Smart Tractor Approach to Variable Rate Technology

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Background

• One of the main objectives of smart farming is to optimize crop production and reduce the environmental footprint by using new digital technologies
• In comparison to the wide-spread use of global navigation satellite system (GNSS) based guidance of field machinery and yield monitors, the adoption of variable rate technology has been somewhat limited and has yielded mixed results

Problem Definition

• Lack of robust decision support mechanisms has been a major limitation when it comes to varying fertilization and seeding rates according to local needs
• The capital costs involved in this technology prevented a number of small and medium farmers from adopting its use
• Many producers understand the need for non-uniform field treatments
• Many farmers can identify distinct field areas where uniform application rates would not be optimal due to the limited, or excessive, crop productivity potential

Objectives

• To equip farmers with a technology that would match tractor operation parameters with local conditions according to the rules established by the operator
• The tractor will recognize the operator-defined conditions using internal or external sensors and it will replicate appropriate operation settings across the field when conditions are similar

Prioritization of Variable-Rate Field Operations

Tillage depth
Seeding depth
Liquid nitrogen in-season fertilization
Liquid manure rate
Solid manure rate
Granular fertilization
Herbicide rate
Liming
Hybrid trials
Seeding rate
Mechanical weeding
Forage harvesting

Importance to the growers
The Concept of JD ASC

Internal Sensors
- Tractor CAN messages
- StarFire receiver

External Sensors
- Specialized low-cost options
- On-site soil moisture sensor
- Ultrasonic crop sensors
- Commercial high-end products
- Crop reflectance sensor

Map Interpreter

ITEC Controller

Prescription Map
- Shape file
- ISXML file

ISOBUS Implementation

Sensor 2
Termination
Implement ECU
IBBC
Implement Bus
TECU
SCV (1-6)
Hitch
Vehicle
Speed
Drive-strategy
Steering
Tractor Bus
Diff Lock
MFWD
PTO
iTEC
VI app
GPS
VT
Sensor 1

Principle of ZOG Algorithm

Sensor 1
Sensor 2
Sensor Data
Travel path

Field

Single-Input Algorithms

Implemented in 2012

Implemented in 2013

Proposed Single-Input Algorithm

Initial Settings
Set A
Set B
Complete Settings

Sensor Input (Elevation)
Control Output (Speed)

Sensor Input (Elevation)
Control Output (Speed)

Sensor Input (Elevation)
Control Output (Speed)

Targeted Applications

- Variable rate liquid manure management according to landscape positioning
- Variable depth planting according to surface soil water content
- Variable speed of operation while harvesting a forage crop according to biomass
- Variable rate herbicide management according to the degree of weed pollution
Variable-Rate Manure Management

Allowed environmentally safe discharge of additional 30% (156 m³) of liquid cattle manure in this 11.1-ha alfalfa field.

Elevation-Based Tractor Speed Control

ZOG log data image

External travel speed log (filtered data)

Variable-Depth Planting

Depth control leverage

Linear actuator

Automation of two out of four planting units

Fixed depth Soil moisture sensors

Soil Moisture Sensor

Capacitance probe

y = -0.08x + 0.45
R² = 0.98

y = -0.07x + 0.35
R² = 0.91

SE < 2.5%

Simulation Study Fields

Nebraska
Iowa
Kansas
South Dakota
Colorado
Minnesota
Missouri
Worming

Simulation Study Fields

North Dakota
South Dakota
Montana
Wyoming

Simulation Study Fields

North Dakota
South Dakota
Montana
Wyoming
**Scaling Methods**

- **Standardization**
  \[ e_{v} = \frac{E_{C_{x}} - \text{average}(E_{C_{x}}, E_{C_{y}})}{\text{std}(E_{C_{x}}, E_{C_{y}})} \]

- **Scaling**
  \[ e_{v} = \frac{E_{C_{x}} - \text{max}(E_{C_{x}}, E_{C_{y}})}{\text{max}(E_{C_{x}}, E_{C_{y}}) - \text{min}(E_{C_{x}}, E_{C_{y}})} \]

- **Normalization**
  \[ e_{v} = \frac{E_{C_{x}}}{\text{median}(E_{C_{x}}, E_{C_{y}})} \]

- **Quartile scaling**
  \[ e_{v} = 0.25 + \frac{E_{C_{x}} - \text{quartile}(E_{C_{x}}, E_{C_{y}})}{\sum (\text{quartile}(E_{C_{x}}, E_{C_{y}}) - \text{quartile}(E_{C_{x}}, E_{C_{y}}))} \]

- **First pass scaling**
  \[ e_{v} = \text{rand}(E_{C_{y}}) = \frac{E_{C_{x}} - \text{E}_{C_{max}}}{\text{E}_{C_{max}} - \text{E}_{C_{min}}} \times \text{rand}(E_{C_{y}}) - \text{rand}(E_{C_{y}}) \]

**Absolute Error Series Example**

**Simulation Study Summary**

<table>
<thead>
<tr>
<th>Field ID</th>
<th>Standardization</th>
<th>Scaling</th>
<th>Normalization</th>
<th>Quartile scaling</th>
<th>First pass scaling</th>
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</thead>
<tbody>
<tr>
<td>BR - forward</td>
<td>0.22</td>
<td>0.53</td>
<td>0.19</td>
<td>0.28</td>
<td>0.20</td>
</tr>
<tr>
<td>BR - backward</td>
<td>0.31</td>
<td>0.48</td>
<td>0.31</td>
<td>0.53</td>
<td>0.28</td>
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<tr>
<td>RA - forward</td>
<td>0.16</td>
<td>0.15</td>
<td>0.12</td>
<td>0.13</td>
<td>0.09</td>
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<tr>
<td>RA - backward</td>
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<td>0.72</td>
<td>0.15</td>
<td>0.24</td>
<td>0.10</td>
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<tr>
<td>KR - forward</td>
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<td>0.58</td>
<td>0.25</td>
<td>0.25</td>
<td>0.54</td>
</tr>
<tr>
<td>KR - backward</td>
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<td>0.59</td>
<td>0.22</td>
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<tr>
<td>LU - forward</td>
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<td>0.15</td>
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<td>HU - forward</td>
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<td>0.04</td>
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<td>0.38</td>
<td>0.17</td>
<td>0.23</td>
<td>0.12</td>
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<tr>
<td>HE - forward</td>
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<td>1.53</td>
<td>0.25</td>
<td>0.28</td>
<td>0.09</td>
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<tr>
<td>HE - backward</td>
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<td>1.74</td>
<td>0.13</td>
<td>0.13</td>
<td>0.04</td>
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<td>Average</td>
<td>0.22</td>
<td>0.62</td>
<td>0.24</td>
<td>0.28</td>
<td>0.14</td>
</tr>
</tbody>
</table>

**Summary**

- Medium-size farm operators frequently resist adopting variable rate technology due to the cost of the equipment and the extra time required to learn the new technologies.
- Many operators intuitively understand the need for differentiating their operations within a field in accordance with local needs.
- Some operators have implemented what can be classified as VRT using manual control.
- What can be called a “smart tractor” concept will enable farmers to implement their intuitive practices in a more replicable and ergonomic way.
- A combination of real-time sensor-based and map-based operations will add versatility.
- The concept is similar to the principles of auto-guidance and will remove the gap between the use of traditional machinery and farming machinery equipped with high-end controllers and actuators.

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