

2013 ASABE Annual International Meeting
Kansas City, Missouri

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

Precision Agriculture Technologies Adoption

Yield monitor adoption (U.S., by crop), 1998-2009
50%

Guidance system adoption (U.S., by crop), 1998-2009
40%

Variable rate technology adoption (U.S., by crop), 1998-2009
16%

Source: Agricultural Resource Management Survey (ARMS), ERS/USDA

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

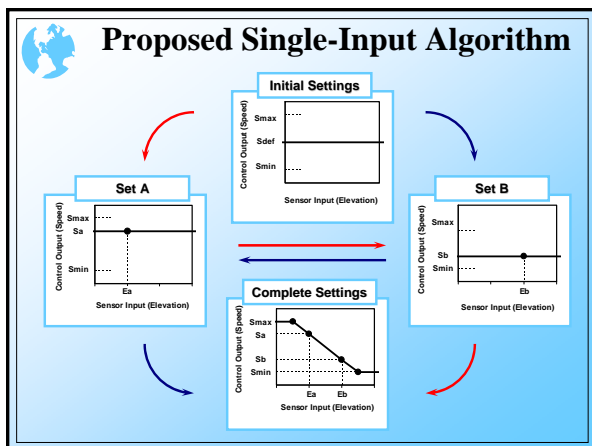
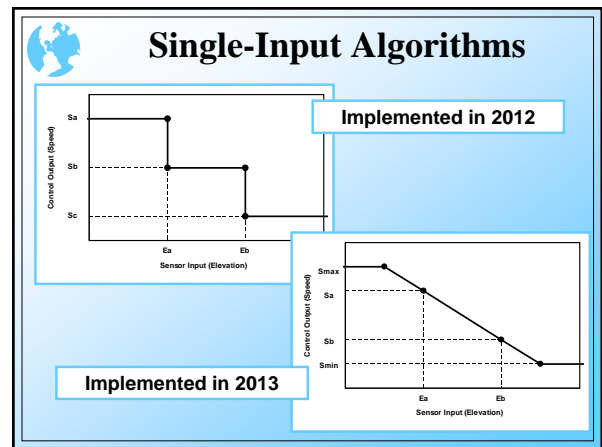
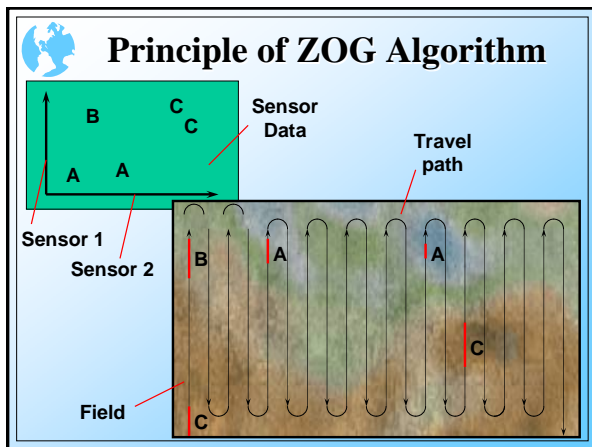
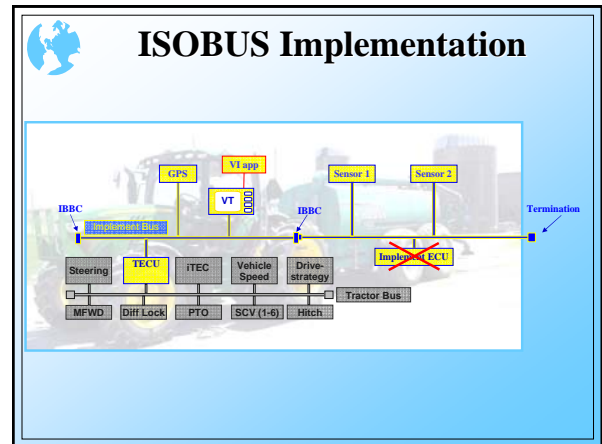
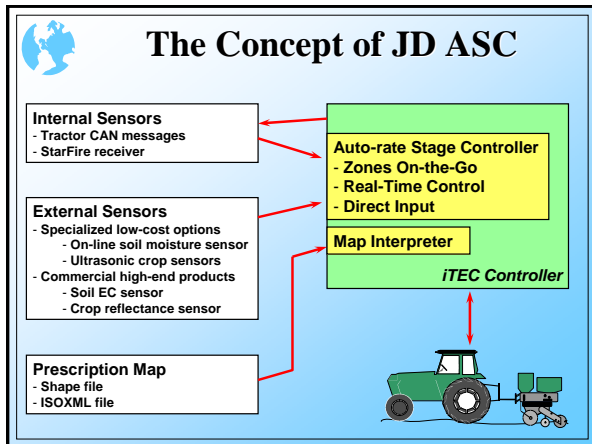
Objectives

- 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

Complexity of a potential solution

Importance to the growers



- ## 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% (150 m³) of liquid cattle manure in this 11.1-ha alfalfa field

The image shows a green manure spreader in a field. Below it is a map of the 11.1-ha alfalfa field with a color-coded legend for manure application rates. The legend indicates:

- Actual Application: Low Rate (Red), High Rate (Blue)
- Desired Application: Low Rate (Red), High Rate (Blue)

Elevation-Based Tractor Speed Control

ZOG log data image

External travel speed log (filtered data)

The image displays two maps of a field. The top map is a 'ZOG log data image' showing colored lines representing data points. The bottom map is an 'External travel speed log (filtered data)' showing a similar map with a different color scheme and data representation.

Elevation-Based Tractor Speed Control

The graph shows 'Travel speed, m/s' on the y-axis (0.0 to 2.0) and 'Time, s' on the x-axis (0 to 5000). The speed fluctuates between approximately 0.8 and 1.8 m/s. Red arrows point to three regions labeled 'Low elevation', 'Medium elevation', and 'High elevation'. Below the graph are three photos: a green tractor, a close-up of a sensor, and a tractor in a field with a sensor on a tripod.

Variable-Depth Planting

Depth control leverage

Linear actuator

Automation of two out of four planting units

Fixed depth Soil moisture sensors

The image shows a tractor with planting units. A diagram on the right illustrates the 'Depth control leverage' mechanism, which includes a 'Linear actuator' and 'Fixed depth Soil moisture sensors'. A label 'Automation of two out of four planting units' points to the relevant components.

Soil Moisture Sensor

Capacitance probe

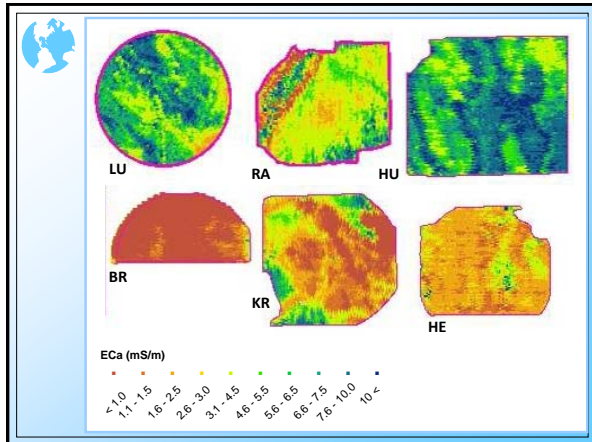
The image shows a 'Capacitance probe' used for soil moisture measurement. Below it is a graph of 'gW/C, g/g' on the y-axis (0.00 to 0.40) and 'Sensor Index' on the x-axis (0 to 5). Two data series are shown:

- Loamy soil (blue circles): $y = -0.07x + 0.35$, $R^2 = 0.91$
- Sandy soil (red squares): $y = -0.08x + 0.45$, $R^2 = 0.98$

 The standard error is noted as $SE < 2.5\%$.

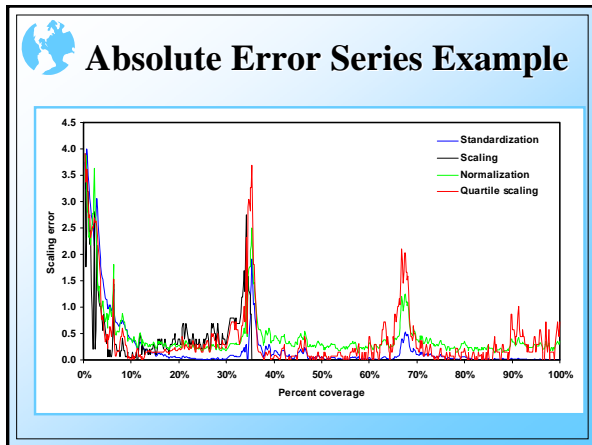
Simulation Study Fields

The image shows a map of the United States with several states highlighted: South Dakota, Minnesota, Iowa, Nebraska, Kansas, Colorado, and Missouri. Specific study fields are marked with yellow outlines and labeled: LU, RA, HU, BR, HE, and KR.



Scaling Methods

- Standardization** $ec_i = \frac{EC_i - \text{average}(EC_i : EC_i)}{\text{stdev}(EC_i : EC_i)}$
- Scaling** $ec_i = \frac{EC_i - \min(EC_i : EC_i)}{\max(EC_i : EC_i) - \min(EC_i : EC_i)}$
- Normalization** $ec_i = \frac{EC_i}{\text{median}(EC_i : EC_i)}$
- Quartile scaling** $ec_i = 0.25 + \frac{EC_i - \text{quartile}(EC_i : EC_i, 1)}{2 \cdot (\text{quartile}(EC_i : EC_i, 3) - \text{quartile}(EC_i : EC_i, 1))}$
- First pass scaling** $ec_i = \text{rank}(EC_A) + \frac{EC_i - EC_A}{EC_B - EC_A} (\text{rank}(EC_B) - \text{rank}(EC_A))$



Simulation Study Summary

Field ID	RMSE/SD for the entire field				
	Standardization	Scaling	Normalization	Quartile scaling	First pass scaling
BR - forward	0.22	0.53	0.19	0.28	0.20
BR - backward	0.31	0.48	0.31	0.53	0.28
RA - forward	0.16	0.15	0.12	0.13	0.09
RA - backward	0.21	0.72	0.15	0.24	0.10
KR - forward	0.22	0.58	0.25	0.25	0.54
KR - backward	0.17	0.59	0.22	0.20	0.12
LU - forward	0.18	0.15	0.30	0.24	0.02
LU - backward	0.32	0.12	0.34	0.40	0.06
HU - forward	0.37	0.46	0.49	0.40	0.04
HU - backward	0.22	0.38	0.17	0.23	0.12
HE - forward	0.16	1.53	0.25	0.28	0.09
HE - backward	0.14	1.74	0.13	0.13	0.04
Average	0.22	0.62	0.24	0.28	0.14

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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