a wavelength filter for the application to multispectral imaging [10, 11]. Our PhC is an alternating multilayer of SiO<sub>2</sub> and Nb<sub>2</sub>O<sub>5</sub> on a grating [5, 6]. As the layout of local grating pitch on a substrate can freely be designed by lithography process, the final lattice constant also becomes position dependent on the substrate. This leads to that multiple filter array can be fabricated on a common substrate by a single fabrication process.

In this manuscript we call the local PhCF region of a constant lattice constant “channel”. The CCD pixels below each channel thus receive the same spectrally filtered light. A set of channels forms a square region and is repeatedly arranged on the substrate. We call the region “unit”. In our PhCF sample, 8x8=64 CCD pixels correspond to one channel,

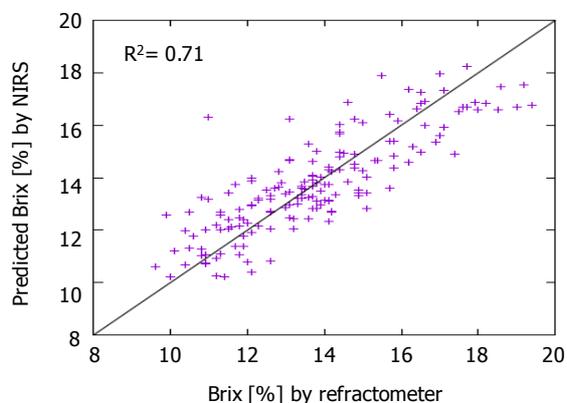


Fig. 3. Calibration curve for the Brix value

5x5=25 channels (40x40 pixels) form a unit, and 32x23 units (1280x920 pixels) covers the CCD image sensor. Each channel function as a long wave pass edge filter. The cutoff wavelengths of channel 1 and 25 are 850nm and 1060nm. The cutoffs of the rest of the channels are evenly spaced between them. We used SONY ICX-205A CCD, which has 1,360x1,024 pixels in total. PhCF was attached on the CCD using UV curable adhesive by aligning mutual pixel positions. CCD camera used was Prosilica GC-1350 (Allied Vision Co. Ltd.).

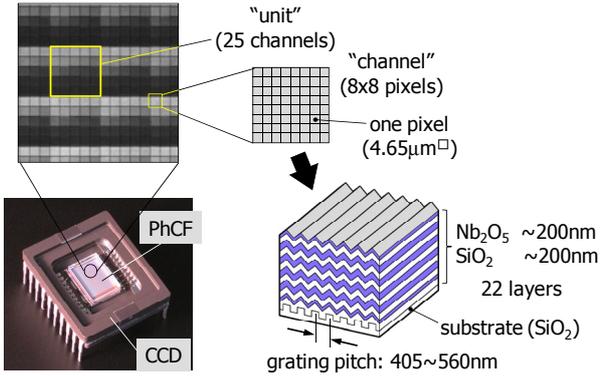


Fig. 4. Schematic view of a PhCF and a picture of a PhCF-mounted CCD image sensor

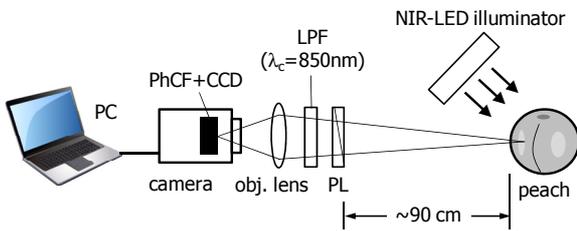


Fig. 5. Experimental setup for the picturing of a peach using PhCF camera. LPF: long-wave pass filter, PL: polarizer

B. Imaging test of a peach fruit

We then conducted an imaging experiment of a peach sample using the PhCF-mounted CCD camera. The setup for the experiment and the example of captured image is shown in Fig. 5 and Fig. 6, respectively. An external short-wave cut filter (Shibuya Optics Inc., LPF850) and a linear polarizer (Meadowlark Inc., VersaLight NIR) were attached to the front of the objective lens. The camera was placed at about 30cm away from the peach. We illuminated the sample by a NIR-LED lamp which covers 780~1020nm (Type K-Light, contains 104 LEDs, Sun-mechatronics Inc.).

From Fig. 6, we can clearly see a mosaic pattern corresponding to each PhCF channel. Mesh like patterns on the decomposed images was caused by a position error between PhCF and CCD at the integration process.

The intensity of each channel belonging to a particular unit (near the center of CCD) is plotted as a solid line in Fig. 7. Lower and upper plots correspond to a peach and a white balance target plate (Edmund Optics Inc., #58609). The error bar indicates minimum and maximum pixel value in individual channels. From the figure we see clear tendency that the received intensity is monotonically decreased along with the channel number. This corresponds to the fact that individual

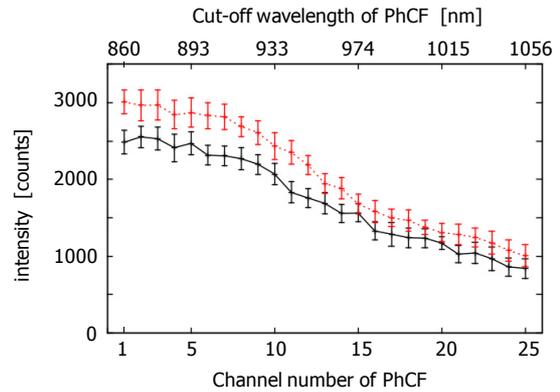


Fig. 7. Pixel intensities of each PhCF channel in a particular unit. Lower and upper plot correspond to peach and white balance target plate, respectively.

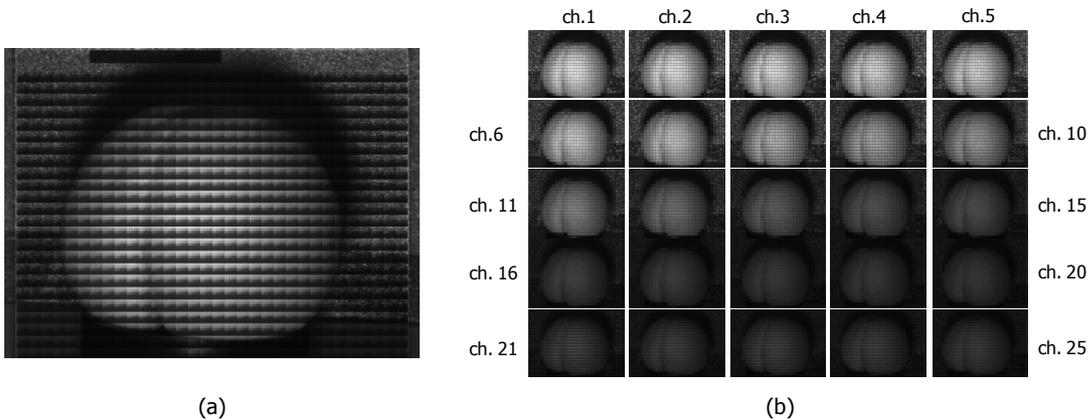


Fig. 6. Example of the captured image of the fruit. (a) Raw image from CCD, (b) Channel-decomposed images

PhCF is a long-wave pass edge filter and receives less power when the channel number increases. We can also see that wavelength dependence is slightly different between peach and white balance target. This implies that the combination of PhCF and CCD has potential ability of detecting fruit-specific diffuse reflection spectra. Detailed discussion about reducing intensity noise or improving contrast between wavelength channels will be presented at the conference.

#### V. CONCLUSION

In this paper we first described the standard flow of predicting SC with measured light absorption spectra. As a first stage of prediction we tried to measure the interactance spectra of peach fruits and the Brix values, and to construct a calibration curve for SC. As a result of that we obtained correlation factor of 0.71. This confirms the NIRS capability of estimating SC of a peach without destruction. Finally we fabricated a 25 wavelength channel PhCF and developed a multispectral camera by integrating it onto CCD. According to

the preliminary picturing test we verified its basic function of capturing a set of spectral images.

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