APPLICATION OF MULTI-SPECTRAL METHOD FOR INSPECTION OF CONCRETE STRUCTURES

HISASHI KANADA[1], TAKETO UOMOTO[2]
[1]Department of Civil Engineering, Graduate School of Engineering The University of Tokyo, Japan
[2]International Center for Urban Safety Engineering, Institute of Industrial Science, The University of Tokyo, Japan

ABSTRACT

Recently, many non-destructive inspection methods have been developed for concrete structures. For example, delamination or loose portion of concrete can be detected by using the infrared thermography method, and the ultrasonic method is used for measurement of crack depth. However, these non-destructive testing methods can obtain only physical information of concrete, such as crack depth, delamination, position of reinforcement etc. near its surface, but chemical information can not be obtained. If there is a method which can detect materials remotely, it will be an epoch-making inspection method.

In this research, material detection on concrete surface is attempted remotely using the technology of remote sensing. Multi-spectral method uses the fact that all substances on earth absorb or reflect the electromagnetic wave differently. Component substances can be determined by using these optical properties of the material. Near-infrared [NIR] spectroscopy has been developed in the agricultural field and visualization of the distribution of sugar content using this technology is in practical use. This paper introduces the application of multi-spectral method for inspection of concrete structures and suggests the visualization method.

1. INTRODUCTION

Visual inspection is carried out as the first step of diagnosis of deteriorated concrete structures. Then, detailed inspections such as non-destructive testing methods or concrete core sampling for componential analysis may be done if necessary. In the case of social infrastructures, the inspection area is large, and environmental condition or location may be tough, therefore, it often requires high labor and cost in order to inspect concrete structures. The applicability of diagnosis of deteriorated concrete using multi-spectral method is examined in this paper. This method would prove to be a very effective technique for inspector because it can be used to remotely obtain chemical information on concrete surface. Figures 1 and 2 show a sample picture of deteriorated concrete structures.

Figure 1: Sample picture of deteriorated concrete structure due to alkali-aggregate reaction

Figure 2: Sample picture of deteriorated concrete structure due to alkali-aggregate reaction and chloride penetration

The cause of deterioration shown in Figure 1 is alkali-aggregate reaction, and shown in Figure 2 is complex deterioration due to alkali-aggregate reaction and chloride penetration. It is difficult to determine the cause of deterioration just by looking at the appearance of damaged concrete structures. In these cases, componential analysis should be carried out by sampling when the exact cause is required. If chemical information such as the gel produced from alkali-aggregate reaction or chloride on concrete surface can be detected in an instant, it would be useful in diagnosing the deterioration at field.

2. INTRODUCTION OF MULTI-SPECTRAL METHOD

The multi-spectral method had been developed in the area of remote sensing and agriculture. In the area of remote sensing, geological conditions or mineral resources can be observed from earth observation satellite. The satellite has several optical sensors which can observe the information of reflected sunlight at particular wavelength from ground. The observed data are analyzed in order to determine the components of ground by combining obtained data from each sensor. Figure 3 shows the sample of spectral reflection properties of different geological conditions.

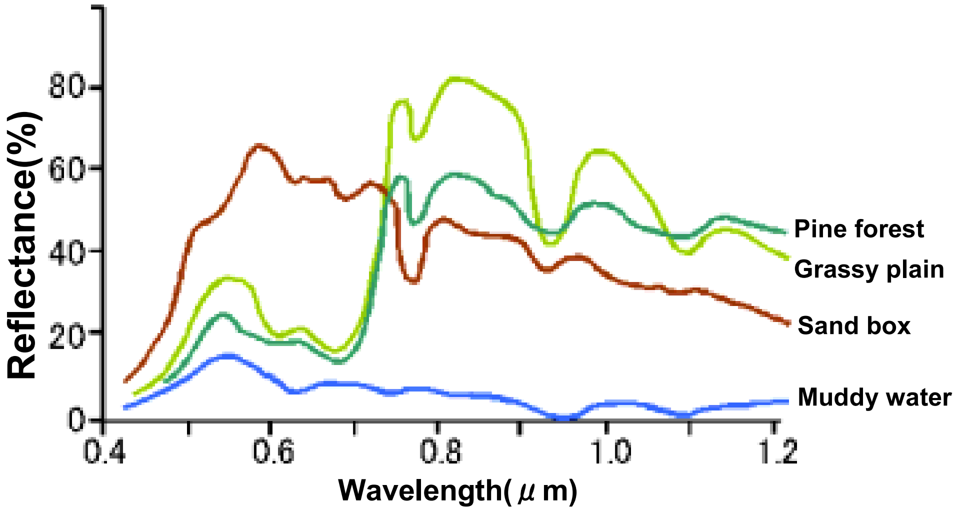

Figure 3: Sample of spectral reflection properties of geological condition

Electromagnetic waves are absorbed or reflected from any substance depending on the characteristics of their components. Though, the patterns of reflectance of plants are similar differences have been observed depending on the kind of plant.

In the area of agriculture or food, protein content of wheat or sugar content of fruit can be measured by this method [2]. Figure 4 shows the distribution of sugar content of melon. Red pixel indicates high concentration of sugar.

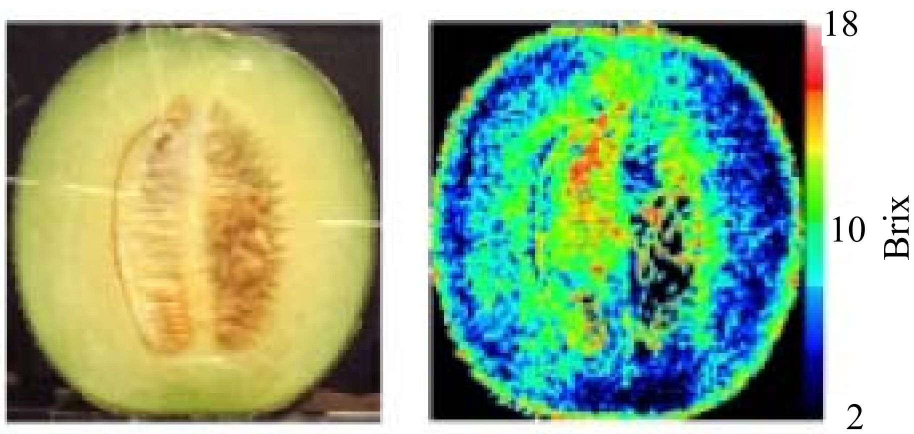

Figure 4: Distribution of sugar content of melon

The sugar content is related to the reflectance at specific wavelength, so the above picture can be shot through the band pass filter of specified wavelength.

This method is not yet much used in the area of concrete engineering. Therefore, in this research, material detection on concrete surface was attempted based on spectral properties of substances.

3. EXPERIMENTS

Causes or grades of deterioration can be estimated from substances such as chloride, calcium carbonate, calcium sulfate, alkali silica gel, rust etc. on concrete surface. If blast furnace slag or fly ash is detected from optical properties, the kind of cement can be determined. In order to determine substances, their basic spectrum should be known. After that, constituents of the sample are estimated by fitting the obtained basic data.

Final goal of this research is visualization of deteriorated part or concentration of generated substances on concrete surface. Substances related to concrete have characteristic optical properties at longer wavelengths (1700nm-2500nm) than ordinarily used wavelengths in near-infrared [NIR] spectroscopy. Unfortunately, the imaging sensors which can capture are rarely-available, therefore, only the experimental results obtained from near-infrared spectrometer are introduced in this paper. The imaging system which can capture the image of wavelength band between 1700 to 2500nm has now been developed.

3.1 Preparation of Samples

Many samples were prepared in so as to obtain basic optical properties of concrete components. Detection method of components has been introduced by taking the chloride concentration as an example in this paper.

Samples, 40 x 40 x 160 mm in size, of chloride containing mortar (Table 1) were prepared. These values are determined by referring to the chloride content on concrete surface described in "Standard Specification for Design and Construction of Concrete Structures"[3]. Chloride (sodium chloride) was directly added into the mixing water.

Table 1: Mix proportions of samples

W/C	Quantity of material per unit volume of concrete (kg/m^3)		
	W	C	S
50%	1397	576	288
Sample No.	Chloride content (kg/m^3)		
N	Not contained		
1	1.2		
2	1.5		
3	2.0		
4	3.0		
5	4.5		
6	9.0		
7	13.0		

3.2 Measurement of reflectance spectrum

Specimens were cured under atmospheric conditions, then, the reflectance spectrums of samples were measured using a near-infrared spectrometer. The Spectral reflectance can be obtained from reflex ratio between sample and barium sulfate used as standard white surface. The absorbance was adopted as the parameter of optical properties by converting reflectance (equation 1) in this case.

$$\text{Absorbance} = \log\left(\frac{1}{\text{Reflectance}}\right) \tag{1}$$

Figure 5 shows the relationship between absorbance and wavelength of sample. Measurements were attempted 5 times for each sample, and then, the average values were taken as experimental results.

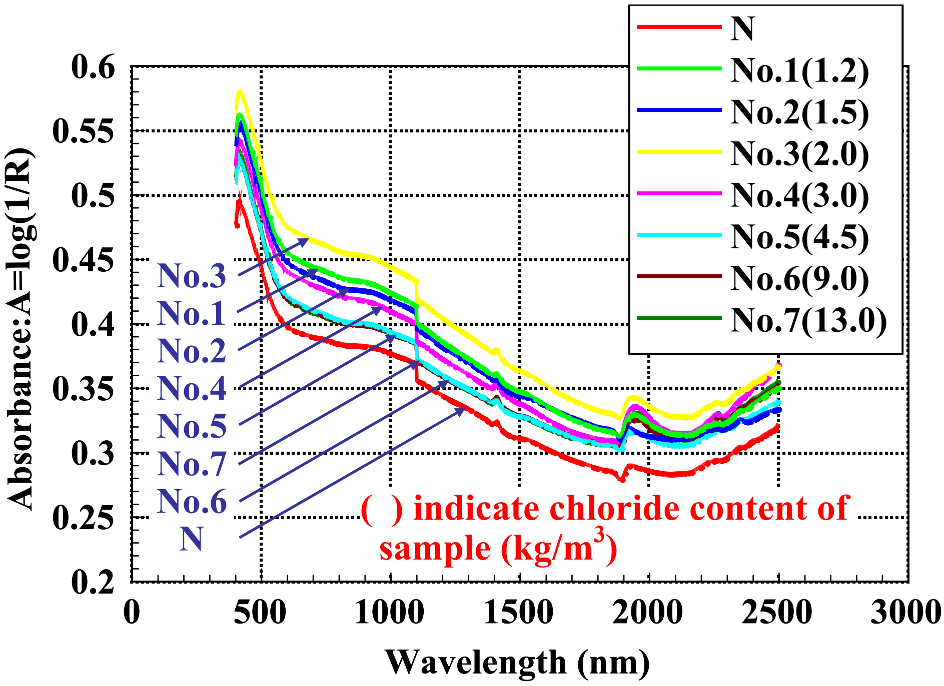

Figure 5: Relationship between absorbance and wavelength of sample

As shown in Figure 5, no relevant relationship was found between absorbance and chloride content.

4. ANALYSIS OF OBTAINED SPECTRAL DATA

It is difficult to estimate chloride content of samples from raw data, therefore, several data analyses are required. The following four steps were taken to derive the calibration curve for chloride detection.

4.1 Applying moving average

The moving average method was applied because the measured spectra had random noise. This method can eliminate noise but it causes the negative effect that spectral component is smoothened or wavelength resolution is decreased when neighborhood data is widely selected. So, appropriate range for averaging should be determined in consideration of number of periods. The values of moving average can be calculated using equation 2.

$$A'_i = \sum_{k=-n}^{n} w_k A_{i+k} \tag{2}$$

where A'_I is the processed absorbance by the moving average, w_k is the weight function, A_i is raw absorbance.

4.2 Applying MSC (Multiplicative Scatter Correction)

Measured absorbances often exhibit significant differences in the spectra due to roughness of concrete surface or measurement angle etc. even if same sample is measured. This method attempts to remove the effects of scattering by linearizing each spectrum to some "ideal" spectrum of the sample.

$$\text{Mean Spectrum: } \overline{A} = \sum_{i=1}^{n} A_{i,j} \tag{3}$$

$$\text{Linear Regression: } A_i = m_i \overline{A} + b_i \tag{4}$$

$$\text{MSC Correction: } A_{i(\mathrm{MSC})} = \frac{(A_i - b_i)}{m_i} \tag{5}$$

where A is the n by p matrix of training set spectral responses for all the wavelengths, $\overline{A}$ is a *1* by p vector of the average responses of all the training set spectra at each wavelength, A_i is a *1* by p vector of the responses for a single spectrum in the training set, n is the number of training spectra, and p is the number of wavelengths in the spectra. The m_i and b_i values are the slope and offset coefficients of the linear regression of the mean spectrum vector $\overline{A}$ versus the A_j spectrum vector.

4.3 Introduction of second derivative spectrum

Second derivative can remove the baseline offset and slope of the turbid interference, and emphasizes the peak of the spectrum. This method is widely used for spectral analysis. The linear baseline of a spectrum is described by the first equation $a \cdot w+C$ (a is slope, w is wavelength, and C is offset), which adds to a function $f(w)$ (the spectrum). First derivative spectrum can be calculated as below

$$\frac{d}{dw} = [f(w) + (a \cdot w + C)] = f'(w) + a \tag{6}$$

Second derivative spectrum can be calculated as below.

$$\frac{d^2}{dw} = [f(w) + (a \cdot w + C)] = f''(w) \tag{7}$$

4.4 Introduction of regression analysis

Regression analysis should be carried out when the relationship between component and optical properties is required. The simplest method of calibration is based on a single independent variable (wavelength), and used for estimation of chloride content. The assumption is that constituent value c (concentrations) are linear function of the absorbance A at some wavelength i:

$$c = K(0) + K(1) \cdot A_i \tag{8}$$

The least squares approach fits the line so as to minimize the sum of squares of deviations between data points and the calibration line and yields two calibration constants: intercept $K(0)$ and slope $K(1)$. Those deviations are taken along the concentration axis, and are hence called concentration residuals.

4.5 Preparation of calibration curve

Chloride content of concrete can be easily estimated from the calibration curve. In this case, this curve was determined from second derivative spectrums and concentrations:

$$c = -5.545 + 12439.92 \cdot A''_i \tag{9}$$

Figure 6 shows the result of regression analysis. The correlation between chloride content and second derivative spectrum is plotted on the x axis, and the wavelength on the y axis.

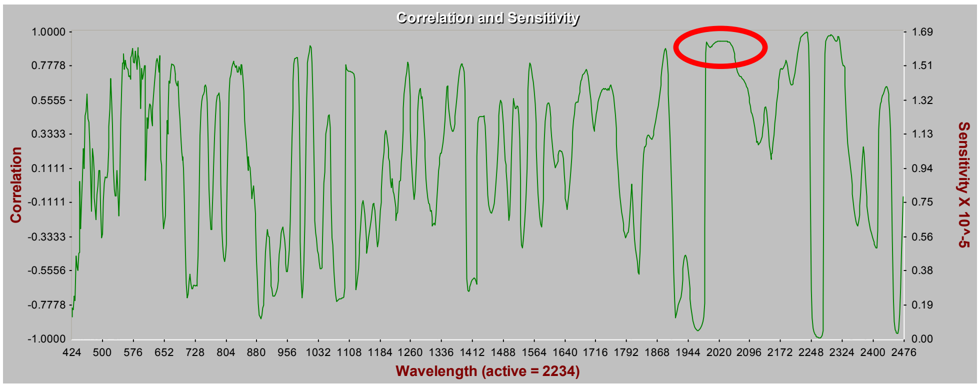

Figure 6: Result of regression analysis

As shown in figure 6, correlation is high and stable at marked wavelength (around 2030nm). The chloride content of sample can be estimated by substituting the value of second derivative spectrum at 2030nm in equation 9..

5. CONCLUSIONS

This paper describes the application of a previously unused technology in the field of Concrete Engineering for maintenance and inspection purposes. Obtaining the chemical information of the surface of concrete involves the following steps.

1) Prepare samples with known components
2) Measure absorbance of samples using near-infrared spectrometer
3) Apply moving average to measured data
4) Apply MSC method to moving averaged data
5) Obtain second derivative spectrum from 4 above
6) Perform regression analysis on component and second derivative
7) Prepare calibration curve in order to estimate components
8) Verify agreement between calculated results and laboratory data

As mentioned above, goal of this research is visualization of deteriorated part or concentration of generated substances on concrete surface. The imaging system has now been prepared as shown in Figure 7.

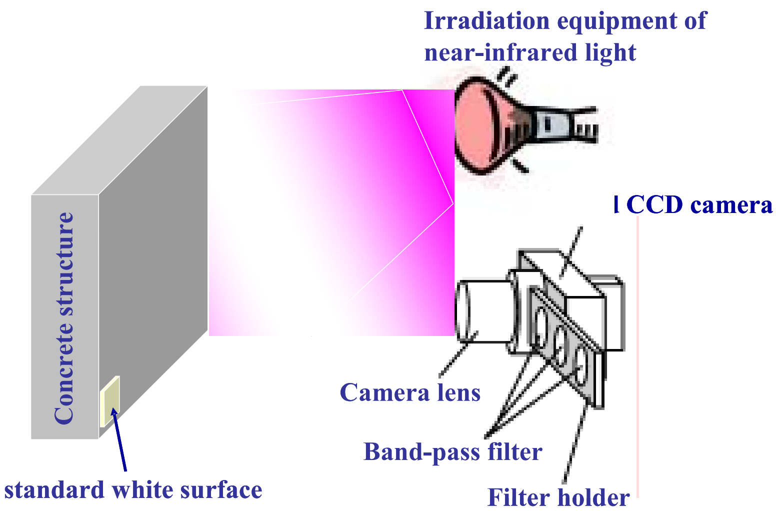

Figure 7: Imaging system (currently under development)

Deteriorated part or concentration of generated substances can be detected with this system by arranging appropriate band-pass filters. The wavelength of band-pass filter should be determined using steps mentioned above.

REFFERENCES

1. S., Masumoto, 2003. *Multi-spectral data and ratioing*. Lecture note of geographical information system by GRASS. Osaka city university. (In Japanese)

2. M., Tsuta and J., Sugiyama, 2002. *Application of near-infrared imaging method (Distribution of sugar content of melon)*. The 31st regular meeting, IR-02-3. The Japan society of infrared science and technology. (In Japanese)

3. Standard Specification for Design and Construction of Concrete Structures, 2002. Japan society of civil engineers. (In Japanese)