Computer-aided Visual Modeling of Rice Leaf Growth Based on Machine Learning

Wenlong Yi, Shiming Dai*, Yingzhao Jiang
School of Software Engineering
Jiangxi Agricultural University
Nanchang, China
*Corresponding author: smdai_002@163.com

Chao Yuan, Le Yang
School of Computer and Information Engineering
Jiangxi Agricultural University
Nanchang, China

***Abstract*. Machine learning can abstract the complex plant growth and development into a high-dimensional feature space, and transform a complex biological process into a mathematical problem. In this paper, with the computer-aided modeling of rice leaf growth as an example, improving the accuracy of prediction models for external environmental factors of rice growth and parameters of leaf shape evolution is investigated. Two machine learning tools, SVR and CNN, are selected to compare and analyze the training and prediction errors of 709 collected sample data. The experimental results show that the prediction accuracy of CNN is about 2 times higher than that of SVR. However, the learning speed of SVR in solving small sample regression is 50 times higher than that of CNN. Finally, the obtained parameters for rice leaf growth shape prediction are subjected to geometric description using the B-spline function, and visual simulation is carried out by visual C++ programming language and OpenGL 3.2. Three-dimensional visual models of plant growth and development with an external growth environment are established using machine learning. The ideal plant morphology is obtained by adjusting external environmental factors reasonably through quantitative analysis. It provides an information tool for the transformation of traditional empirical agricultural production to precise mode.**

Keywords: virtual rice; machine learning; physiology and ecology; geometric modeling

I. INTRODUCTION

Plant morphogenesis is a very complex life process. The rich and diverse morphological structure of plants is one of the most prominent external characteristics of the life system, which largely determines the functions of living substances, such as photosynthesis and transpiration on rice leaves. These biological processes are mainly affected by three factors: 1) light; 2) soil nutrients; 3) physiological and ecological factors of the plant growth environment. In order to improve plant morphological structure and promote its functions, people have actively explored the formation rules of plant morphological structure. Relevant research in the past five years is summarized as follows. Peng et al. simulated the growth process of the virtual jujube tree using L-systems and logistic models [1]. Yi et al. established the correlation between pigment contents and RGB that were components of rice leaf color using multiple linear regressions, providing a theoretical basis for color rendering of virtual rice leaves. Liang et al. improved the visual quality of virtual wheat using a collision detection technology [3]. Oqielat proposed a mathematical method RBF-CT to obtain the accuracy of its geometric model from leaf scanning data [4]. Evers et al. studied the plant function-structure model to quantitatively analyze the complementarity of the physiological and ecological data of different varieties of plants and proposed that mixed planting of related crops could effectively improve their productivity. However, to obtain a more comprehensive rule of morphological changes in plants, more factors in the whole process of plant growth and development should be combined and analyzed, which results in the complexity of plant growth simulation. With the vigorous development of machine learning, new opportunities are brought to solve such problems [5]. On this basis, the whole process of rice leaf growth and development was simulated and predicted in this study using SVR-based shallow learning and CNN-based deep learning respectively, and the results are compared. The final results are applied in the visual modeling of virtual rice.

This study had been completed with the financial support from the projects of the National Natural Science Foundation of China (Grant No. 61762048, Grant No. 61862032).

II. MATERIALS AND METHODS

In this study, the physiological and ecological data measured in the whole process of rice growth and development are used as the original dataset, which is mainly divided into the following three categories:

1) Appearance data of leaves: Maximum leaf length, Maximum leaf width, leaf angle and RGB values of leaf color.

2) Physiological data of leaves: SPAD, chlorophyll a, chlorophyll b, carotenoids, and leaf age.

3) External environment data of rice growth: Effective accumulated temperature and fertilization levels (N, P, and K fertilization).

The research process is divided into four steps, as seen in Fig. 1. In step 1, data cleaning based on the outlier removal algorithm designed in the early stage is used to improve the quality of the measured dataset [7]. In step 2 and 3, machine learning is performed using Gauss radial basis function-based Support Vector Regression (SVR) and AlexNet-based Convolution Neural Network (CNN), respectively, to establish prediction models of physiological and ecological parameters and leaf appearance parameters during rice growth. In step 4, the accuracy and training speed of the learning and prediction model based on SVR and CNN are compared, and the predicted parameter model is visualized using B-splines.

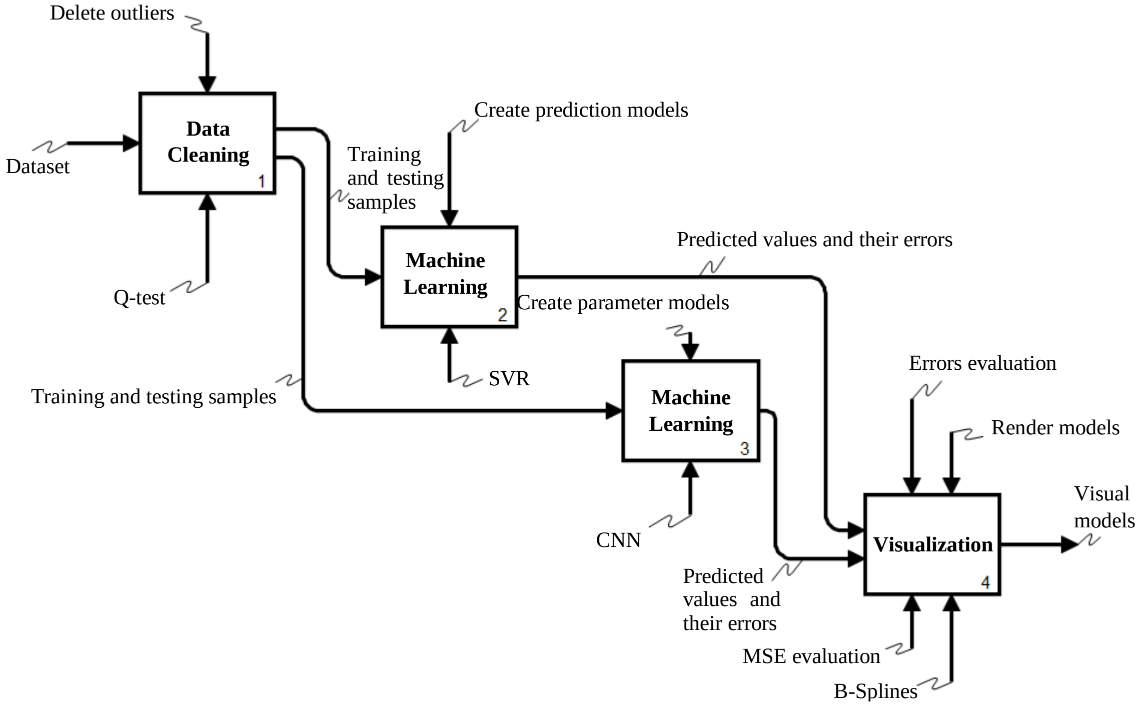

Fig. 1. Research tasks and methods

III. Experiments and Discussion

A. Experimental environment

Programing language Python 3.7 and machine learning framework TensorFlow 2.0 (Google) were used. Computer configuration is CPU-Intel(R) Core(TM) i7-9750H, with working-memory capacity of 8 GB and operating system of Windows10-64 bit (Microsoft). In this study, five parameter prediction models for "maximum leaf length", "maximum leaf width", leaf color components "R", "G" and "B" during rice leaf growth were established using SVR and CNN respectively, as shown in Fig. 2–Fig. 6.

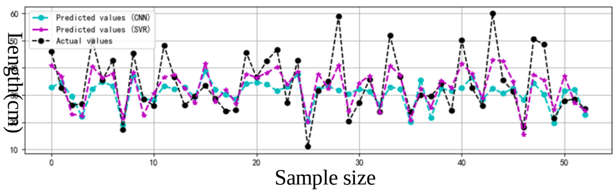

Fig. 2. Prediction of maximum leaf length

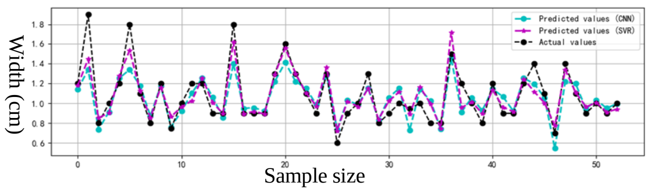

Fig. 3. Prediction of maximum leaf width

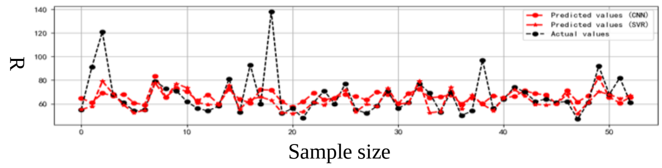

Fig. 4. Prediction of leaf color channel R

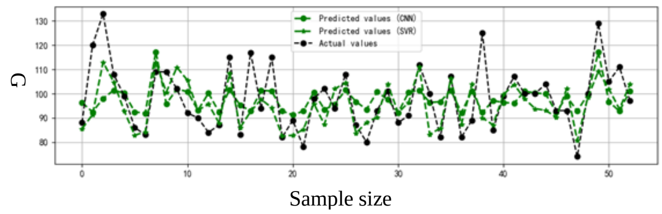

Fig. 5. Prediction of leaf color channel G

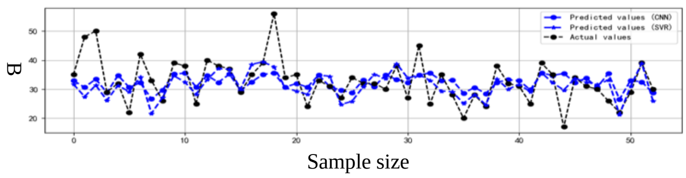

Fig. 6. Prediction of leaf color channel B

The quality of the established parameter prediction models for leaf growth and development using machine learning is the key. As seen in Table 1, in this study, 709 data on rice growth and development were obtained, 655 of which were used as a training sample set of SVR and CNN, and 54 of which were used as test data set of the models. The prediction errors of the models were calculated using Mean Square Error (MSE), as shown in (1).

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(f(x_i) - y_i)^2 \tag{1}$$

Where $f(x_i)$ is the predicted value; y_i is the actual value; and n is the number of tested samples. The training sample set was composed of the second and third categories of data during rice leaf growth (see the introduction in section II of this paper), with 7- dimensional vectors. The predicted parameter set was divided into five labels: maximum leaf length, maximum leaf width, leaf color components R, G and B, as showed in Table I.

TABLE I. COMPARISON IN REGRESSION EFFECT AMONG LEAF DATA MODELS

Objects	Training set size	Testing set size	SVR (*Gauss Kernel Function*)	CNN (*RELU*)	MSE (%)	Time (s)
Maximum leaf length	655	54	√	-	12.962704	0.179518
			-	√	9.69434	8.80358
Maximum leaf width	655	54	√	-	0.35531	0.164377
			-	√	0.156817	8.871697
Leaf color channel R	655	54	√	-	19.271654	0.159681
			-	√	16.1934039	9.054353
Leaf color channel G	655	54	√	-	16.25839	0.159861
			-	√	12.17307	9.071026
Leaf color channel B	655	54	√	-	8.663976	0.170171
			-	√	6.84809	9.240329

The experimental results showed that the MSE of the predicted values in CNN ranged from 0.16 to 16.9%, and its model accuracy was higher than SVR. The prediction time range of SVR was between 0.16s – 0.18s, and its model execution speed was higher than CNN.

B. Rice visualization

Three-dimensional (3D) computer simulation of rice leaves was carried out on the Visual Studio 2017 development platform using Visual C++ (OpenGL 3.2) and graphics rendering library (GLSL 330). Five parameters predicted by CNN were used as geometric parameters and leaf color variables. In this study, three geometric models of rice with four leaves were established using B-splines, as shown in Fig. 7. The values of leaf angles were the variable isolated by the program, with their parameters temporarily set by the user. In order to further investigate the photosynthesis of virtual plants, the sun was rendered in this figure, which was represented by the coordinates of the red circle.

a) b) c)

Fig. 7. Rendering effect of virtual rice

a) Leaf length: 16 cm, leaf width: 0.6 cm, leaf angle: 20°;
b) Leaf length: 20 cm, leaf width: 1.0 cm, leaf angle: 30°;
c) Leaf length: 18 cm, leaf width: 0.6 cm, leaf angle: 40°.

IV. CONCLUSION

The virtualization and visualization of plant morphological structure help people to describe and investigate plant life system by qualitative and quantitative, local and overall, and certain and uncertain combinations. To a great extent, this stimulates people’s expectation for the application of virtual technology in the computer modeling of plant morphological structure. The conclusions of this study are as follows:

1) Many data of plant growth are measured outdoors with high measurement error, so it is necessary to clean the data before training these samples.

2) Both SVR and CNN can predict the physiological and ecological parameters during plant growth. They both have advantages and disadvantages. The model accuracy of SVR is lower than CNN, but the training time of CNN is longer than SVR.

3) During SVR-based specific sample set training, it is necessary to optimally select the three meta-parameters to improve the prediction accuracy of the model [8].

4) Adjusting the external parameters of the virtual rice model to observe the changes in leaves can help people to formulate accurate scheme for rice cultivation.

References

[1] F. Peng, H. Zheng, S. Lu, Z. Shi, X. Liu, L. Li, "Growth model and visualization of a virtual jujube tree" // Computers and electronics in agriculture, 2019, 157, pp. 146-153.

[2] W. Yi, H. He, H. Yang, L. Wang and B. Zhong, "Relationship between RGB components and pigment contents in rice leaf"// Bangladesh journal of botany, 2018, 47(1), pp. 123-131.

[3] L. Tang, W. Song, T. Hou, L. Liu, W. Cao, Y. Zhu, "Collision detection of virtual plant based on bounding volume hierarchy: A case study on virtual wheat" // Journal of integrative agriculture, 2018, 17(2), pp.306-314.

[4] M.N. Oqielat, "Surface fitting methods for modelling leaf surface from scanned data" // Journal of King Saud University-Science, 2019, 31(2), pp. 215-221.

[5] J.B. Evers, W. van der Werf, T.J. Stomph, L. Bastiaans, "Understanding and optimizing species mixtures using functional-structural plant modelling" // Journal of experimental botany, 2019, 70(9), pp. 2381-2388.

[6] K.G. Liakos, P. Busato, D. Moshou, S. Pearson, D. Bochtis, "Machine learning in agriculture: A review" // Sensors, 2018, 18(8), pp.2674.

[7] W. Yi, I.V. Gerasimov, H. He and S.A. Kuzmin, "Design and implementation of a processing algorithm of measurement errors in multi-dimensional data acquisition," 2017 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), St. Petersburg, 2017, pp. 605-608.

[8] W. Yi, I.V. Gerasimov, S.A. Kuzmin, H. He, "An intelligent algorithm of Support Vector Regression parameters optimization in soft measurements," 2016 XIX IEEE International Conference on Soft Computing and Measurements (SCM), St. Petersburg, 2016, pp. 404-406.