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Research Paper

Prediction of seed distribution in rectangular vibrating tray using grey model and artificial neural network

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To maintain good continuous working performance in a vacuum plate seeder, it is important to monitor the distribution of seeds in real time and automatically adjust vibration parameters accordingly. Seed motion in a rectangular vibrating tray with vibration varying with time and interference by direction angle was simulated using the discrete element method (DEM). A plane model P was used to describe the variation of seed layer thickness. Four square areas on the bottom of the tray were divided symmetrically near the four corners to measure seed layer thickness, and a monitoring plane model P_m was established. DEM simulation results showed that the models P_m and P had the similar change rules, although there were some differences in fitting parameters. There was obvious time delay in the change of P_m compared with P. Therefore, a grey system model (GM) was adopted to predict the change of P_m, and two back-propagation (BP) neural networks which take GM prediction results as input parameters were developed respectively. Then, according to the BP neural networks outputs, a prediction plane model P_p was proposed to predict the seed distribution. Experiments were carried out on a test-rig to validate these predictions. The seed distribution plane P was measured manually, the monitoring plane P_m was established using seed layer thickness measurement results and the prediction plane P_p was established using the GM and BP neural networks. The results indicated that the proposed method had good precision and stability and provides the basis for the design of an automatic control system for the vibrating tray to promote a uniform seed distribution.

1. Introduction

Rice is the most important staple food for more than half of the global population. Nursery growing and transplanting is the main cultivation technique since it produces strong seedlings and extends the growth period for more than half a month (He, Luo, Li, Wang, & Zhang, 2008). At present, more than 50% by area of rice cultivation in China is utilises hybrid rice. Precision seeding has gradually become a major planting

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Nomenclature

a	Development coefficient of GM model
A	Vibration amplitude of seeds tray, mm
b	Driving coefficient of GM model
f	Vibration frequency of seeds tray, Hz
n	Sample number
h_0	Average seed layer thickness, mm
h_1, h_2, h_3, h_4	Seed layer thickness in four monitoring areas, mm
$h_{I\times J}$	Seed layer thickness in square regions, mm
h_j	Output of neuron j in hidden layer
L	Number of neurons in hidden layer
$\mathbf{n}_m$	Normal vector of monitoring plane
$\mathbf{n}_p$	Normal vector of seed distribution plane
$\mathbf{n}_v$	Vibration direction vector of the tray
N	Number of input neurons
O_k	Outputs of neuron k in output layer
p	Prediction step
P	Seed distribution plane model
P_m	Monitoring plane model
P_p	Prediction plane model
t	Time, s
T_s	Vibration termination moment
x_I, y_J	Coordinates of square regions
x_m, y_m	Projection coordinates of $\mathbf{n}_m$ in XY plane
x_{m+p}, y_{m+p}	Prediction results of x_m and y_m
x_p, y_p	Projection coordinates of $\mathbf{n}_p$ in XY plane
x_{BP}, y_{BP}	BP output of x_p and y_p
$X^{(0)}$	Original numerical sequences
$X^{(1)}$	First order AGO data
α_m	Angle between projection of $\mathbf{n}_m$ and X axis, °
α_{m+p}	Prediction results of α_m, °
α_p	Angle between projection of $\mathbf{n}_p$ and X axis, °
α_v	Angle between projection of $\mathbf{n}_v$ and X axis, °
α_{BP}	Angle calculated using x_{BP} and y_{BP}, °
β_m	Angle between projection of $\mathbf{n}_m$ and Y axis, °
β_p	Angle between projection of $\mathbf{n}_p$ and Y axis, °
β_v	Angle between projection of $\mathbf{n}_v$ and Y axis, °
γ_m	Angle between $\mathbf{n}_m$ and Z axis, °
γ_{m+p}	Prediction results of γ_m, °
γ_p	Angle between $\mathbf{n}_p$ and Z axis, °
γ_v	Angle between $\mathbf{n}_v$ and Z axis, °
γ_t	Time varying interference angle, °
γ_{BP}	BP output of γ_p, °
η	Learning rate
η_0	Initial learning rate
υ_{ij}	Connection weighs between neuron i in input layer and neuron j in hidden layer
υ_{jk}	Connection weighs between neuron j in hidden layer and neuron k in output layer

technique to improve the yield because hybrid rice, which uses the seeding technique, has a greater ability to tiller than ordinary rice (Yang, Li, Ma, Sun, & Xu, 2014; Yi, Liu, Wang, & Tao, 2014).

Rice seed has irregular shape and has a frangible glume on the surface. Existing mechanical metering devices cannot meet its precision seeding agronomic requirements, and damaged seeds are a serious problem. Pneumatic metering technology has been widely developed for precision seeding because it does little damage to the seeds and has broad spectrum of applications (Movahedi, Rrzvani, & Hemmat, 2016; Topakci, Karayel, Canakci, Furat, & Uzun, 2011; Yazgi & Degirmencioglu, 2014). Structure design, parameters optimisation and performance experiments of different pneumatic seeders have been researched extensively (Abdolahzare, Asoodar, Kazemi, Rahnama, & Mehdizadeh, 2016; Altikat, Celik, & Gozubuyuk, 2013; Fanigliulo & Pochi, 2011). Karayel, Barut, and Özmerzi (2004) determined the optimum vacuum pressure of a precision seeder and developed mathematical models by using some physical properties of seeds such as mass, density, sphericity and projected area. Gaikwad and Sirohi (2008) designed a vacuum seeder for sowing vegetable seeds in plug tray and optimised the operation parameters such as vacuum pressure and nozzle diameter. Önal, Degirmencioglu, and Yazgi (2012) established a theoretical model of seeds sowing uniformity performance. Ding, Liao, and Huang (2013) analysed the relationship between seeding migration trajectory and working pressure of a pneumatic precision seeder and Xing et al. (2017) developed a pneumatic seeder to meet the requirements for the field seeding of hybrid rice.

As a precision seeding device for rice nursery seedlings, the vacuum plate seeder is primarily composed of a rectangular suction plate and a seed tray (Liu & Song, 2004). The tray needs to vibrate at high frequency and low amplitude so that the seeds in the tray are separated to reduce interactive forces and allow for easy and precise seed pick up. The slider-crank mechanism is the most commonly used device to drive the tray and reciprocate it along a guiding axis.

The necessary condition for improving the continuous working performance of a vacuum plate seeder is that the seeds should be uniformly distributed in the vibrating tray, because this can maintain a uniform distance between the suction nozzles in the vacuum plate and the vibrating seeds. However, under practical conditions, it is inevitable that there is an uncertain angle between the vibration direction and the vertical direction, and that this angle usually varies with time. This causes the seeds to flow in the tray resulting in an uneven distribution of seeds with time. In this case, it is hard to maintain the vertical distance between the suction nozzles in different regions of the suction plate and the seeds and this can seriously restrict working performance (Gong, Chen, Li, & Li, 2014). A feasible solution is to adjust the vibration direction of the tray to promote the motion of seeds orderly and uniformly. This requires the real time prediction of seed distribution. The prediction of material distribution in systems under vibration is also widely used in agricultural cleaning and screening systems (Craessaerts, Saeys, Missotten, & De Baerdemaeker, 2010).

The discrete element method (DEM) is an important technique for research into the granular dynamics of agricultural systems (Boac, Ambrose, Casada, Maghirang, & Maier, 2014; Kruggel-Emden, Rickelt, Wirtz, & Scherer, 2008; Tijskens, Ramon, & De Baerdemaeker, 2003). It can provide the motion parameters of each granular unit during the whole calculation process. In an earlier paper the influence of mechanical properties on the impact behaviour of rice seeds excited by a