CONTROL SYSTEM APPLIED TO NO-TILL SEEDING FOR HIGH-QUALITY OPERATION

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ABSTRACT

A high quality crop seeding operation should enable a rapid and uniform establishment of a desired plant population. Therefore, a no-till seeder must provide a seeding environment that allows the absorption of water by seeds and appropriate temperature and aeration conditions for germination and emergence processes. To stimulate these processes, the seed needs full contact with soil in order to accelerate the absorption of water and oxygen. Covering the furrow with straw is another important aspect, since it prevents soil water losses and surface crusting besides reducing soil thermal amplitude and seedlings stress. Soil contact no-till seeder components are responsible for the accomplishment of this overall function, which depends on correct setting of each individual component for residue cutting, furrow opening, distribution of fertilizer and seeds, furrow closing with soil and straw (grounding) and soil compaction laterally or over the seed. However, the setup and consequently the performance of these components is directly influenced by soil water content, compaction state and particle size of topsoil as well as the amount of straw over soil surface. These factors present a remarkable spatial variability and determine, for the same field, different operational conditions for grounding and compaction components of the seeder. Using of control systems at variable rates with electronic maps is not the best option to solve this problem because the required previous analysis of soil parameters is a time consuming and expensive activity and usually is physical and economically unfeasible. Thus, the quality of no-till seeding can be improved by the development of a real-time control system, operating on-the-go, and controlling the operational parameters of the grounding and compaction components based on information generated by a sensing system of soil conditions. The real-time control system discussed in this paper employs a set of transducers for measurement of soil and operational parameters and based on this information and on computational models estimates the main soil conditions and acts on the components of grounding and compaction in order to get a high seeding quality. The logic of the control system and its functional and non-functional specifications were defined from literature and analysis of field experiments at the Agricultural Research Institute of Paraná State (IAPAR), Brazil, between 2011 and 2012. The system will perform the control, in real time, of two no-till seeder components, i.e. the angle of a pair of grounding discs and the compression of a spring of compaction wheels. The control algorithm employs the autoregressive error function (AREF), a neural network and two arrays. The AREF and the neural network estimate soil moisture from time series of forces acting on a narrow tine and from operation speed. The soil moisture and depth of operation data are the inputs to an algorithm which determines the operational parameters of the grounding and compaction components using two arrays. The neural network with better performance was a Multi-Layer Perceptron type, 2-6-1, with sigmoid activation functions. The AREF uses the time series of forces on the narrow tine with a sample rate of 100 Hz, computing the last 3 m (118 in) readings from sampling position. The control system is under development and will consist of four sensors: a pair of load cells that measure horizontal and vertical forces acting on the tine; a radar that measures the tool operation speed and a laser distance sensor that measures the tool operation depth. The processing will be performed by an ARM microcontroller under a Linux operational platform. Two linear actuators with servo-motors will control the seeder components adjusting the working angle of a pair of grounding discs and the working pressure of the furrow compaction wheel.

Keywords: precision agriculture, autoregressive error function, time series

INTRODUCTION

Maize is the world's third largest commodity and U.S., China and Brazil are the largest producers with more than 800 million tons produced in 2012 (FAO, 2012). Brazilian maize production is mainly under conservation tillage, which reduces soil erosion and provides better conditions for establishment and growth of crops.

Maize seeding quality is very important because the plant does not have ability to compensate spacing failures between plants resulting from problems during no-till seeding. Moreover, the plants emergence must occur simultaneously to ensure good harvest conditions and yield.

A low seeding quality results in seeds that do not emerge or do this unevenly resulting important yield losses.

The seeding of crops with high quality should provide rapid and uniform establishment of desired plant population and constitutes an important step in maize production process. Thus, the seeding environment created by the seeder should allow water absorption by seeds and appropriate conditions of temperature and aeration for the processes of germination and emergence (Muzilli, 2006). For this occurs quickly, the seed requires full contact with the soil in order to accelerate water and oxygen absorption. The furrow cover with straw is another important aspect under tropical conditions. It prevents soil water losses and soil surface crusting besides reducing soil thermal amplitude and seedlings stress (Casão Junior and Siqueira, 2006).

The soil contact components from no-till seeders are responsible for these functions, which depend on the correct adjustment of the components of covering, cutting, furrow opening, distribution of fertilizer and seeds, closing the furrow with soil and straw (grounding) and soil compaction. However, the adjustment and, consequently, the performance of these components is directly influenced by the soil water content, compaction state and the particle size of the topsoil as well as the amount of straw over the surface. These factors have a marked spatial variability and determine, for the same area, different operational conditions of the seeder components. The solution of this problem with the use of control systems and digital maps in variable rate is a time consuming and expensive option, since it requires intensive fieldwork.

Thus, seeding quality can be improved by the development of a control system in real time (on the go), acting on the operational parameters of the grounding and compaction components of a no-till seeder, using information generated by a soil sensing system.

The purpose is to employ a set of transducers for measuring soil and operational parameters and, based on this information and on computational models, estimate in real time the soil conditions and act on the components of soil grounding and soil compression aiming to get a high quality seeding.

MATERIAL AND METHODS

The project was organized into 4 main phases described below:

1. Definition and validation of soil-tool interaction model

A literature review was performed focusing on existing mathematical models which describe soil behavior in terms of its mobilization provided by a soil tillage tool, forces involved and energy required. The analysis of these papers show that a stochastic approach and a time series forces analysis was more appropriate.

It was employed the autoregressive error function (AREF) employed in the work of (Sakai et al., 2005) which quantifies the complexity of the patterns of force, producing two output parameters that can be related to the soil physical condition. To relate the coefficients from AREF with soil conditions we chose to use artificial neural networks.

The validation of using the AREF together with ANNs was assessed using data obtained from two experiments conducted at the experimental field of Agricultural Research Institute of Paraná State (IAPAR), on clay soil. In these experiments it was used a specific device, (Figure 1) similar to an incomplete no-till seeding row, equipped with a straw cutting disc and an instrumented narrow tine with three shear beam type load cells, class C3, from HBM, two for measuring the horizontal draft force and one for measuring the vertical force.

The experimental design was a complete randomized block design with 3 replications and 8 treatments. The treatments were two moisture conditions (dry and wet), two levels of compaction (no-till with and without additional soil compression represented by two tractor passes with approximately 35 kN) and two operation speeds (0.83 and 1.7 $m.s^{-1}$). The data were collected at 100Hz rate using a Somat eDAClite datalogger, equipped with a GPS Gramin 5Hz for speed measurement and a laser barrier to record points with additional information in the field. In these points it was measured soil moisture and density, penetration resistance and soil mobilization. The calculation of AREF coefficients were performed using force data 3m prior from the additional information points.

The validation was performed using two error metrics, the determination coefficient (R) and the root mean square error (RMSE).

2. Development of control logic

A preliminary data analysis of the experiments it was observed that soil moisture and tine operation depth were the most relevant parameters to determine the adjustments of grounding components, i.e., the angle of covering discs and pressure in the compaction wheel.

Soil moisture and tine depth were related to the adjustments by two tables (arrays) generated from experimental and theoretical data.

Thus, the control logic combines the AREF + RNAs model, developed in the previous phase, with three-dimensional arrays so as to obtain the operational parameters, which are the working angle of a pair of covering discs and the compaction wheels pressure.

Figure 2 illustrates the control logic design.

Fig. 1. The specific device used in experiments conducted at IAPAR.

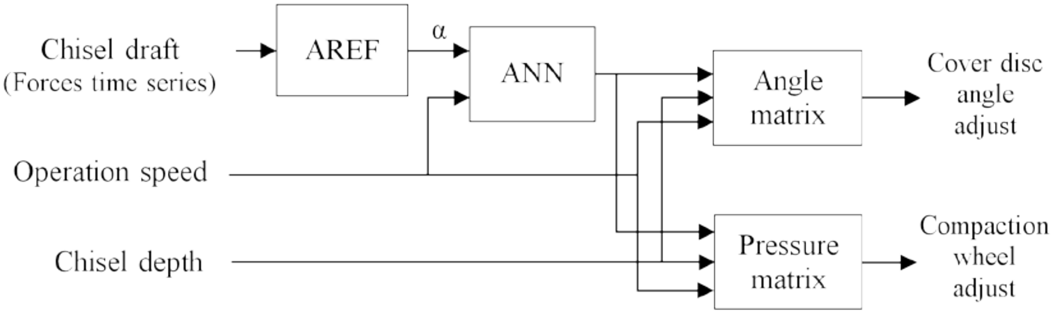

Fig. 2. Data flow for the control algorithm.

3. Requirements of soil, straw and soil compaction pressure for no-till high quality seeding

To determine the values that will compose the three-dimensional matrices described in previous phase, will be evaluated the requirements of soil pressure and amounts of soil and straw on seeds of corn and soybeans for rapid and uniform germination and seedling emergence. For this purpose, laboratory experiments will be carried varying levels of soil and straw and pressure on the seeds in different textures and levels of soil moisture.

4. Development of the real-time embedded control system

The control system will consist of tree measurement systems:

- A pair of load cells for measurement of horizontal and vertical forces acting on the tine. The signals from these cells will be read by a specific A/D converter;
- A radar for measuring operational speed;
- A laser distance sensor, which measures the tine operation depth.

The processing will be carried out by an ARM Cortex microcontroller running a Linux operational system. The control application and the software drives of interfaces and devices will be written in C++ language, using the gcc compiler. The control algorithm receives the input signals at 100Hz sample rate, and will process the output parameters at 2 Hz sample rate.

The components control will be made by 2 linear actuators equipped with servo-drivers. An actuator will adjust the working angle of a pair of covering discs, while the other shift the spring pressure setting over the compactor wheel.

Figure 3 illustrates how the control system will work.

RESULTS

The data from the two experiments were analyzed using four statistical approaches: analysis of variance, including the F and Tukey test for all measurement parameters; analysis of correlation matrices, hierarchical cluster analysis and a principal component analysis.

It was observed strong influence of soil moisture on soil behavior, dividing the data into two groups, one for the dry soil condition and another for moist soil condition.

The working depth showed high correlation with the mobilized soil area, compared with the other parameters (0.62), demonstrating a strong interaction between them. The soil mobilization area also correlated with parameters of moisture (0.20) and density (0.15).

It was observed that the angle between Fx and Fy was influenced by soil moisture (correlation of 0.40) and traffic condition, higher in wet soils and less in trafficked soils. It also showed correlation with the AREF coefficients (0.31 and 0.29 with α and β).

The coefficients of AREF, in particular α, showed less variability when compared with other parameters from the experiments. These coefficients correlated well with average values of the tine force components (0.61 between α and Fx, and 0.17 between α and Fy, 0.24 between β and Fx and 0.26 between β and Fy) and correlation with the penetration resistance indices until a depth of 10 cm (0.43 on average), same working depth of the tine.

The operating speed has a strong influence on the parameters of AREF function, with correlations of 0.82 and 0.65 with α and β, and also influenced the average horizontal force on the tine, with a correlation of 0.23.

The results from analyzes concluded until now agree with the results of (Mckyes and Ali, 1977) and (Liu et al., 2008), as well as assisted in defining the parameters of the model proposed by this study.

Analysis of these data demonstrated the feasibility of combining AREF + RNA for predicting soil moisture from the forces acting on tine. A neural network with best performance was a Multilayer Perceptron type, with 2-6-1 neurons and sigmoid activation functions, getting a validation performance with RMSE = 0.017 and R = 0.89.

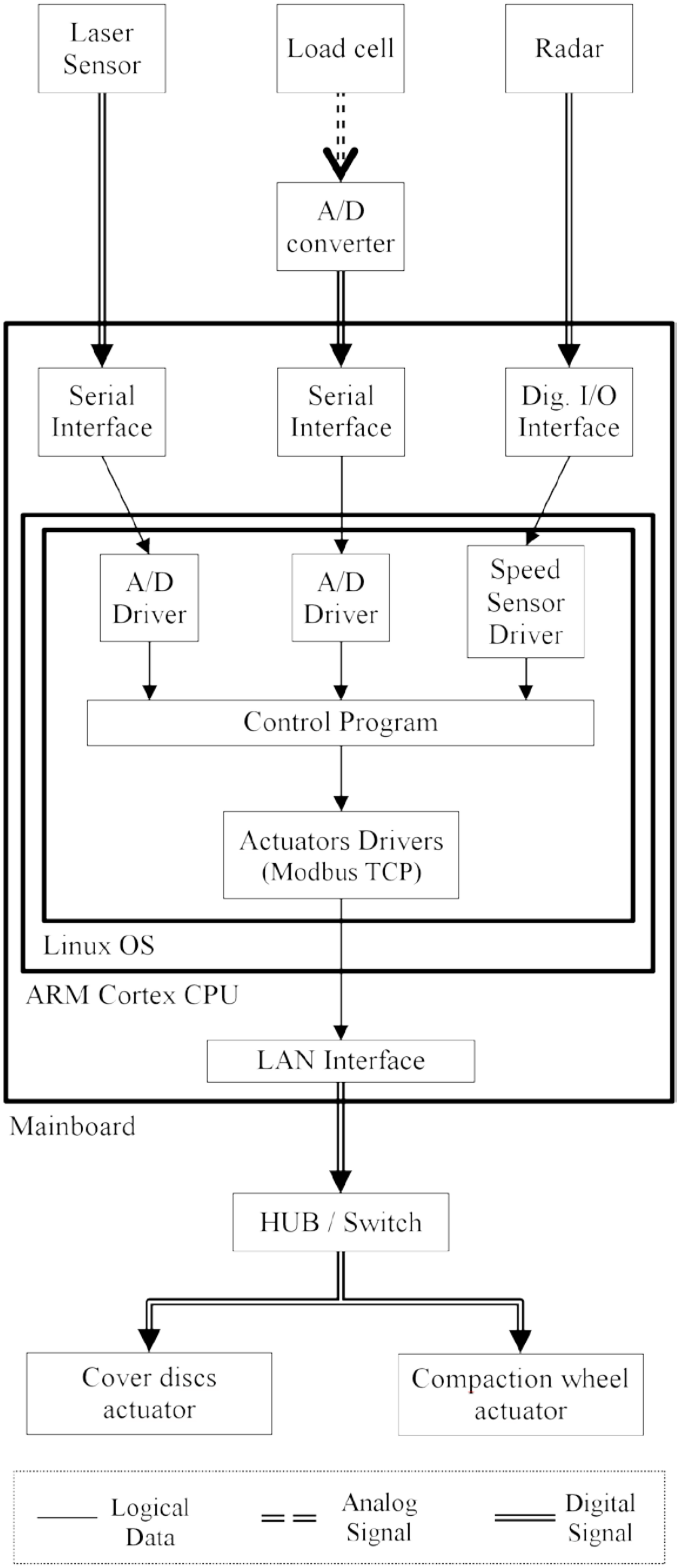

Fig. 3. Scheme of signal and data flow inside the control system.

Until now it was conducted two experiments, of the phase 3, to check the requirements of soil, straw and pressure in way to determine the values for the arrays that will compose the control logic. However, these experiments did not obtain consistent results. It is expected that further analysis of the results from the two experiments of phase 1, conducted at IAPAR experimental field, as well as data from new experiments for the same phase, that are being conducted now for the conditions of clay and sandy soil, will be able to obtain information that together with the two experiments conducted in the phase 3, allows to define the values that make up the arrays used by the control logic.

CONCLUSIONS

The combination AREF + RNA for predicting soil moisture from the forces acting on tine is a valid modeling process that can be used in the control system algorithm.

The control algorithm, using the combination of AREF + RNA with two arrays for adjustment of covering discs and compaction wheel operation will require complementary analysis including new experimental field data.

The hardware platform chosen is widely used in many other applications and the use of free software for control system developing reduces costs. Thus, the system becomes more affordable.

The control system is still under development therefore new tests in laboratory and field to assess their performance are required.

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REFERENCES

Casão Junior, R.; Siqueira, R. 2006. Máquinas para manejo de vegetações e semeadura em plantio direto. p. 85-126. *In* Sistema de Plantio Direto com Qualidade, ITAIPU - Binacional, Foz do Iguaçu.

FAO – Food and Agriculture Organization of the United Nations. 2012. FAOSTAT Crops Production Database: 2012. http://faostat3.fao.org/faostat-gateway/go/to/browse/Q/QC/E, (accessed 28 Apr. 2014).

Liu, J. et al. 2008. Steady-state models for the movement of de soil and straw during tillage with a single sweep. Transactions of ASABE, v. 51, n. 3, p. 781-789.

Mckyes, E.; Ali, O. S. 1977. The cutting of soil by narrow blades. Journal of Terramechanics, v. 14, n. 2, p. 43-58.

Muzilli, O. 2006. Manejo do solo em sistema de plantio direto. p. 9-27. *In* Sistema de Plantio Direto com Qualidade. ITAIPU - Binacional, Foz do Iguaçú.

Sakai, K.; Andrade-Sanches, P.; Upadhyaya, S. K. 2005. Periodicity and stochastic hierarchical orders of soil cutting force data detected by an "auto-regressive error distribution function" (AREF). Transactions of the ASAE, v. 48, n. 6, p. 2039-2046.