Automation in Crop Production
- State-of-the-art und where to we go from here?

Hermann Auernhammer
Freising-Weihenstephan
Germany

18th World Congress of CIGR
Section III Keynote
2014 Sep 16
Beijing
China
Don’t forget

Anybody, who is unfamiliar with the history, is damned to repeat it!

Georg Santayana: The Life of Reason, 1905

And don’t forget, there are about 30 million of tractors in use worldwide compared with a very small number of self propelled harvesters, sprayers and spreaders (may be a total of 1.5 Mio.)!

Herrmann 2001, DLM Hohenheim (Germany)
1. A very true saying from yesterday and figures of today

2. Automation from yesterday
   • Draft control
   • Auto guidance
   • Continuous variable transmissions

3. Automation, state-of-the-art
   • Availability
   • Main influences
   • Reasons for tomorrow

4. Automation tomorrow
   • Tractor
   • Self-propelled technology only
   • Tractor implement combinations

5. Conclusions
The idea of Harry Ferguson – Draft Control

The Black Tractor

After Harry Ferguson had invented the 3 point linkage he needed a lightweight tractor to demonstrate its advantages. It became clear to him that the only way forward lay in building a prototype tractor incorporating his own inventions which could ultimately be built cheaply and be useful on the smallest farms as well as the largest.

As the design progressed Ferguson insisted that it should be painted black, probably because of his own liking for functional simplicity. The Black Tractor was completed in 1925 and immediately put to test and became the fore-runner of all modern day tractors with its 3 point linkage and hydraulics, weight transference and automatic depth control.

More than any other single development, this invention revolutionised the use of the farm tractor, and nearly all subsequent designs have incorporated its design principles. In particular the Black Tractor was the fore-runner of the TE20, lovingly known as the "Fergie", a descendant that became a common sight on farms all over Britain and the world in the 1940s and early 1950s.
Gigantic simple, as...

... the upper link engages the actuator (no additional equipment)
... the actuator is an internal part of the tractor
... it guarantees 100% of reliability
... it enables slip reduction
... it enables light weight construction
... handling is simple

But (keep in mind) there is...
... diverse working depth
... getting stuck at abrupt change in soil type (mainly with rubber tires)

Probably the most famous tractor in the world "The Black Tractor" - currently housed at the Science Museum in London. Now, through the use of innovative technology, a high specification 3D image of the Black Tractor is now available.

This tractor, built by Harry Ferguson himself has been brought to life with stunning imagery giving the opportunity to see it from all angles and great detail.

Click and drag picture to rotate.
“Sensing wheel(s) measure the depth of the plough and transfer control signals to the control unit. Small unevenness is neglected. Plough is permanently carried by the hydraulics. Weight transfer to tractor rear axle is well (e.g. Hanomag).”

Brenner, 1963

An idea 30 years later – equal working depth

- Similar working depth with constant hydraulic pressure
- Useable for different implements with the need of constant surface distance
- Handling trivial

- Sensor is an additional implement element (sensing wheel)
- Control unit (actuator) is an additional tractor element
- Manufacturer specific solution
- Missing standard prevent wider use on farm level
- No beneficial agronomic proof of constant working depth
Robotic Plough (Eicher 1964)

- Simple field preparation (lateral furrow) with no headland
- Able to work 24 hours/day (with 1-body similar to a 3-body tractor plough)
- Build from existing serial production parts (engine, axle, gearbox, plough)

Agrirobot, a one-body autonomous plough with mechanical control. Driving direction was changed at field end after passing with the “switch wheel” across a previously established lateral furrow.

Source: Grundl. Landtechnik 18 (1968) 17
Row guidance – Self propelled harvesters

- Company specific control integration (independent from competitors)
- High accuracy with increased productivity
- No additional infrastructure required
- Handling trivial by steering wheel activation
- Simple manual over-steering
- Retrofitting possible

- Stabile field conditions for automation required (walking-stick-like rows/plants or clean edges)
Variable rate application (VAR) – Fertilizer and pest control

- Procedure follows the well-known manual control (creates best conditions for acceptance)
- Reacts on in-field variability
- Allows high control quality even with less-/no-trained laborers

- Expensive sensor technology
- Specific non-standardized integration to the used spreaders/sprayers
- Shortage of well adopted control algorithms related to crops and varieties
- Lack in the integration of additional data sources (field history, soil, weather, previous treatments, … )
Continuous variable transmissions (CVT) – Tractors

- Adjustable to any needed implement speed by
  1. Lowest fuel consumption
  2. Max. engine power
  3. Any or rated/max. engine speed
  4. Rated pto speed
  5. Max. torque

- Driver comfort (less work load) by pre-programmed (finger-tip) driving strategies

- Still higher investment costs
- Still lower rate of efficiency related to stepped transmissions

http://mediatum.ub.tum.de/?id=731564
GNSS guidance – Tractors and self propelled harvesters

Steering assist

- Company specific control integration (independent from competitors)
- High accuracy with increased productivity (reduced working time, no overlapping)
- Handling trivial (comfort)
- Simple manual over-steering
- Retrofitting possible
- Extension to headland management possible

Automatic Guidance

- Additional infrastructure required (but worldwide available for free in the future too with increasing accuracy)
- A-B line adjustment or route planning required
- In tractor implement combinations tractor guidance accuracy only

Source: Grundl. Landtechnik 18 (1968) 17
<table>
<thead>
<tr>
<th>Control criteria</th>
<th>Tractor</th>
<th>Implement</th>
<th>Self-propelled machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Draft control</strong></td>
<td>Manufacturer specific sensors, actuator+s, control units, standardized three-point-linkage</td>
<td>Standardized three-point-linkage</td>
<td></td>
</tr>
<tr>
<td><strong>Drive line management</strong></td>
<td>CVT automation through engine management,</td>
<td>pTIM stop-and-go pTIM speed control</td>
<td>Header control Cruise control</td>
</tr>
<tr>
<td></td>
<td>- velocity management</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Guidance</strong></td>
<td>A-B-guidance Map-guidance</td>
<td>Track-guidance of towed sprayer vehicles, spreader vehicles</td>
<td>Row-guidance A-B-guidance Map-guidance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Headland management</strong></td>
<td>PTO on/off Lift control &amp; adjustment, A-B adjustment</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Variable-Rate-Control</strong></td>
<td></td>
<td>Map-based-control with ISOBUS UT and ISOBUS TC</td>
<td>Map-based control (ISOBUS like)</td>
</tr>
<tr>
<td><strong>Loading/Unloading</strong></td>
<td></td>
<td></td>
<td>Filling adjustment</td>
</tr>
<tr>
<td><strong>Documentation</strong></td>
<td>ISOBUS TC tractor internal data acquisition, processing and transfer</td>
<td>ISOBUS data acquisition and processing</td>
<td>Proprietary data acquisition, processing and transfer (ISOBUS like)</td>
</tr>
</tbody>
</table>
Where do we go from here?*

A challenging question as it means:

• What's now?
• What would/could/should be?
• What might be?

The only clear thing:

• Nothing is clear
  or
• No answer at all!

But “why”...
## Automation – at Field-level since ? Years (rough estimations)

<table>
<thead>
<tr>
<th>Control criteria</th>
<th>Tractor</th>
<th>Implement</th>
<th>Self-propelled machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Draft control</strong></td>
<td>Manufacturer specific sensors, actuator, control units, standardized 3-point-linkage</td>
<td>Standardized three-point-linkage</td>
<td></td>
</tr>
<tr>
<td><strong>Drive line management</strong></td>
<td>CVT automation through - engine management - velocity management</td>
<td>pTIM stop and go pTIM speed control</td>
<td>Header control Cruise control</td>
</tr>
<tr>
<td><strong>Guidance</strong></td>
<td>A-B-guidance, Map-guidance</td>
<td>Track-guidance of towed - sprayer vehicles - spreader vehicles</td>
<td>Row-guidance A-B-guidance Map-guidance</td>
</tr>
<tr>
<td><strong>Headland management</strong></td>
<td>PTO on/off Lift control &amp; adjustment A-B adjustment</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Variable-Rate-Control</strong></td>
<td>Map-based-control with ISOBUS UT and ISOBUS TC</td>
<td></td>
<td>Map-based control (ISOBUS like)</td>
</tr>
<tr>
<td><strong>Loading/Unloading</strong></td>
<td></td>
<td></td>
<td>Filling adjustment</td>
</tr>
<tr>
<td><strong>Documentation</strong></td>
<td>ISOBUS TC tractor internal data acquisition, processing and transfer</td>
<td>ISOBUS data acquisition and processing</td>
<td>Proprietary data acquisition, processing and transfer (ISOBUS like)</td>
</tr>
</tbody>
</table>
Automation – at Field-level since ? Years (rough estimations)

<table>
<thead>
<tr>
<th>Control criteria</th>
<th>Tractor</th>
<th>Implement</th>
<th>Self-propelled machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft control</td>
<td>Manufacturer specific sensors,</td>
<td>Standardized three-point-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>actuator, control units,</td>
<td>linkage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>standardized three-point-</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>linkage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drive line management</td>
<td>CVT automation through</td>
<td>Speed control</td>
<td>Header control</td>
</tr>
<tr>
<td></td>
<td>- engine management</td>
<td></td>
<td>Cruise control</td>
</tr>
<tr>
<td></td>
<td>- velocity management</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

• Open to everyone (no patents)
• Simple in handling
• Standard equipment in tractors as well as in mounted implements
• May be used with new implements without extra investment

→ Standardized and worldwide accepted!

<table>
<thead>
<tr>
<th>Loading/Unloading</th>
<th></th>
<th>Filling adjustment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Documentation</td>
<td>ISOBUS TC tractor internal</td>
<td>ISOBUS data acquisition,</td>
</tr>
<tr>
<td></td>
<td>data acquisition, processing</td>
<td>and processing</td>
</tr>
<tr>
<td></td>
<td>and transfer</td>
<td></td>
</tr>
</tbody>
</table>

© Auernhammer 2014
### Automation – at Field-level since ? Years (rough estimations)

<table>
<thead>
<tr>
<th>Control criteria</th>
<th>Tractor</th>
<th>Implement</th>
<th>Self-propelled machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft control</td>
<td>Manufacturer specific sensors, actuators, control units, standardized 3-point-linkage</td>
<td>Standardized three-point-linkage</td>
<td>Header control</td>
</tr>
<tr>
<td>Drive line management</td>
<td></td>
<td></td>
<td>Cruise control</td>
</tr>
<tr>
<td>Guidance</td>
<td></td>
<td></td>
<td>Row-controlling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A-B-geo-sensing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Map-geo-sensing</td>
</tr>
<tr>
<td>Headland management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable Rate Control</td>
<td>Map-based control with ISOBUS UT and ISOBUS TC</td>
<td>Map-based control (ISOBUS TC)</td>
<td></td>
</tr>
<tr>
<td>Loading/Unloading</td>
<td></td>
<td></td>
<td>Filling adjustment</td>
</tr>
<tr>
<td>Documentation</td>
<td>ISOBUS TC tractor internal data acquisition, processing and transfer</td>
<td>ISOBUS data acquisition and processing</td>
<td>Proprietary data acquisition, processing and transfer (ISOBUS like)</td>
</tr>
</tbody>
</table>

- Company specific solution
- Target optimization
- M2M integration
- Increase in machinery performance
- Often protection by patent

→ Market independence!
Automation – at Field-level since ? Years (rough estimations)

<table>
<thead>
<tr>
<th>Control criteria</th>
<th>Tractor</th>
<th>Implement</th>
<th>Self-propelled machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Draft control</td>
<td>Manufacturer specific sensors, actuators, control units, standardized three-point-linkage</td>
<td>Standardized three-point-linkage</td>
<td></td>
</tr>
<tr>
<td>Drive line management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guidance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Headland management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable-Rate-Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loading/Unloading</td>
<td></td>
<td></td>
<td>Filling adjustment</td>
</tr>
<tr>
<td>Documentation</td>
<td>ISOBUS TC tractor internal data acquisition, processing and transfer</td>
<td>ISOBUS data acquisition and processing</td>
<td>Proprietary data acquisition, processing and transfer (ISOBUS like)</td>
</tr>
</tbody>
</table>

- Pre-definition in a coming standard (LBS, ISOBUS)
- Available data dictionary
- Increase of program performance
- Challenge for software companies
- Lead against market competitors

→ Protection of investments!
## Automation – Driving forces at Field-level

<table>
<thead>
<tr>
<th>Control criteria</th>
<th>Tractor</th>
<th>Implement</th>
<th>Self-propelled machinery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Draft control</strong></td>
<td>Manufacturer specific sensors, actuators, components, standardized three-point-linkage</td>
<td>Standardized three-point-linkage</td>
<td></td>
</tr>
<tr>
<td><strong>Drive line management</strong></td>
<td>A-B-guidance, map-guidance</td>
<td>Map-guidance</td>
<td></td>
</tr>
<tr>
<td><strong>Guidance</strong></td>
<td>PTO on/off, lift control &amp; adjustment, A-B adjustment</td>
<td>Map-based-control with ISOBUS UT and</td>
<td>Map-based control (ISOBUS like)</td>
</tr>
<tr>
<td><strong>Headland management</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Variable-Rate-Control</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Loading/Unloading</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Documentation</strong></td>
<td>ISOBUS TC tractor internal data acquisition, processing and transfer</td>
<td>ISOBUS data acquisition and processing</td>
<td>Proprietary data acquisition, processing and transfer (ISOBUS like)</td>
</tr>
</tbody>
</table>

→ **Standardized and worldwide accepted !**

→ **Market independence !**

→ **Protection of investments !**
Automation tomorrow - Draft Control still needed?

No as ...

... invented mainly for plowing and plowing worldwide is avoided when ever it is possible

... mounted ploughs (up to 6 boddies) today differ in dimensions and kinematics referred to the “original ballanced draft control system”

... implements with extended working width are towed

Yes as ...

... in more humid areas plows eliminate soil compaction caused by heavy harvesters

... organic farmers need the plows for weed control

http://www.ferguson-museum.co.uk/black_tractor.htm

Source: Gassner
**Automation tomorrow – Large self propelled systems only?**

The “missing link” in “Combinable Crop Rotations” related to “Self Propelled Tillage”

**Trends:**
- Increasing usage of self propelled vehicles worldwide
- Mainly used by contractors
- Attempts in logistics to follow either climatic and/or agronomic conditions

**Partly „Yes“ as …**
- … nearly no preparation time
- … nothing is twice
- … optimized for specific tasks
- … friendly to any type of field structure
- … automation may be quickly realized

**No as …**
- … very high investment costs
- … less working hours/year

**Fully „Yes“ when …**
- … contractors overtake all field work
- … transport is overtaken by trucks and tractors lose in importance
- … green surface is required (cover crops with no time lag behind main crop) and tractors are engaged in transportation

http://www.househamsprayers.co.uk/library
### Automation tomorrow – Small autonomous systems only?

<table>
<thead>
<tr>
<th>Category</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tillage</td>
<td>![Tillage Image]</td>
</tr>
<tr>
<td>Plant Husbandry</td>
<td>![Plant Husbandry Image]</td>
</tr>
<tr>
<td>Harvesting</td>
<td>![Harvesting Image]</td>
</tr>
</tbody>
</table>

#### No as ...
- ... legislation allows no “unmanned vehicles” (Convention Road Traffic Vienna, 1968)
- ... harvesting of large yields (up to 180 t/ha) seems to be impossible

#### Partly „Yes“ when ...
- ... legislation is adapted
- ... no or little load is required
- ... cheaper sensors from mass-production can be used
- ... communication standards are available and accepted

#### Fully „Yes“ when ...
- ... “one” company offers the whole system to “one” specific crop or specific crop rotation

---

Source: Blackmore, S.: A specification for an autonomous mechanisation system. Guangzhou (China) 2008
A tractor itself does nothing, it/he only offers

- power supply
- mobility
- (loading capacity)

Work is done by implements/tools …

- but still tractor manufacturers believe that they know what implements need for doing optimized field work
- and now we have electronics

Yes as …

... tractors will dominate agricultural mechanization in the future too

... no tractor manufacturer will share more than 50% of the market

... implements will be produced by small and medium sized enterprises

... implements will be more and more intelligent

... implements have specific requirements to optimize its work

Automation requires “Tractor Implement Management” (TIM)
Automation tomorrow – Sensor-based field work (fertilizing)

Inside the cab yesterday and today

No as …
… sensors are still not ISOBUS integrated
… sensor fusion with on-line information and historical data, soil data, water flow, inclination and others is proprietary

Yes as …
… more sensors will be available
… site-specific application requires comprehensive data sources
… production agents increase in prices
… over-application result in extra cost and in environment pollution

“we can, if …”

Automation tomorrow – **sensors in an extended ISOBUS**!
Automation tomorrow – implement controlled production

Allowed (in one color) as …
… proprietary messages are part of ISOBUS (TIM $\rightarrow$ $pTIM$)
… advantage over competitor
… system safety in “one hand”

Birth defect in ISOBUS !?

But farmers target to get …
… freedom in choice of products
… optimized implement performance
… simple handling and operation
… high comfort
… trusted fail-safe status

Independence
Automation tomorrow – no TIM without “Safety Controller”!

Mapping Approach
→ Maps with specifications (Part in ISOBUS (from LBS at end of the 80s))

Real-time Approach with Map-Overlay (Sensor Fusion)
→ Maps + Rules (Needs ISOBUS extension)

Farm Management Information System

- GNNS NMEA 2000
- Task Controller
- In-field Controller
- User Terminal
- TIM Safety Controller
- Tractor ECU
- On-line sensor: Plant/Crop parameter
- On-line sensor: Soil parameter
- Implement Controller

ISO 11783
Automation tomorrow – **Precision Farming → Cloud Farming**

**Web services (Apps)**
- Soil service
- Extension service
- Wether service
- Fleet management service (logistics)
- Book keeping service
- Farm management service
- Other services

**AgMac-Server** (incl. Firewall)

**Mapping Approach**
→ **Maps with specifications**
   (Part in ISOBUS (from LBS, it's end of the 80s))

**Real-time Approach with Map-Overlay (Sensor Fusion)**
→ **Maps + Rules**
   (Needs ISOBUS extension)

- File Server
- GNNS NMEA 2000
- Task Controller
- In-field Controller
- User Terminal
- TIM Safety Controller
- Implement Controller
- Tractor ECU
- On-line sensor Plant/Crop parameter
- On-line sensor Soil parameter

**Realtime-Approach → Rules**
(Needs ISOBUS extension)

---

Automation in Crop Production
© Auernhammer 2014
A14-11 (27)
ISOBUS & Power-BUS – two worlds migrate (standardized ?)

- GNNS NMEA 2000
- Task Controller
- In-field Controller
- User Terminal
- TIM Safety Controller
- Tractor ECU
- Implement Controller

ECU = Electronical Control Unit meets
EDU = Electric Drive Unit

Example: Combine harvester by Gallmeier 2007
Automation tomorrow – the „Big Data“ challenge

„Big Data“

Web-Services (Apps)

Other services

Soil service

Process data service

Application service

Fleet management service (logistics)

Extension service

Wether service

Book keeping service

Farm management service

Farm and labor management

Nutrient supply

Seeding

Liquid manure

Mineral fertilizing

Automated data acquisition

ISOBUS
Power BUS

Auernhammer 1991

Auernhammer 1991
Conclusions

There is no prescription for Automation in crop production at all

**Draft control in tractors and auto steer** in self propelled harvesters, lately in tractors, are predominantly used automation technologies in crop farming worldwide today and tomorrow

Automated variable rate control is **still one-dimensional** based on maps or online sensors and has to be multi-dimensional

**Automation in self propelled technology** is well accepted on farm level when it comes from “one hand” even if this are small autonomous vehicles

**Sensors and sensor fusion** offer a wide range for automation if they are standardized members in an electronic communication environment

Improved crop production needs **standardized tractor implement management (TIM)** systems for optimized field work

**Automatic data acquisition** systems and web services allow for “Automation in cloud farming of tomorrow”