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Using the artificial neural network to estimate leaf area

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ABSTRACT

Artificial neural network (ANN) is applied for many subjects in agricultural science such as: crop yield and evapotranspiration prediction, soil parameters estimation, water demand forecasting, hydrological forecasting. Leaf area is one of parameters that is used to assess the plant vegetative growth. In this study, leaf areas of 61 plant species with different leaf shapes were estimated by ANNs and the effect of input data and pre-processing methods on ANNs performance was assessed. Results showed that the ANNs could provide good estimation of leaf area. ANNs input variable combination affected the ANNs performance to estimate the leaf area. With increase in number of hidden layers the epochs decreased and accuracy of the leaf area prediction and running speed increased. Results of test data set showed that MinMax pre-processing method resulted in more accurate prediction in comparison with the no pre-processed method and Norm STD method. The most conclusive result of this study is the application of ANNs for all of plant species, whereas, in application of other methods: specific equation should be prepared for each plant.

1. Introduction

Artificial neural networks (ANNs) are becoming a common tool for modeling complex input–output dependencies (Maren et al., 1990). Different investigators have shown that ANN models often give better results than traditional methods (Moosavi and Sepaskha, 2012). Artificial neural network is applied for many subjects in agricultural science such as: crop yield prediction (Dai et al., 2011; Moosavizadeh-Mojarad and Sepaskhah, 2012; Kaul et al., 2005), fruit weight prediction (Naroui Rad et al., 2015; Soares et al., 2013) evapotranspiration prediction (Dehbozorgi and Sepaskhah, 2012; Trajkovic, 2005; Kumar et al., 2002), soil parameters estimation (Moosavi and Sepaskha, 2012), water demand forecasting (Pulido-Calvo et al., 2007), hydrological forecasting (Thirumalaiah and Deo, 2000; Azadi and Sepaskhah, 2012) etc.

Leaf is an important part of plant that affects the photosynthesis rate, dry matter accumulation, and crop growth. Leaf area is one of parameters that is used to assess the plant vegetative growth. Leaf area index is applied in crop modeling and calibration and validation of crop models. For example, it is used for relationship between leaf area index and evapotranspiration (Sepaskhah et al., 2013; Shabani et al., 2014), crop growth rate and relative growth rate (Shabani et al., 2013; Poorter and Remkes, 1990) and radiation interception (Weiss et al., 2004). Among different direct and non-destructive methods for measuring leaf area, the leaf area determination based on parameters such as length and width of leaf is common. In this method, relationship between the leaf area and the leaf length and width and/or length × width is determined, then leaf area of the plant is estimated by direct measurement of length and width of plant leaf by ruler in the field or pot (Sepaskhah, 1977; Shabani et al., 2013; Montero et al., 2000; Mousavi Bazaz et al., 2011; Shabani and Sepaskhah, 2016). This method is especially used in pot experiment that the number of leaves is low. Regression analysis is commonly used to determine the relationship between the leaf area and the leaf length and width and/or length × width. However, other methods such as artificial neural network can be used instead of this method. There are two types of plant leaf growth pattern. First: leaf growth occurs along with changes in leaf shape [i.e., rapeseed (Shabani et al., 2013), radish . . .]. Second: leaf growth occurs along with changes in leaf size. Therefore, more than one equation for relationship between the leaf area and leaf dimensions is needed for the first leaf group pattern. However, for the second growth pattern one equation is used. In this study, leaf areas of 61 plant species with different leaf shapes were estimated by ANNs

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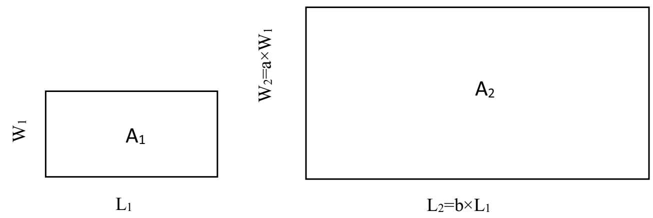


Fig. 1. Relation between width and length of two rectangles.

and the effect of input data and pre-processing methods of input data on ANNs performance was assessed.

2. Materials and methods

2.1. Theoretical principle

Ellipse and circle area is determined as follows:

$$A = \frac{\pi}{4}LW \tag{1}$$

where A, L and W are the area, length of major axis (maximum length) and minor axis (maximum width), respectively (Table 1). Based on Eq. (1), the area of many other geometric shapes can be calculated by using maximum length and maximum width by unique equation as follows:

$$A = K\left(\frac{\pi}{4}LW\right) \tag{2}$$

where K is a coefficient that is specified for some categorized shape (Table 1). The value of K is not dependent on the size of the geometric shape. In the other words, K is constant for similar shape, i.e., rectangles, triangles, and circles, but with different sizes (Table 1).

If length (L) and width (W) of a large rectangular surface is a constant as a and b times L and W of the small rectangular surface, respectively (Fig. 1), the ratio of two rectangles areas is as follows:

$$A_2/A_1 = a \times b \tag{3}$$

where A_1 and A_2 are the areas of small and large rectangular surfaces, respectively (Fig. 1).

Therefore, if the ratio of length and width of two rectangles is known, the area of one rectangular surface can be determined based on the area of another rectangular surface. As mentioned by Shabani and Sepaskhah (2016), this method can be used to estimate the leaf area in plants that the leaf grows along with changes in leaf size and not in leaf shape. In these plants, leaf area is increased with increase in width and length of the leaf.

Therefore, similar to the area of rectangles (Fig. 1), the area of a large leaf can be estimated by using the area of smaller leaf if the K coefficient is determined by using the area, width and length of smallest leaf of plant as follows:

$$K = \frac{LA_S}{\frac{\pi}{4} \times L_S \times W_S} \tag{4}$$

where LA_S, L_S and W_S are the area, length and width of smallest leaf at beginning of the leaf growth period or at any growth stage, respectively. The K value is specified for each plant (Table 1). Therefore, the area of larger leaf can be estimated by the following equation:

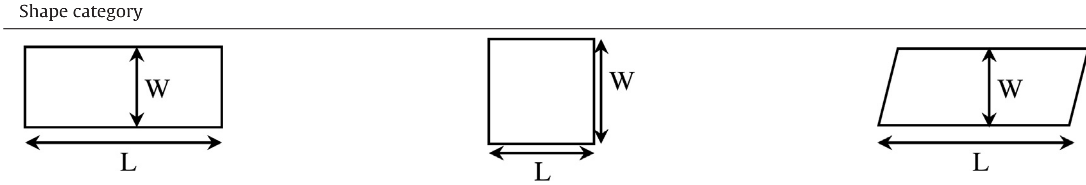
$$LA_L = K \times \frac{\pi}{4} \times L_L \times W_L \tag{5}$$

where LA_L, L_L and W_L are the area, length and width of larger leaf, respectively. This method can be used to estimate the leaf area in pot experiments with limited number of leaves and assessment of leaf area change is obtained without detaching the plant leaves. In this investigation, K coefficient in Eq. (4) was determined in two states: a) without considering π/4 (K_1) and b) with considering π/4 (K_2). Minimum K_1 and K_2 can be determined for each plant by smallest leaf.

2.2. Experimental procedure

To assess the presented principle, 61 plant species with different leaf shapes were selected. The common name and scientific name of plants are shown in Table 2. Leaves were prepared from orchards, greenhouses, landscape and other locations. Criteria to select the plant were the shape, size and age of leaves. Small, medium and large leaf with different ages was detached from one tree or bush. Twelve to forty five leaves of each plant were detached and transferred to laboratory. The area, length and width of each leaf was measured by leaf area meter (WinArea_UT_11) and the smallest leaf was selected to determine the minimum of K_1 and K_2 [without and with considering π/4 in Eq. (4), respectively] for each plant species. Minimum of K_1 and K_2 can be used to estimate the area of plant larger leaves by using Eq. (5).

Table 1
Specific coefficient for different shapes.

Shape category	K
	$4/\pi$
	$2/\pi$
	1.0