CONTROLLER PERFORMANCE CRITERIA FOR SENSOR BASED VARIABLE RATE APPLICATION

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ABSTRACT

Sensor based variable rate application of crop inputs provides unique challenges for traditional rate controllers when compared to map based applications. The controller set point is typically changing every second whereas with a map based systems the set point changes much less frequently. As applied data files for a sensor based variable rate nitrogen applicator were obtained from a wheat field in north central Oklahoma. These data were analyzed to determine the magnitude and frequency of rate changes. A model based a commercially available rate controller was developed. Results from this model predicted a mean absolute application error of 12.9 L ha^{-1}. This error could likely be reduced by half if the controller delay was reduced by 1 second.

Keywords: precision application, nitrogen, time delay, response time

INTRODUCTION

The application of precision agriculture technologies has generally followed one of two paths. One based entirely on map based information and the other based on real time sensors. The map based approach allows use of historical information, while sensors allow us to assess in season conditions. Map based information is typically gathered with yield monitors, through soil testing, and/or with remotely sensing. The primary difference between map and sensor based strategies is data analysis and interpretation. With map based variable rate application, the practitioner must collect and analyze data for input to an expected crop response algorithm and then transfer the prescription to a variable rate applicator.

The sensor based approach to precision agriculture uses sensors to measure crop and/or soil properties in real time as the applicator moves across the field. Data from the sensor is collected, processed, and interpreted by the on-board computer and sends a signal to a rate controller. One of the advantages of this approach is automating the data analysis and interpretation step of the map based strategy. A predetermined algorithm is used to convert the sensor information to an application rate. This algorithm is typically constant at a field scale and often at the regional scale.

Due to its potential environmental risk, spatial nitrogen management has been one of the primary goals of the precision agriculture movement. Management strategies have ranged from applying traditional nitrogen recommendation methods to sub-field units to using sensors to measure in-season nitrogen needs. Employing a traditional recommendation will usually rely on a yield goal and knowledge of nitrogen credits, primarily soil organic matter and soil nitrate test. Applying a traditional function spatially will require spatial yield goals and credits. Schmidt et al. (2002) conducted nitrogen rate trials for irrigated corn at multiple locations within three fields to evaluate the affect of soil organic matter on yield response. The yield maximizing nitrogen rate ranged from 52 to 182 kg ha^{-1}. However, yield response to nitrogen was not consistently related to soil organic matter as they had hypothesized leading them to conclude that using soil organic matter to determine nitrogen management zones would likely be ineffective. However, Mamo et al. (2003) concluded that soil type and elevation (likely proxies for yield potential) were valuable in predicting the magnitude of site specific nitrogen response. They found that variable rate nitrogen application was more profitable than uniform application by reducing the total amount of nitrogen applied.

Koch et al. (2004) concluded that variable yield goal based zones for nitrogen management were more profitable than uniform nitrogen management. Scharf et al. (2005) evaluated nitrogen needs in production corn fields to determine economically optimum nitrogen rates. They concluded that a few coarse management zones would likely improve nitrogen management, but the ability to manage nitrogen at a smaller scale would likely be more beneficial. With minimal coarse management zones the number of rate changes that a controller would receive would be minimal, but likely have some magnitude. Managing nitrogen at a smaller scale would require more frequent rate changes from the sprayer controller.

Raun et al. (2002) found that using optical sensors to determine nitrogen needs at the 1 m^2 area was more profitable and efficient than multiple uniform application strategies. This management strategy incorporates a non-nitrogen limiting strip to determine the potential response to additional nitrogen fertilizer. Sensors are used to estimate yield potential in both the nitrogen reference strip and an adjacent area which are used to determine the optimum in season nitrogen rate (Raun et al., 2001). The variable rate technology to accomplish application at the submeter scale is currently unavailable. However, sensor systems that provide a single nitrogen application rate to a traditional rate controller are gaining popularity. While there have been efforts to improve variable rate application for typical map based approaches, very little work has been directed at sensor based variable rate application. The process for the rate controller is similar in that the it receives an updated rate and must operate a control valve to achieve the desired flow rate. However, with a sensor based system the controller typically receives an updated rate every second and does not have the opportunity to stabilize. Thus the objective of this research was to model a typical rate controller and predict the response to a sensor-based variable rate prescription.

METHODS

A Raven 440 SCS (Raven Industries, Sioux Falls, ND) rate controller was evaluated on a static test stand to determine performance with two different control valves. A fast close (FC) valve (Raven Industries, Sioux Falls, ND - P/N 1-063-0172-170) was tested with the manufacturer recommended VALVE CAL setting of 0743.

The static test stand consisted of a electric powered centrifugal pump and associated tanks and plumbing. The Raven controller was plumbed into the system along with an independent flow meter and two pressure transducers (Fig. 1). The flow meter and pressure transducer signals were recorded using LabVIEW software and a USB-6210 data acquisition device (National Instruments Corp, Austin, Texas). Data were recorded at 10 Hz. Rate changes were triggered from LabVIEW via the serial port on the Raven controller.

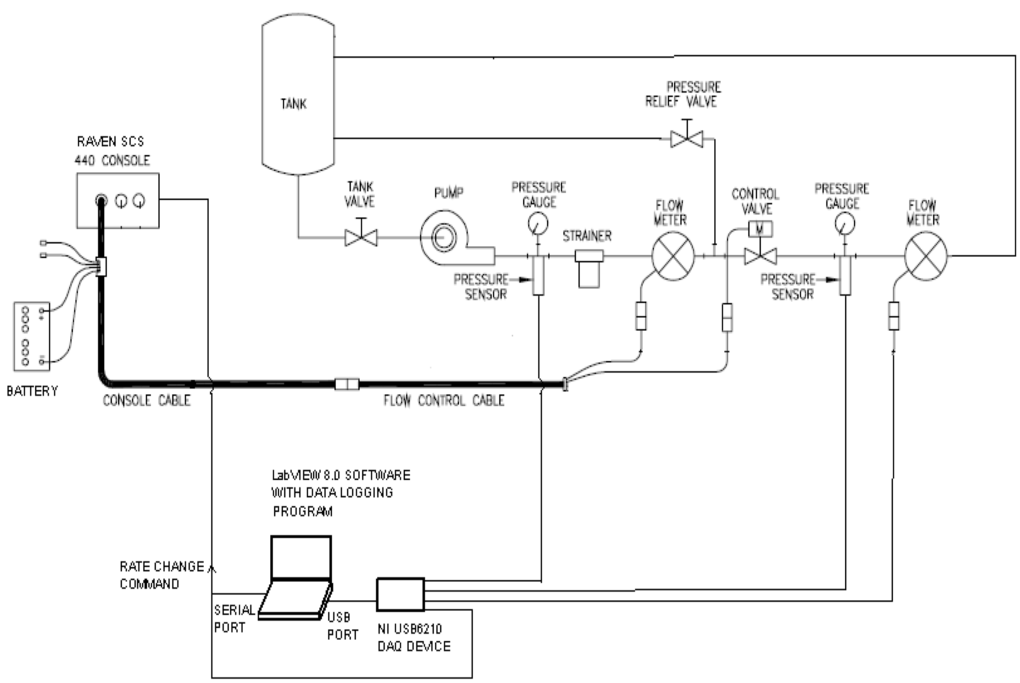

Figure 1. Plumbing and data acquisition diagram for the static test stand.

Various step rate changes were sent to the rate controller and the response was measured. Rate changes were chosen based on expected rate changes observed in data files. The open loop response of the fast close valve was measured. The valve was approximated by a first order plus time delay (FOPTD) transfer function after determining the open loop response of the valve. The standard transfer function of a FOPTD process is shown in equation 1. From the open loop response, the gain, time constant, and time delay of the system were determined to be 1.0, 1.0, and 0.4 respectively.

$$G(s) = \frac{Ke^{-\tau_d s}}{Ts + 1} \qquad \text{Eq. 1}$$

where K is gain
T is time constant
τ_d is time delay

The controller was modeled as a proportional integral controller similar to that described by Shoukat Choudhury et al. (2005). A proportional gain of 1.28 and integral gain of 1.16 were chosen to match response data from the entire control system. The control system was modeled in MATLAB Simulink (version R2007a, The MathWorks, Inc.) as show in figure 2.

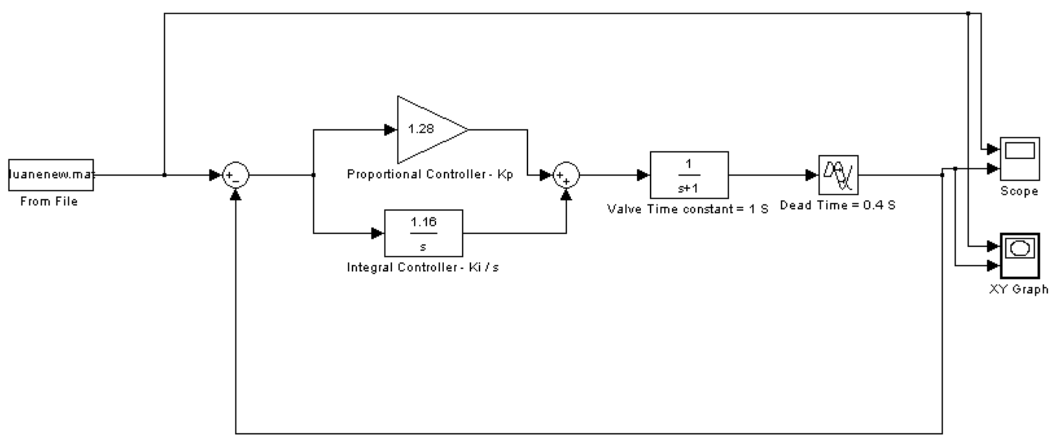

Figure 2. MATLAB model of sprayer control system including integral and proportional controller coefficients and a first order response valve.

Data were collected from field operation of a GreenSeeker® RT200 (N-Tech Industries, Ukiah, CA) sensor system. These data were from variable rate application of nitrogen to wheat in early 2005. The sprayer had a 27.4 m wide boom and operated at an average ground speed of 15.4 km h^{-1}. The file was separated into individual passes and used as inputs to the model. There were eight passes across this field and descriptive statistics for these passes are shown in Table 1.

Table 1. Summary statistics for the controller input signal by pass recorded during nitrogen application to wheat in 2005.

pass	Obs	Mean	Minimum	Maximum	Std dev	Max rate increase	Max rate decrease
		- L ha^{-1} -					
1	162	168.4	121.4	205.8	19.6	42.8	-50.6
2	162	162.1	121.4	205.8	18.2	58.1	-27.5
3	149	179.6	134.5	205.8	17.4	50.3	-58.6
4	150	175.7	120.1	205.8	19.6	44.0	-47.2
5	175	168.2	118.3	205.8	24.4	34.9	-44.8
6	183	165.0	118.3	205.8	22.3	44.8	-36.8
7	88	175.8	118.3	205.8	19.5	58.6	-83.6
8	85	167.8	102.9	205.8	23.8	80.1	-53.3

RESULTS AND DISCUSSION

The data in table 1 show that the maximum rate was set at 205.8 L ha^{-1}. The mean application rate for all passes was similar. The maximum rate change for any 1 s period within a pass ranged from -83.6 to 80.1 L ha^{-1}. The prescribed rate as a function of time is shown in figure 3 for pass 1. A new rate is being sent to the rate controller every second. While there are some spikes and rapid rate changes, there is also an underlying trend with areas of similar rates.

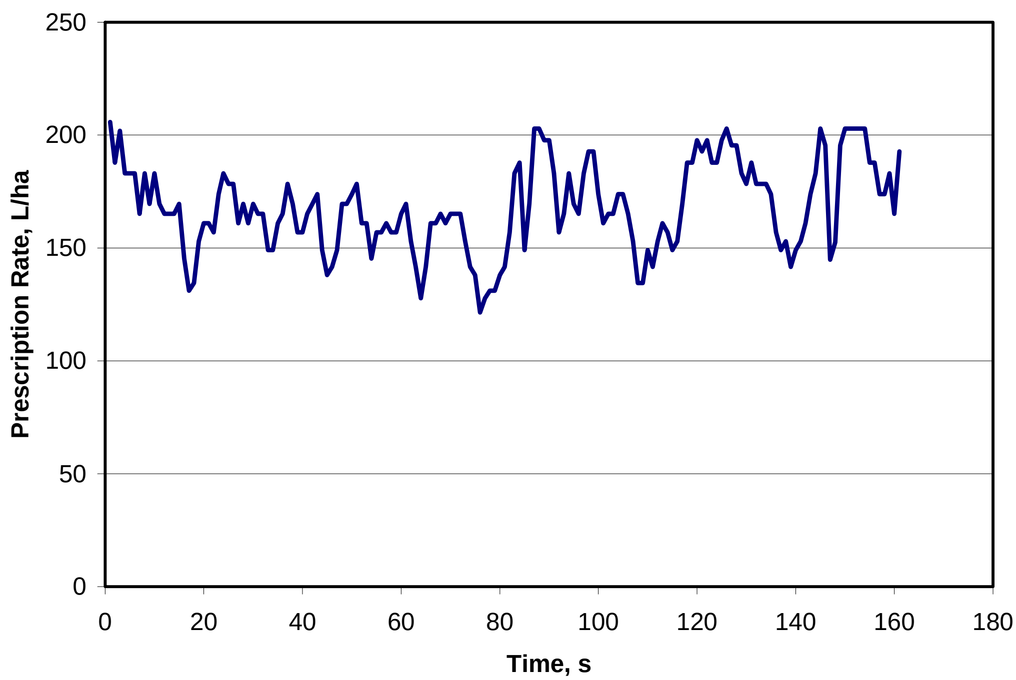

Figure 3. Prescribed nitrogen application rate sent to the controller for pass 1.

In general, the model output followed the controller input fairly well. Figure 4 shows the model output rate for pass 1 graphed as a function of the prescribed rate with a linear regression. Simply lagging the model output by 1 second improves the regression results (Figure 5).

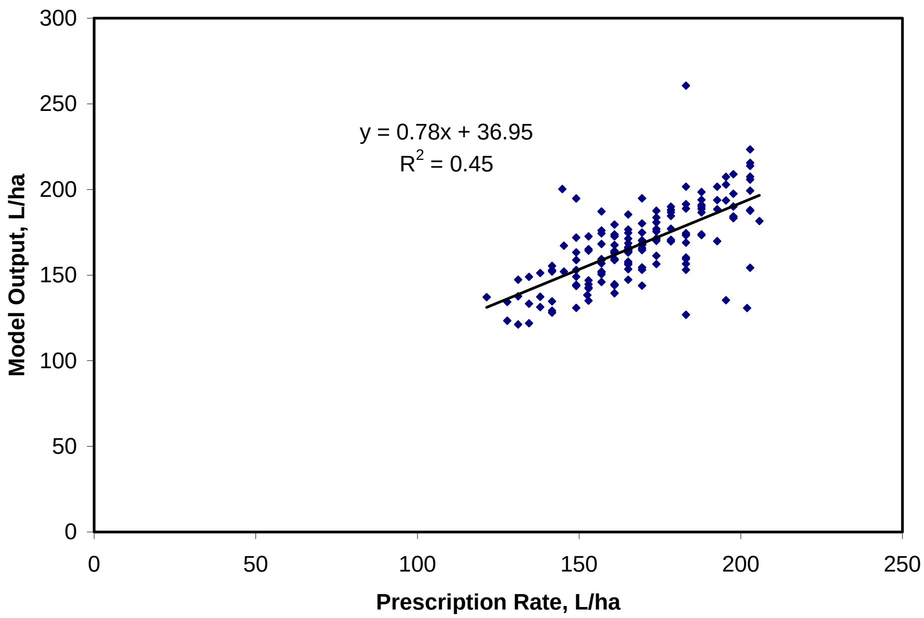

Figure 4. Predicted application rate from the model output plotted as a function of the prescription rate for pass 1.

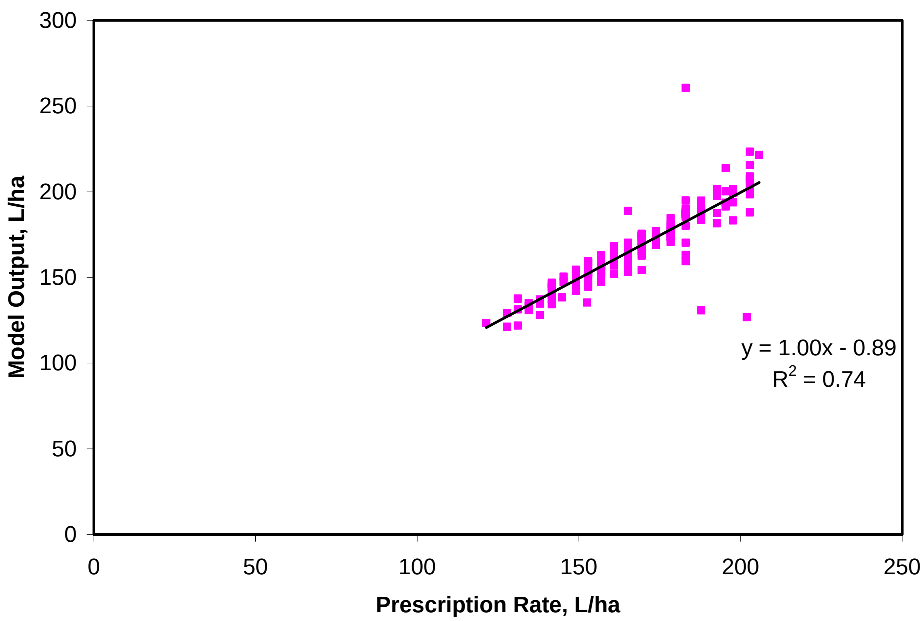

Figure 5. Predicted application rate from the model output with a 1 second lag plotted as a function of the prescription rate for pass 1.

Table 2 shows the r-squared vales from linear regression of model output application rate as a function of prescription rate as well as the equation slope and the mean absolute application error. These results are shown for the actual model output and the model output lagged by 1 second. Ideally the slope would be 1.0, but it is less than 1.0 for all passes when data are not lagged. However, lagging the data by 1 second improves the r-squared value and results in slopes closer to 1.0. The mean absolute error was determined by taking the absolute difference of the prescribed application rate and the predicted application rate from the model. These values are less than 10 percent of the mean rates shown in table 1. However, the mean absolute errors from the 1 second lag data are generally half of those without a time lag. The data in table 1 indicate that reducing the delay in the sprayer control system by 1 second would improve the ability to achieve the desired application rate.

Table 2. Coefficient of determination and slope results from regressing model output as a function of prescribed rate with 0 and 1 second lags along with the mean absolute application errors.

pass	0 sec lag			1 sec lag		
	r^2	slope	Mean abs error, L ha^{-1}	r^2	slope	Mean abs error, L ha^{-1}
1	0.45	0.78	11.6	0.74	1.00	6.0
2	0.45	0.76	11.5	0.87	1.04	4.8
3	0.35	0.67	12.8	0.84	1.03	6.1
4	0.35	0.67	14.7	0.84	1.04	7.0
5	0.67	0.87	11.6	0.93	1.02	5.1
6	0.62	0.85	11.5	0.93	1.04	5.1
7	0.26	0.61	14.7	0.85	1.11	6.9
8	0.24	0.58	18.6	0.83	1.08	11.2

CONCLUSIONS

A Raven SCS 440 controller was modeled as a simple proportional integral controller. A fast close valve was approximated by a first order plus time delay transfer function. This system was simulated and used to predict the response of a sensor based fertilizer applicator. The modeled results showed a mean absolute application error of 12.9 L ha^{-1}. These results further indicate that the predicted response lagged the prescribed rate by approximately 1 second. This resulting misapplication could be reduced by half if the controller delay was reduced by 1 second.

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