1D-CNN model development for soluble solids content evaluation of apple using Vis/NIR spectroscopy

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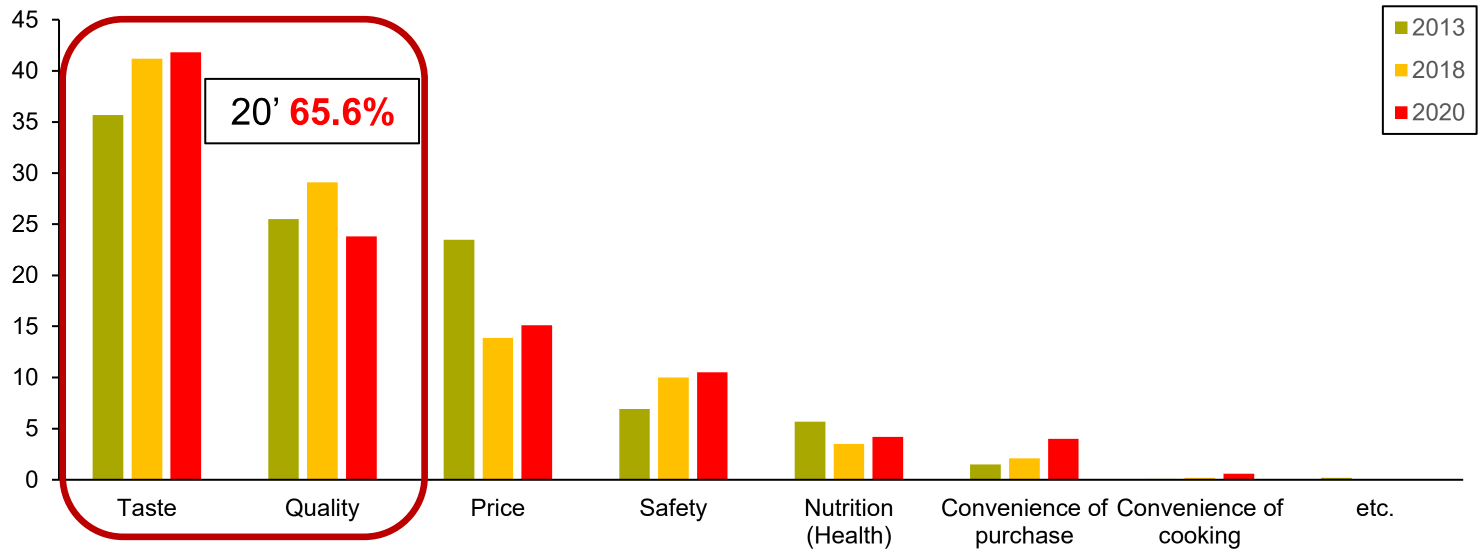
Contents

1. Introduction

1. Introduction

- **Apple** : The most cultivated fruit among Korea's representative fruits and the most favored by consumers
- Consumers **demand high internal quality** agricultural produce
- **Fruit sorting** : very important as an essential process not only to improve **value-added** but also to **guarantee the quality** of agricultural products, standardization, and improve distribution efficiency.



Major considerations when purchasing fruits

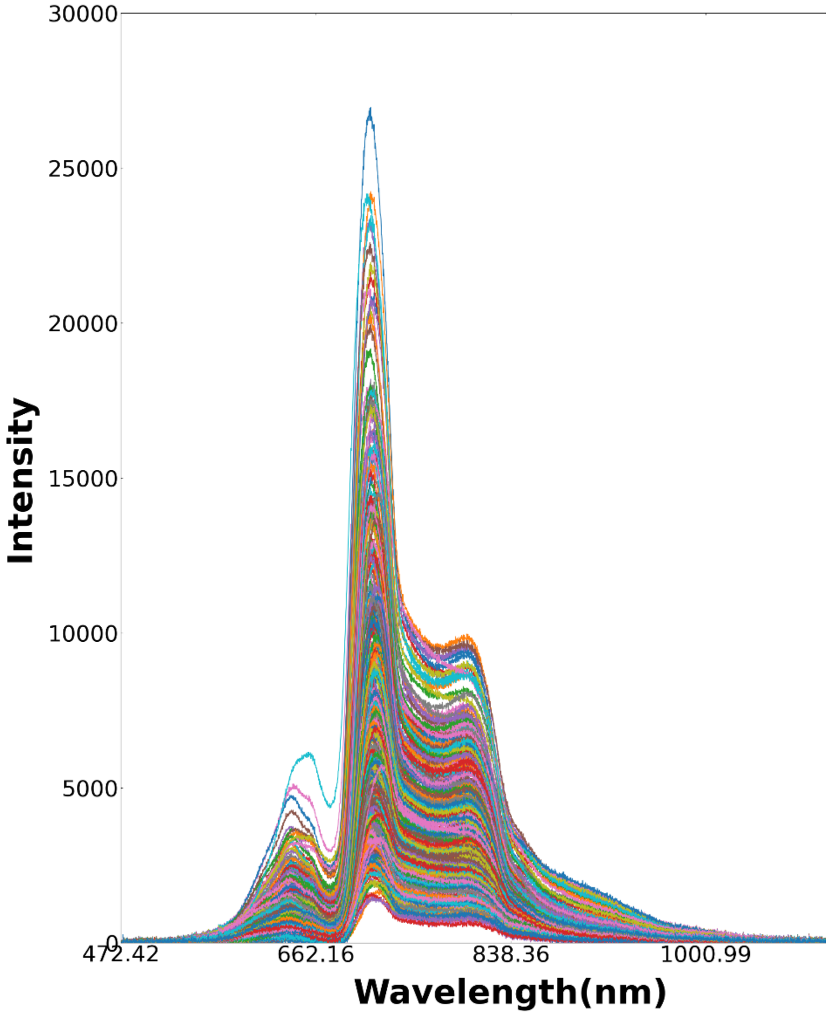
1. Introduction

Quality factor

- **External quality**
  : Size, color, weight, shape, external defect, etc.
- **Internal quality**
  : Sugar, acidity, moisture content, internal defects, etc.

- **Determination of Internal quality: Near-infrared spectroscopy**

- **Near-infrared(NIR) spectroscopy**
  : A technique for calculating the sugar content by **measuring transmitted or reflected light** with a spectrometer when **NIR rays** (700 to 2500 nm) are applied to a fruit.



The transmission spectrum of an apple

- **Spectroscopic mode**

a. Reflectance mode

: Using reflected light on the fruit surface

Simple structure, only the components of the surface can be measured

b. Full-transmittance mode

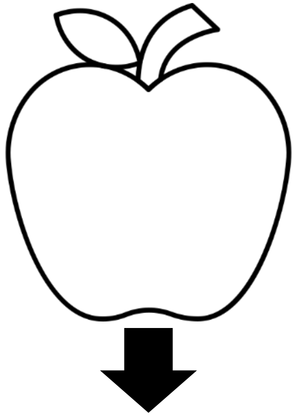
: Using light that penetrates the entire interior of the fruit

Overall component of the fruit can be measured,
but the amount of light transmitted is small

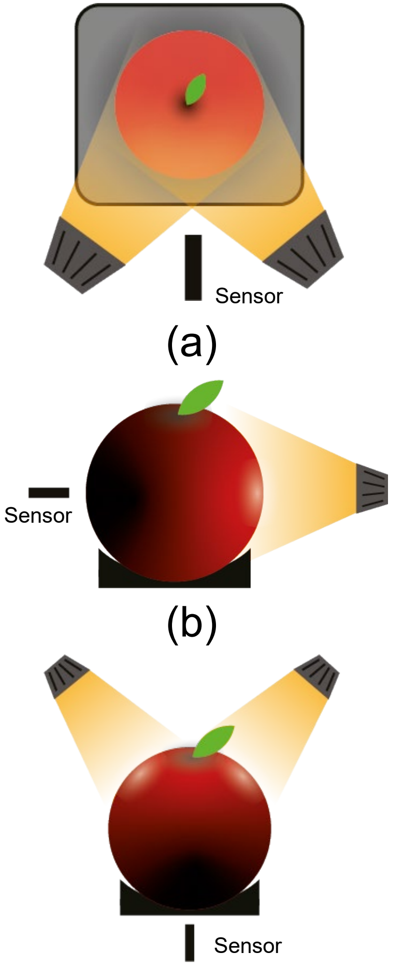
c. Semi-transmittance mode

: Use of light via part of the inside of the fruit

Overall component of fruit can be measured,
the amount of light transmitted is large,
but a lot of light is required

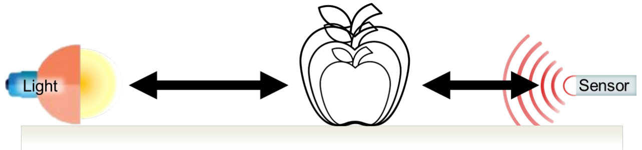


Full/Semi-transmittance mode
is commonly used in **apple**



(a) (b) (c)

1. Introduction



- Fruit : 90%(water), Others(sugar, acid, etc.)

  → Sugar and acid components cannot cause significant variations in the transmission spectrum

  Changes in the optical path due to **differences in sample size**, etc. cause greater

- Currently, the spectroscopic measurement unit of the non-destructive sugar sorter **maintains a constant distance** between the light source and the sensor **regardless of the size of the fruit**

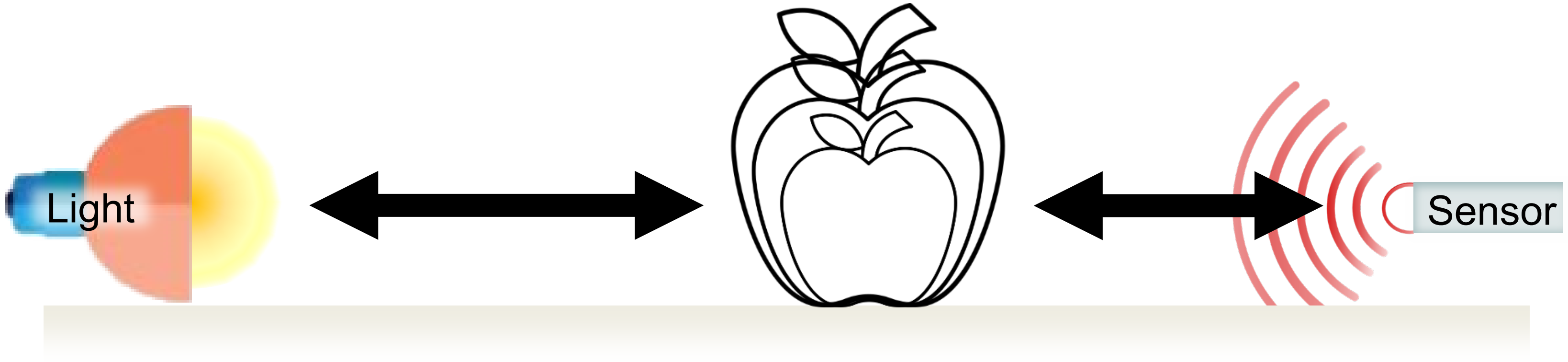
  ➔ **Decreased soluble solids content (SSC) measurement performance**

- **No studies** have corrected this **'fruit size effect'** in a **physical way** other than the preprocessing of the spectrum

- There is an attempt to develop SSC prediction model using **deep learning** (1D-Convolutional Neural Network) in addition to machine learning (Partial Least Squares, support vector machine), which has been widely used in the past.

▪ Research Purpose

- Determination of **optimal light source and sensor distance by size** in transmission spectroscopic analysis for predicting the SSC of apples
- Development of **1D-CNN SSC prediction model** using **optimal distance**



How the optical path changes depending on the size of the apple

2. Materials and Methods

2. Materials and Methods – Sample

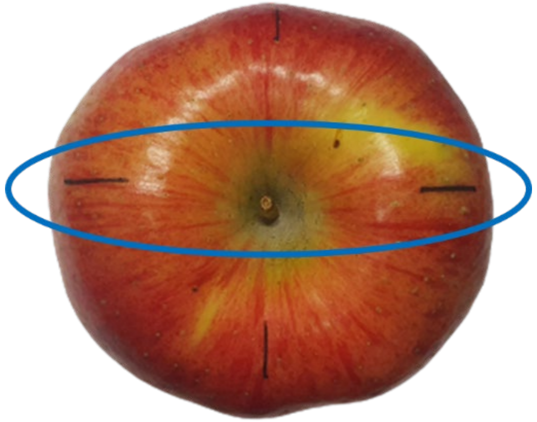
- **Apple** : Fuji (Chungju agricultural products processing center (APC))
- Classification by weight : **Level Ⅰ~Ⅵ**, 411 apples

Size classification of apples in standard specifications of agricultural products in Korea

Level	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ
Weight(g)	375 ≥	300 ≥ 375 <	250 ≥ 300 <	214 ≥ 250 <	188 ≥ 214 <	167 ≥ 188 <

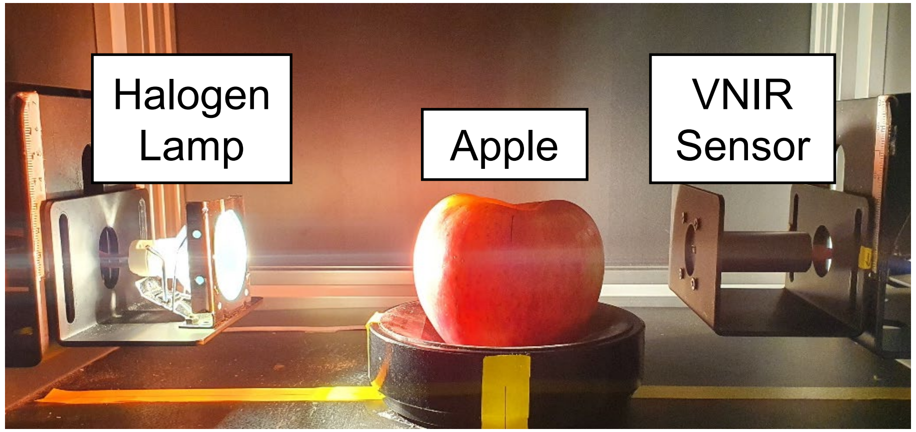
Average maximum diameter, weight of apple

	Level					
	Ⅰ	Ⅱ	Ⅲ	Ⅳ	Ⅴ	Ⅵ
Number	82	57	72	60	70	70
Avg.(S.D.) Max. Diameter (mm)	99.16 (2.78)	90.17 (3.10)	88.23 (2.53)	80.8 (2.45)	78.92 (3.19)	75.63 (2.98)
Avg.(S.D.) Weight (g)	398.02 (9.43)	318.41 (7.95)	285.16 (4.02)	223.19 (3.77)	194.55 (3.12)	182.28 (3.78)



mark the maximum diameter of an apple

- **Vis/NIR spectrometer**
  - USB4000, Ocean Optics, US
  - Wavelength range
    : 472 – 1150 nm
  - Resolution : about 0.2 nm
- **Light source**
  - 64637, OSRAM, Germany
  - Tungsten-halogen light 100W 12V
- **Refractometer**
  - PLA-3, ATAGO, Japan
  - Brix scale : Brix 0.1%
  - Accuracy : Brix ±0.1%



Spectroscopic measurement system


Measuring spectral data

2. Materials and Methods – Equipment

- **Vis/NIR spectrometer**
  - USB4000, Ocean Optics, US
  - Wavelength range
    : 472 – 1150 nm
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- **Light source**
  - 64637, OSRAM, Germany
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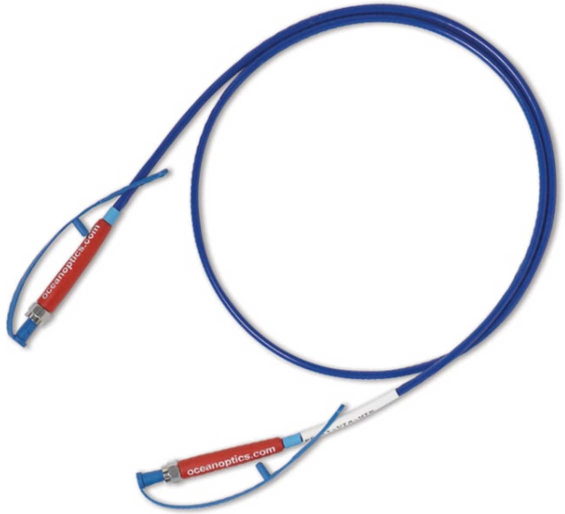
Spectrometer

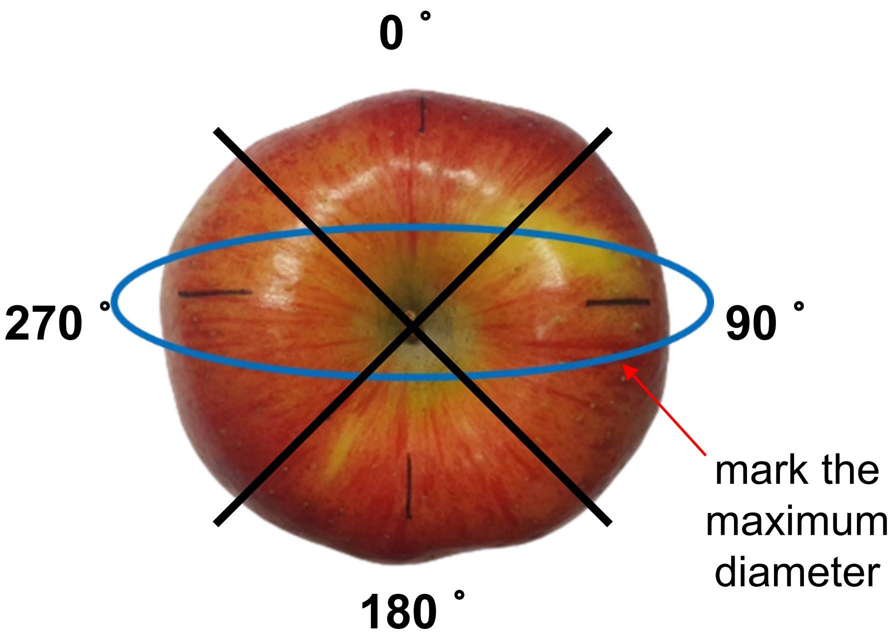


Optical fiber

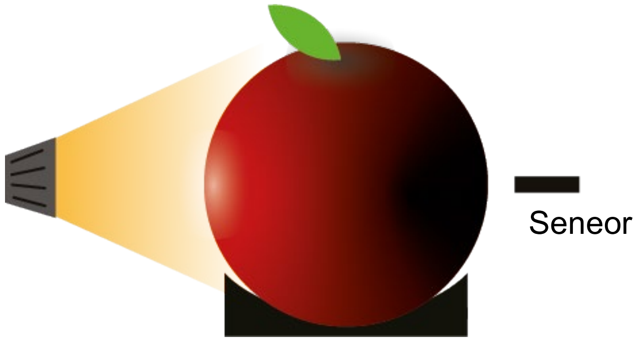
Refractometer

2. Materials and Methods – Equipment

- **Spectrum and SSC acquisition**
  - **Measurement area**
    : 0, 90, 180, 270 degree area of an apple
- **Spectroscopic mode**
  - Full-transmittance mode
- **Spectroscopic condition**
  - Integration Time : 100 msec
  - Spectra Averaged : 5 times

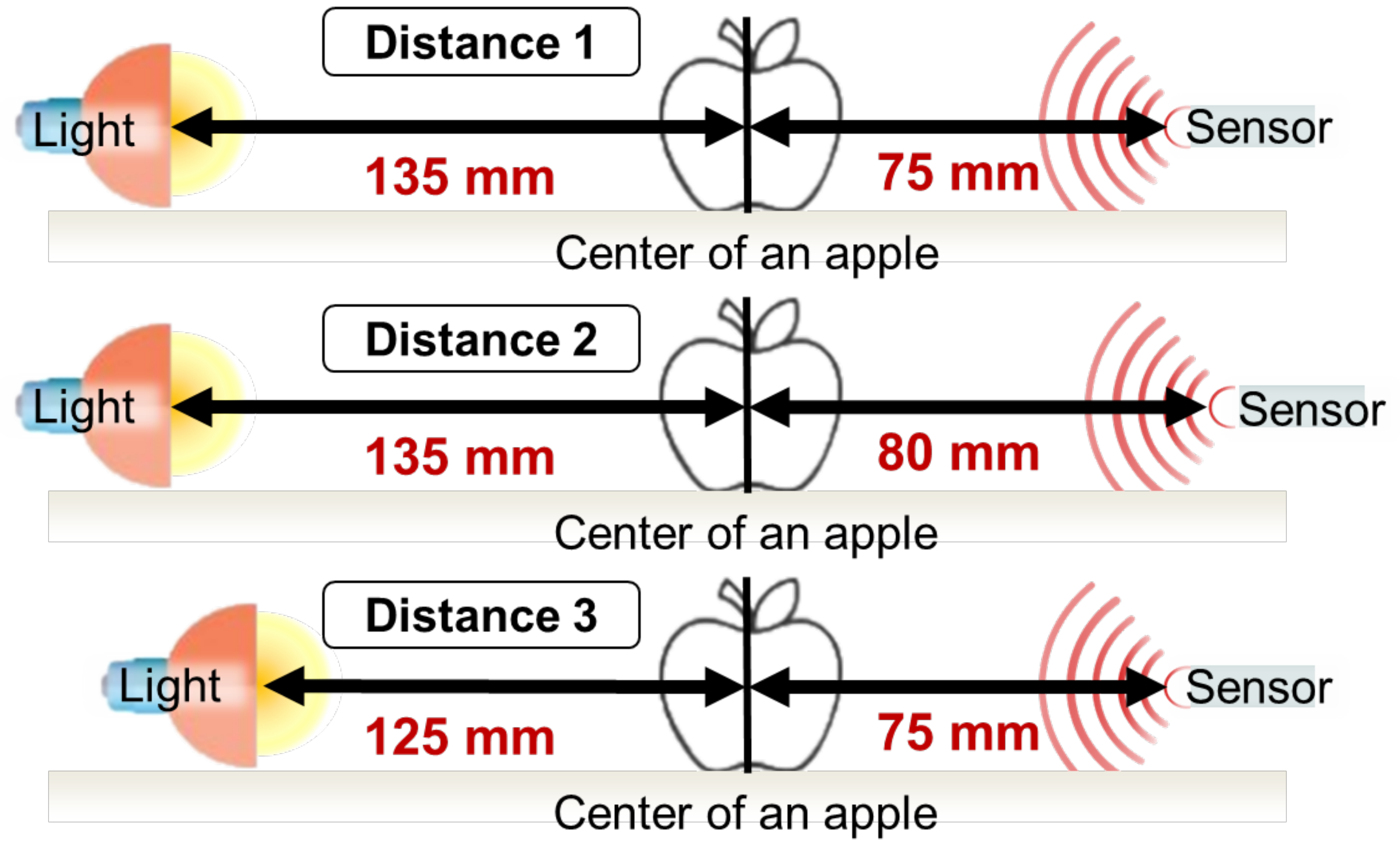


Measurement area of an apple



Full-transmittance mode

- **Distance** between light source - apple - sensor



3 optimal distances between light source – apple - sensor

Spectral Preprocessing

➢ Increasing the number of spectra

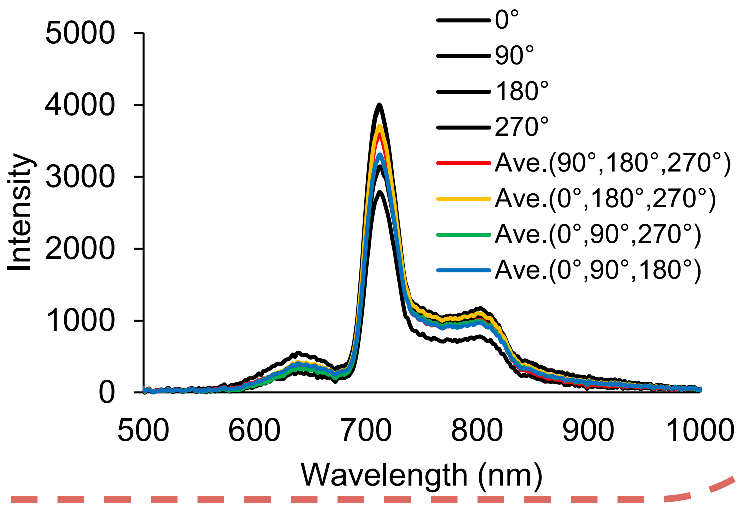
- Number of measured spectra by apple size : 228 ~ 328
- Increase the number of spectra to **avoid overfitting** and **improve performance** on CNN

(Tian et al., 2022)

: 4 spectra measured from 1 apple

→ Create new spectra by averaging 3 out of 4 spectra

→ A total of **8 spectra** can be obtained from **1 apple**



Spectral preprocessing

- **Reduced**
  - Reduce the resolution of the spectrum from 0.2 nm to 2 nm

    → **Noise cancellation**, **faster spectrum processing**

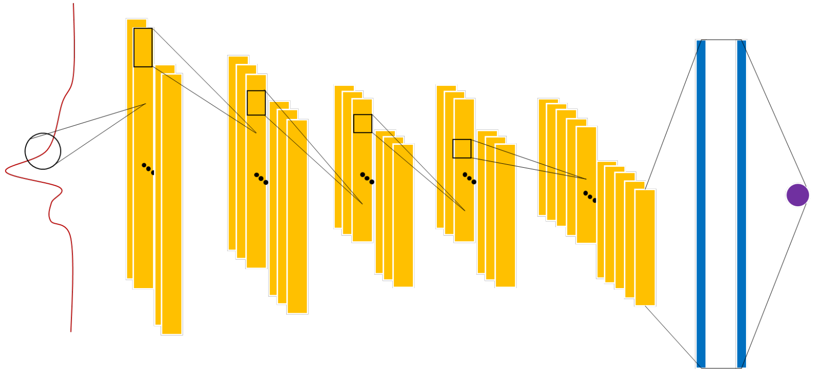
- **Multiplicative scattering correction (MSC)**
  - Calibrating light scattering using an ideal spectrum (mean of spectra)

- **Standard normal variable (SNV)**
  - Calibrating light scattering using normalization of spectrum

Development of SSC prediction model

1D-Convolutional Neural Network (1D-CNN)

- One of the deep learning algorithms
- Used a lot for image processing
- Captures feature points of input data
- 1D-CNN has 1D input data and filter on normal CNNs
- (ex. Spectral Data)
- Reference Architecture : **AlexNet**



Calibration set : Prediction set = 8 : 2

▪ 1D-CNN architecture

Layer	Settings
Input	Input shape : 456 ~ 656 x 1, Samples : 328,656
Conv 1D layer 1 + Relu	Filter size: 11 x 1, Stride: 4 Number of filters : 96, Padding: valid
Max pooling 1D 1	Pool size: 3 x 1, Stride : 2
BatchNormalization 1	
Conv 1D layer 2 + Relu	Filter size: 5 x 1, Stride: 1 Number of filters : 4, Padding: same
Max pooling 1D 2	Pool size: 3 x 1, Stride : 2
BatchNormalization 2	
Conv 1D layer 3 + Relu	Filter size: 3 x 1, Stride: 1
Conv 1D layer 4 + Relu	Number of filters : 384, Padding: same
Conv 1D layer 5 + Relu	Filter size: 3 x 1, Stride: 1 Number of filters : 256, Padding: same
Max pooling 1D 3	Pool size: 3 x 1, Stride : 2
Flatten	
Dense + Relu	Nodes: 4096
Dropout	Probability: 0.5
Dense + Relu	Nodes: 4096
Dropout	Probability: 0.5
Dense	Nodes: 1

Other setting values

- Batch size : 14
- Epoch : 300
- EarlyStopping patience : 70

▪ Model Evaluation

- R^2_{pre} (Coefficient of determination of prediction)

$$= \left(\frac{\sqrt{\sum_{i=1}^{n}(y_{pi}-y_{mean})^2}}{\sqrt{\sum_{i=1}^{n}(y_{mi}-y_{mean})^2}}\right)^2$$

- $RMSEP$ (Root mean square error of prediction)

$$= \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_{pi}-y_{mi})^2}$$

y_{pi} : Predicted SSC for the i -th apple

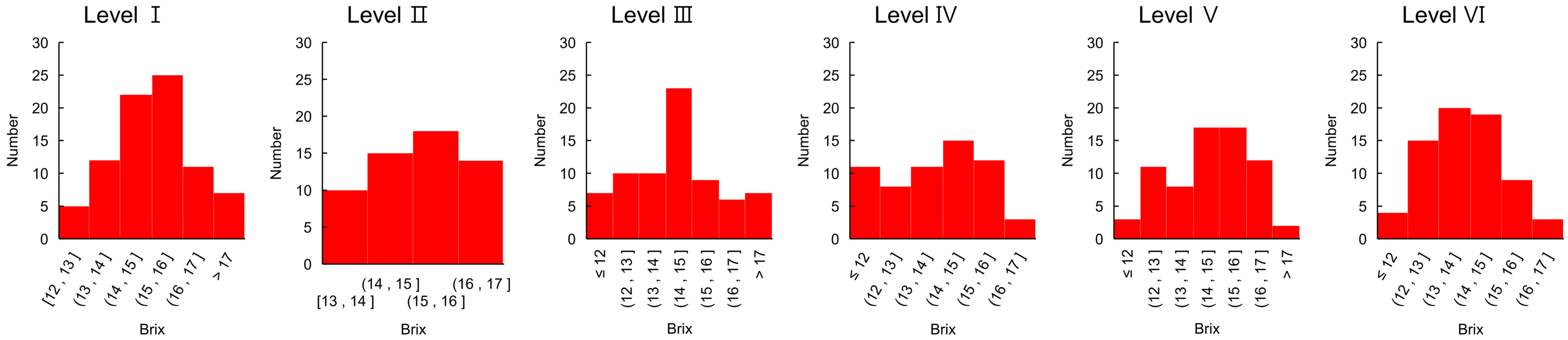
y_{mi} : Measured SSC for the i -th apple

y_{mean} : Average value of prediction set

n : Number of prediction set

3. Results and Discussion

- **The distribution of the SSC of apples**

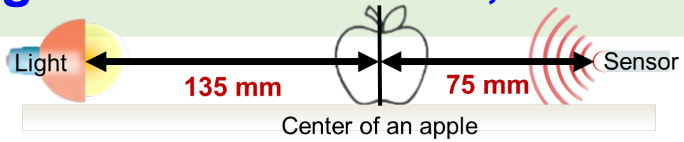


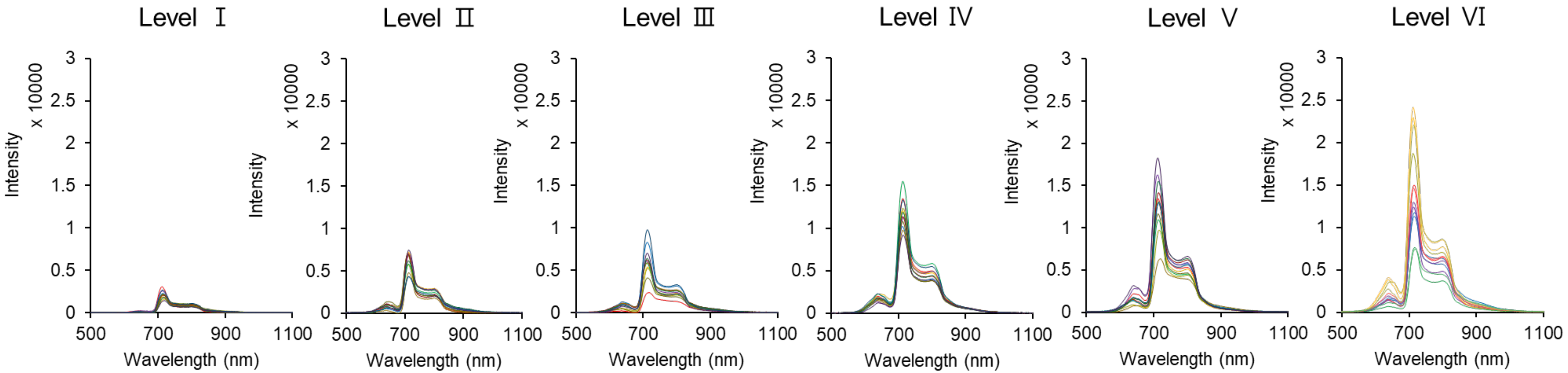
Histogram of SSC distribution by Level

Table of SSC distribution by Level

		Level					
		Ⅰ	Ⅱ	Ⅲ	IV	Ⅴ	VI
Number		82	57	72	60	70	70
SSC (Brix)	**Avg.**	15.10	14.93	14.38	13.68	14.57	13.86
	SD	1.31	1.06	1.80	1.77	1.51	1.21

- **[Distance 1]** Transmission spectrum by apple size at **light source 135 mm, sensor 75 mm**



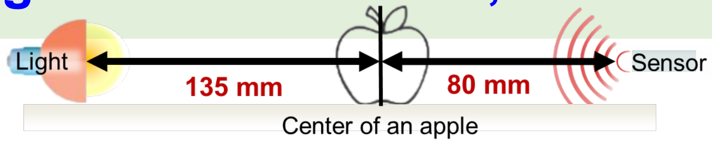


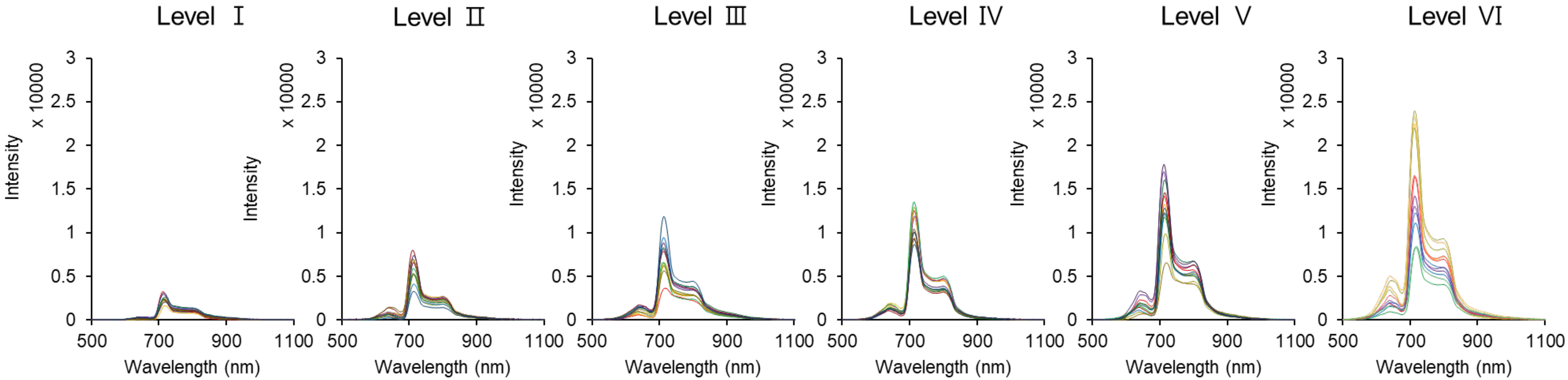
Measured transmission spectrum

- **Larger apples** tend to have **smaller transmitted light intensity**
- **The distance of the light source** has a **greater influence** on transmitted light intensity than the distance of the sensor

3. Results and Discussion

- **[Distance 2]** Transmission spectrum by apple size at **light source 135 mm, sensor 80 mm**



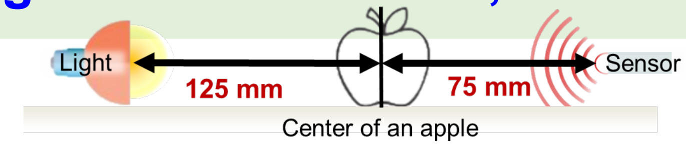


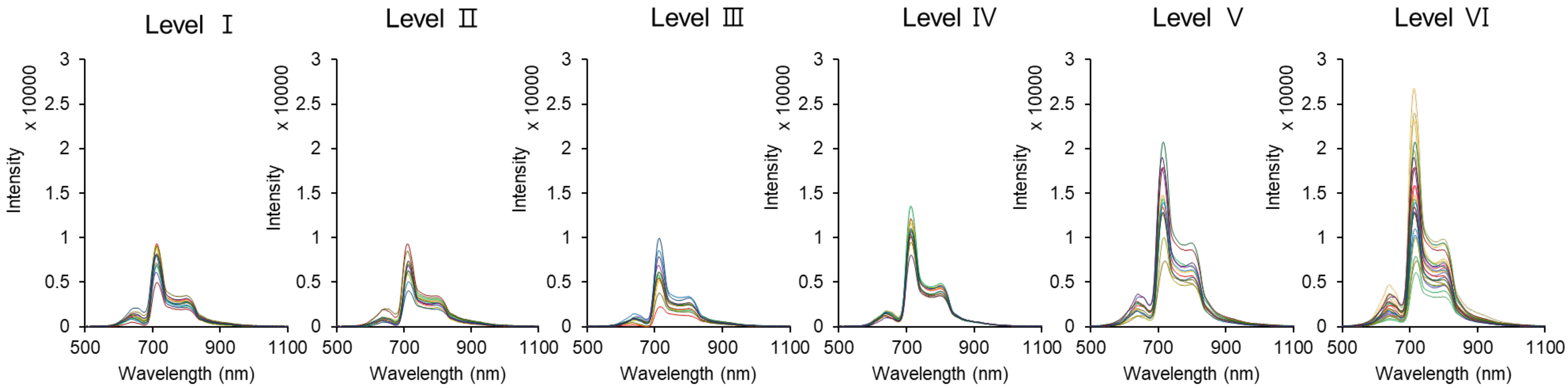
Measured transmission spectrum

- **Larger apples** tend to have **smaller transmitted light intensity**
- **The distance of the light source** has a **greater influence** on transmitted light intensity than the distance of the sensor

3. Results and Discussion

- **[Distance 3]** Transmission spectrum by apple size at **light source 125 mm, sensor 75 mm**





Measured transmission spectrum

- **Larger apples** tend to have **smaller transmitted light intensity**
- **The distance of the light source** has a **greater influence** on transmitted light intensity than the distance of the sensor

3. Results and Discussion

- **Performance of SSC prediction model by distance between light source and sensor**

- Level Ⅰ

Performance of the SSC prediction model of Level I

Level	Distance (Light - Sensor)	Preprocessing	Loss	Val_loss	$RMSEC$	R^2_{pre}	$RMSEP$
Ⅰ	135 mm - 75 mm	SNV	0.322	0.526	0.780	0.56	0.780
		MSC	**0.287**	**0.391**	**0.579**	**0.76**	**0.579**
	135 mm - 80 mm	SNV	0.398	0.461	0.679	0.67	0.679
		MSC	**0.333**	**0.325**	**0.500**	**0.82**	**0.500**
	125 mm - 75 mm	SNV	1.476	1.014	0.815	0.59	0.815
		MSC	0.621	0.987	0.823	0.58	0.823

Optimal value

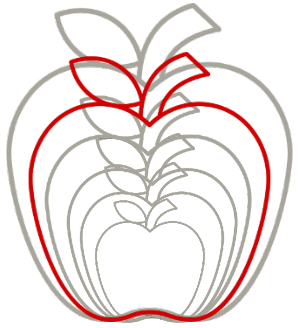
- Preprocessing : MSC
- R^2_{pre} : 0.82
- $RMSEP$: 0.500 Brix

- **Performance of SSC prediction model by distance between light source and sensor**

- Level Ⅱ

Performance of the SSC prediction model of Level Ⅱ

Level	Distance (Light - Sensor)	Preprocessing	Loss	Val_loss	$RMSEC$	R^2_{pre}	$RMSEP$
Ⅱ	135 mm - 75 mm	SNV	0.386	0.670	0.819	0.46	0.819
		MSC	0.364	0.279	0.519	0.78	0.520
	135 mm - 80 mm	SNV	0.730	1.021	0.629	0.68	0.629
		MSC	0.322	0.643	0.725	0.58	0.725
	125 mm - 75 mm	SNV	0.506	0.627	0.642	0.67	0.642
		MSC	1.745	1.314	0.904	0.35	0.904



Optimal value

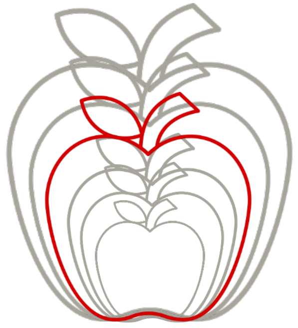
- Preprocessing : MSC
- R^2_{pre} : 0.78
- $RMSEP$: 0.520 Brix

- **Performance of SSC prediction model by distance between light source and sensor**

- Level Ⅲ

Performance of the SSC prediction model of Level Ⅲ

Level	Distance (Light - Sensor)	Preprocessing	Loss	Val_loss	$RMSEC$	R^2_{pre}	$RMSEP$
Ⅲ	135 mm - 75 mm	SNV	0.416	0.697	0.770	0.83	0.769
		MSC	0.477	1.329	0.761	0.84	0.761
	135 mm - 80 mm	SNV	1.702	1.225	0.884	0.78	0.884
		MSC	0.422	1.013	0.799	0.82	0.799
	125 mm - 75 mm	SNV	1.476	1.386	0.938	0.75	0.938
		MSC	2.030	1.378	0.987	0.72	0.987



Optimal value

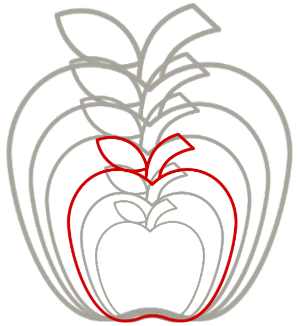
- Preprocessing : MSC
- R^2_{pre} : 0.84
- $RMSEP$: 0.761 Brix

- **Performance of SSC prediction model by distance between light source and sensor**

- Level IV

Performance of the SSC prediction model of Level IV

Level	Distance (Light - Sensor)	Preprocessing	Loss	Val_loss	$RMSEC$	R^2_{pre}	$RMSEP$
IV	135 mm - 75 mm	SNV	0.461	0.607	0.779	0.84	0.779
		MSC	**0.403**	**0.930**	**0.765**	**0.85**	**0.765**
	135 mm - 80 mm	SNV	1.167	0.934	0.839	0.82	0.838
		MSC	0.907	1.089	0.925	0.78	0.925
	125 mm - 75 mm	SNV	0.813	0.726	0.852	0.81	0.852
		MSC	**0.478**	**0.566**	**0.752**	**0.85**	**0.752**



Optimal value

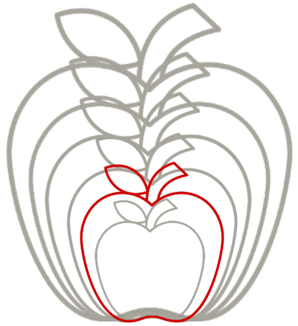
- **Preprocessing : MSC**
- R^2_{pre} : **0.85**
- $RMSEP$: **0.752 Brix**

- **Performance of SSC prediction model by distance between light source and sensor**

- Level Ⅴ

Performance of the SSC prediction model of Level Ⅴ

Level	Distance (Light - Sensor)	Preprocessing	Loss	Val_loss	$RMSEC$	R^2_{pre}	$RMSEP$
V	135 mm - 75 mm	SNV	1.084	0.991	0.892	0.64	0.892
		MSC	0.481	1.082	1.040	0.50	1.040
	135 mm - 80 mm	**SNV**	**0.410**	**0.572**	**0.756**	**0.74**	**0.756**
		MSC	0.516	1.349	0.810	0.70	0.810
	125 mm - 75 mm	**SNV**	**0.893**	**1.022**	**0.781**	**0.72**	**0.780**
		MSC	1.374	2.368	1.036	0.51	1.036



Optimal value

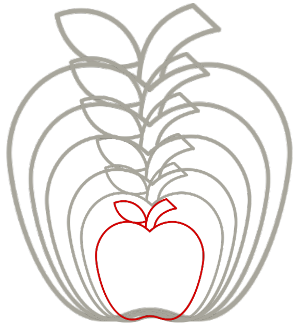
- **Preprocessing : MSC**
- R^2_{pre} : **0.74**
- $RMSEP$: **0.756 Brix**

- **Performance of SSC prediction model by distance between light source and sensor**

- Level VI

Performance of the SSC prediction model of Level VI

Level	Distance (Light - Sensor)	Preprocessing	Loss	Val_loss	$RMSEC$	R^2_{pre}	$RMSEP$
VI	135 mm - 75 mm	SNV	0.670	0.563	0.624	0.75	0.624
		MSC	1.121	0.763	0.797	0.58	0.797
	135 mm - 80 mm	SNV	0.837	0.656	0.693	0.69	0.693
		MSC	1.872	1.740	0.902	0.47	0.902
	125 mm - 75 mm	SNV	0.525	0.554	0.744	0.64	0.744
		MSC	0.335	0.729	0.741	0.64	0.741



Optimal value

- Preprocessing : MSC
- R^2_{pre} : 0.75
- $RMSEP$: 0.624 Brix

3. Results and Discussion

- **Performance of SSC prediction model by distance between light source and sensor**

- Total

Best performance of SSC prediction model by Level

Level	Distance (Light - Sensor)	Preprocessing	Loss	Val_loss	$RMSEC$	R^2_{pre}	$RMSEP$
Ⅰ	135 mm - 80 mm	MSC	0.333	0.325	0.500	0.82	0.500
Ⅱ	135 mm - 75 mm	MSC	0.364	0.279	0.519	0.78	0.520
Ⅲ	135 mm - 75 mm	MSC	0.477	1.329	0.761	0.84	0.761
Ⅳ	125 mm - 75 mm	MSC	0.478	0.566	0.752	0.85	0.752
Ⅴ	135 mm - 80 mm	SNV	0.410	0.572	0.756	0.74	0.756
Ⅵ	135 mm - 75 mm	SNV	0.670	0.563	0.624	0.75	0.624

Optimal Preprocessing

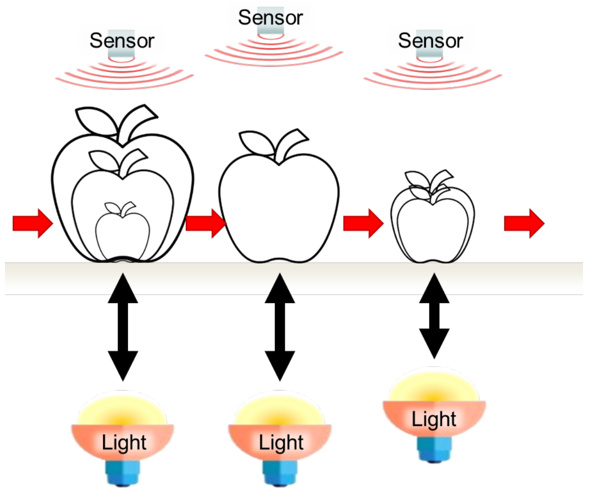
Large size : MSC

Small size : SNV

Optimal Value

R^2_{pre} : 0.74 ~ 0.85

$RMSEP$: 0.500 ~ 0.761 Brix



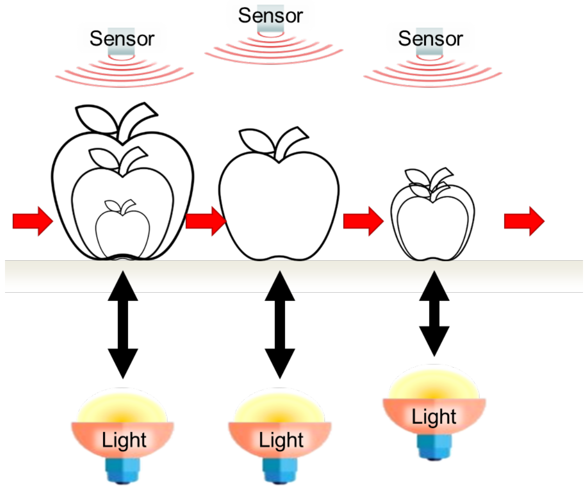
4. Conclusions

College of Agriculture and Life Sciences Kangwon National University
Non-destructive Smart Sensing Lab.

4. Conclusions

- **Characterization of transmission spectrum by size** of apple in transmission spectroscopy
  - **Larger apples** tend to have **smaller transmitted light intensity**
  - **The distance of the light source** has a **greater influence** on transmitted light intensity than the distance of the sensor

- **Development** of **SSC prediction model** of 3 distances of light source and sensor
  - The **distance** between the light source and the sensor representing optimal performance is **different for each level** of the apple
  - **Optimal preprocessing** varies **by apple size** (large apple: **MSC**, small apple: **SNV**)



Thank you

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