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Gaussian processes based bivariate control parameters optimization of variable-rate granular fertilizer applicator

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ABSTRACT

Taking into account the scarcity of feasible fertilizing rate feedback from on-board sensors and the limited computation power of controller mounted on the variable-rate granular fertilizer applicator, optimum control index chart is a good option for controller design to achieve accurate variable-rate fertilizing control. The index chart contains a list of optimum control parameters optimized to meet combined objectives: fertilizing accuracy, energy saving and fertilizing consistency. To generate such list, the probabilistic meta-model based on Gaussian Processes (GP) is firstly utilized to identify the variable-rate fertilizing process with the indoor experimental data. Consequently, the meta-model-based optimization process is presented with the given fertilizing rate, previous opening length and its adjusting direction. The optimal control parameters chart is obtained by the iterative multi-objectives optimization based on Genetic Algorithm (GA). Thus, the fertilizing prescription can be converted to the controller's actions by searching the optimum control parameters chart. The well-trained GP models predict the fertilizing rate and the fertilizing coefficient of variation with limiting mean relative error to 0.014 and 0.089, respectively. Finally, by considering four main error sources, the verified fertilizing model improves the average fertilizing rate error to no more than 5% at given management zone scale in field test.

1. Introduction

Precision agriculture offers the promise of increasing yield and quality of agricultural products and minimizing the environmental contamination. Variable Rate Technology (VRT) is an important part of precision agriculture by applying production inputs, such as fertilizers or seed, to specific levels appropriate to the management zone. Generally, a VRT system covers fertilizing rate decision sub-system and variable-rate implementation sub-system. Classified by the fertilizing rate decision methods, there are two types of VRT systems: map-based and sensor-based VRT (Ess et al., 2001). The map-based VRT is implemented with a prescription map generated by field grid sampling analysis and field yield or even manually setting according to experience, and then utilizing such map to control a variable-rate applicator.

At present, different kinds of variable-rate applicators have been developed, such as variable-rate applicators for liquid fertilizer (Yang, 2001), variable-rate applicators for granular fertilizer (Miller et al., 2005), etc. The prescription maps in the remote service center must be converted into a form which can be identified by the controller of the applicator before they are implemented. The desired fertilizing rate from prescription map should be calculated timely based on the amount of fertilizer at each zone.

A variable-rate fertilizing system mainly is composed of variable-rate fertilizing actuators and variable-rate fertilizing controller. The former should have controllable adjustable parameters. Namely, it derives different fertilizing rates in the working of different parameters. The variable-rate fertilizing control scheme should be simple and easy to achieve high-precision control. In addition, the development of variable-rate fertilizing system is also limited to cost control in China. Inspired by the existing variable-rate fertilization machine and its control characteristics, a wireless network supported fertilizing system based on fluted roller adjustment to realize variable-rate fertilization was developed by Shanghai Jiao Tong University.

Considering the cost of fertilizer control system and the scarcity of sensors for online accurate measurement of the fertilizing rate, the multi-variants control scheme may not establish closed loop control. Moreover, taking in account the limited computation capability of the controller, some pre-setting optimum control parameters index chart could be used to implement a sustainable precise control. Therefore, the fertilizer application prescriptions can be turned into the control instructions of fertilizing system by searching the indexed chart. The design of optimum control index chart aims at finding the best parameters for the operations. Artifi-

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cial neural networks have been utilized for modeling the nonlinear features in parameters optimization scheme (Kumar et al., 2009).

Recently, Gaussian processes (GP) (Rasmussen and Williams, 2006) have been popularly developed in nonlinear system regression (Yuan et al., 2008; Williams et al., 2006), even modeling dynamic system (Kocijan and Likar, 2008), based on input and output data with noise. The GP model is a probabilistic, non-parametric model. It differs from most other regression models, such as neural networks, as the system nonlinearity approximation by fitting the parameters of the basic functions does not resort to non-convex optimization.

Flow of seed or fertilizer through the fluted roller with control parameters is a nonlinearity physical phenomenon. Therefore, in this paper, the fertilizer control application is identified firstly by GP models trained with experimental dataset. For the generation of control index chart, the bivariate control parameters are optimized by Genetic Algorithm (GA) with the combining accuracy, energy saving and consistency objectives. At last, the fertilizing system using the optimum control index chart is verified by indoor static calibration and field dynamic test. The present work was undertaken with the objectives as mentioned in Section 2.

2. Objectives

i. To study a optimum bivariate control of the developed granular variable-rate fertilizer applicator without online fertilizing rate feedback.
ii. To develop a probabilistic model for flowing rate of seed or fertilizing rate based on GP.
iii. To obtain the optimum control index chart of control parameters for achieving the precise fertilizing rate with minimum adjusted power consumption and maximum fertilizing consistency of each fluted metering rollers.

3. Materials and methods

3.1. Description of variable-rate fertilizer applicator system

The variable-rate fertilizer and seed applicator is mainly composed of four components: fertilizer applicator body, fertilizing controller, field computer and remote server. The system architecture and its workflow of map-based variable-rate fertilizer applicator system are shown in Fig. 1.

On the one hand, the GIS (Geographic Information System) decision support system in the remote server generates fertilizing prescription that could be downloaded to field computer system via the GPRS (General Packet Radio Service) (Esteban et al., 2005) network and saved in a CF card. During the process of field fertilizing, the variable-rate fertilizing control system combines the real-time signals from the DGPS (Differential Global Positioning Systems) receiver with traveling speed of tractor. Moreover, supported by the fertilizing local zone and its fertilizing rate from prescription, the fertilizing control parameters sequence, contained the opening length and rotational speed of fluted roller, is generated by searching optimum control index chart. Thus, the microcontroller drives the implementation of the controlled components via motor driver, so as to achieve remote automatic variable-rate fertilization.

On the other hand, the fertilizer applicators collect its applicator identification, location and working states from metering sensors, and send through GPRS network to remote central server. Thus, multiple operations of fertilizer applicators are monitored

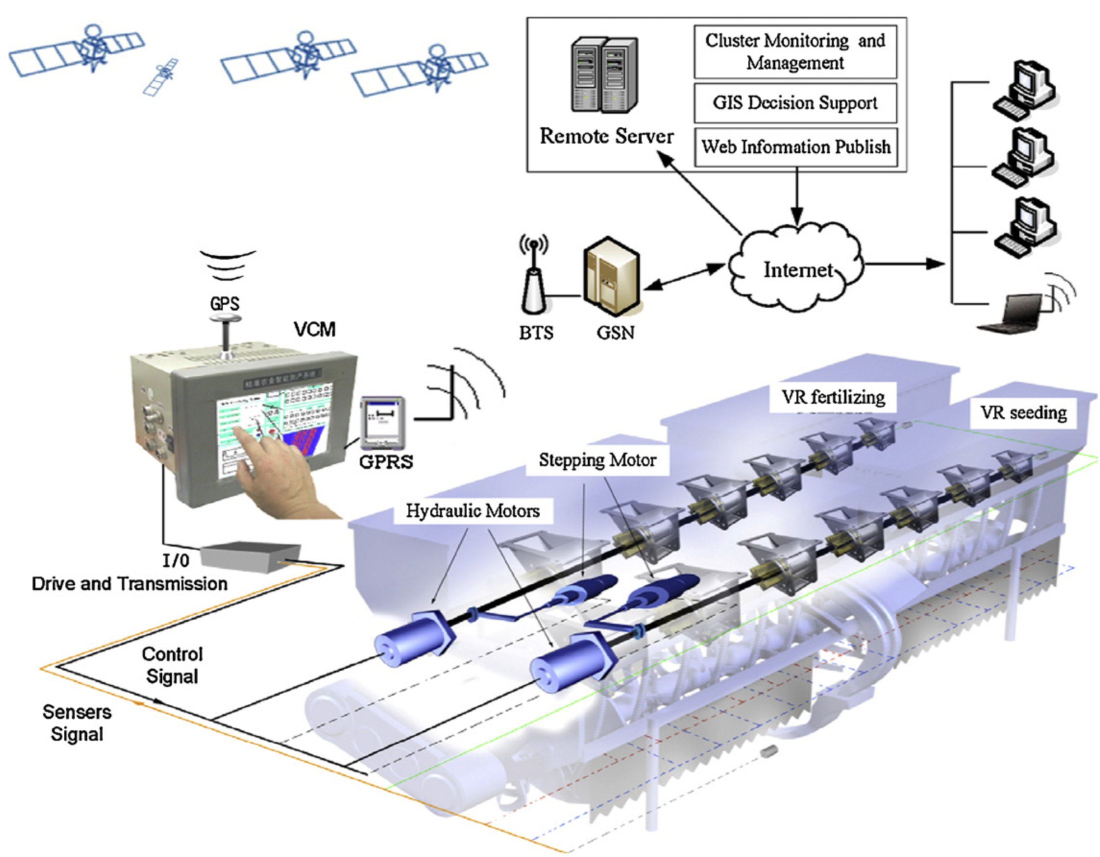

Fig. 1. Illustration of the structure and signal flow of the control system for network-based variable-rate fertilizer applicator.