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## PREDICTION OF LETTUCE SPAD VALUE DURING GROWTH BY A MULTI-SPECTRAL IMAGE SENSOR USING MACHINE LEARNING MODEL

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### ABSTRACT

In this study, we aimed to improve previous LR (Linear regression) model for prediction of lettuce SPAD value, and used several machine learning (ML) models such as SVR (Support vector regression), KNN (K-nearest neighbors regression), KRR (Kernel ridge regression), DTR (Decision tree regression), RFR (Random forest regression), and ANN (Artificial neural network). K-means clustering algorithm was used to separate lettuce sample from background, and the reflectance from multi-spectral images containing red, green, and NIR (Near-infrared) channels was extracted. And the extracted reflectance was calculated as vegetation indices such as NDVI (Normalized difference vegetation index), RVI (Ratio vegetation index), and RGRI (Red-green ratio index), and calculated vegetation dices were transferred to ML models. We evaluated the predictive performance according to both vegetation dices and ML models. As a result, the model based on NDVI or RVI provided high accuracy than the model based on RGRI, and all ML models could predict the lettuce SPAD value with high accuracy than previous LR model. Especially, KRR model based on NDVI accurately predicted SPAD value with R<sup>2</sup> of 0.91, RMSE of 0.93, and RPD of 3.26. Thus, we considered that the multi-spectral image sensor (MSIS) using KRR model could be used for prediction of lettuce SPAD value during growth in a closed-type plant factory.

**Keywords:** SPAD, Image sensor, Machine learning, Multi-spectral, Artificial neural network(ANN).

### INTRODUCTION

Lettuce (*Lactuca sativa* L.) is one of the most popular leafy vegetable, and has been consumed as a main ingredient in ssam and salad in Korea. Also, lettuce is known as a crop suitable for production in a closed-type plant factory and especially, growing lettuce in controlled environments. Some studies are also being conducted to manage agricultural products remotely in closed-type plant factory. Nagano et al. (2019) developed a leaf-movement-based growth prediction model using optical flow analysis and machine learning in a closed-type plant factory, and reported that the plant growth model produced a correlation coefficient of 0.743. Meanwhile, machine learning (ML) is the branch of computer science that allows computers to learn finding the solutions to problems on their own, and is a comparatively new concept in the agricultural sector (Rakhra et al., 2021). In this study, we aimed to improve the previous SPAD prediction model based on both multi-spectral image sensor (MSIS) and linear regression (LR) model (Cho et al., 2018). Thus, we used several machine learning models to improve the previous SPAD prediction model, and evaluated the predictive performance of the lettuce

SPAD value according to each machine learning model.

## MATERIALS AND METHODS

### LETTUCE DATA SET

In this study, we used a lettuce data set for developing the SPAD prediction model of lettuce. The lettuce data set consists of both multi-spectral images and SPAD values of lettuce, and has totally 54 data (Cho et al., 2018). In addition, the data set includes the images and SPAD values of lettuce from 10 day to 20 day after seeding. SPAD value of lettuce was measured using a SPAD meter (SPAD-502Plus, Minolta Co., Ltd., Osaka, Japan). Lettuce images were obtained using a MSIS (MS4100, Duncan Tech, CA, USA).

### IMAGE PROCESSING

A few simple image processing steps were considered for extracting the lettuce reflectance for each channel, and the Scikit-image and OpenCV Python libraries were used for image processing (Van der Walt et al., 2014; Mustafa and Khairul, 2017). A flowchart diagram of the image processing steps is shown in Fig. 1. And then each vegetation index was transferred to linear regression and ML(LR, SVR, KNN, KRR, DTR, RFR, ANN) models.

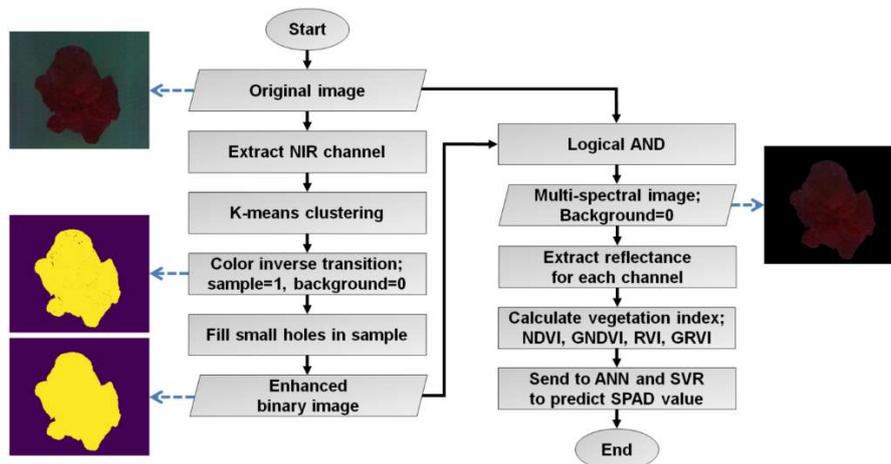


Fig. 1. Flow diagram of the algorithm employed for the reflectance extraction of lettuce

### MODEL EVALUATION

The entire database had 54 images, and was randomly divided into two datasets such as the training set (90%, 40 images) and the testing set (10%, 14 images). In this study, a 3-fold cross-validation was used to select the best model, and the validity of ML models was confirmed by the coefficient of determination ( $R^2$ ), the root mean squared error (RMSE), and ratio of performance to deviation (RPD).

## RESULTS & DISCUSSION

The performance of each ML model was assessed and compared to predict the SPAD value of lettuce leaves. KRR model based on NDVI and ANN model based on RVI accurately predicted the SPAD value of lettuce with the  $R^2$  value higher than 0.90 and RMSE value under 0.97. Meanwhile, the other ML models had lower accuracy than KRR and ANN but showed high accuracy than previous LR model. In addition, the RPD value also was the highest at 3.26 in KRR model based on NDVI, and ANN model based on RVI also showed relatively high RPD value at 3.13. Meanwhile, previous LR model based on RVI showed lowest RPD value at 2.44.