Assessment of Guidance Systems in Agriculture under European Conditions

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Freising (Germany)

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1. Agriculture in Europe

2. Precision in the past and today

3. Guidance systems in autonomous vehicles

4. Guidance systems in driver operated vehicles

5. Assessment of driver operated guidance systems

6. Conclusions
Europe and the Enlargement

<table>
<thead>
<tr>
<th>Year</th>
<th>Integrated countries</th>
<th>Mem.</th>
<th>Population</th>
<th>Increase</th>
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<td>BG, RO</td>
<td>27</td>
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Europe and others

<table>
<thead>
<tr>
<th>Country</th>
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<td>USA</td>
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www.geographixx.de
Main rural areas outside the high population density
Agriculture in nearly whole Europe
<table>
<thead>
<tr>
<th>Country</th>
<th>Share of civil laborers in agriculture, forestry and fishery [%]</th>
<th>Laborers per 100 ha [n]</th>
<th>Share of farm owners &lt;35 years [%]</th>
<th>Share of farm owners &gt;65 years [%]</th>
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## Farm Sizes and Share of cultivated Land EU\textsubscript{15}

<table>
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<tr>
<th></th>
<th>average Farm size [ha]</th>
<th>Share of farms &lt;5 ha [%]</th>
<th>Share of cultivated land by farms &lt;5 ha [%]</th>
<th>Share of farms &gt;100 ha [%]</th>
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<td><strong>4.1</strong></td>
<td><strong>46.0</strong></td>
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</table>
Very small farms in east and south
Baseline Indicators
Context 15
Water use

% irrigated 'UAA'
≤ 1%
1 - 5%
5 - 10%
10 - 25%
> 25%
N.A.

EU-25 Average: 7.16% (excluding DE, EE, LT)

Source: EUROSTAT - Farm Structure Survey
Year: 2003
Calculations: DG AGRI - G2
Cartography: DG AGRI GIS Team 08/2008
© EuroGeographics for the administrative boundaries

Irrigation still low importance, but increasing!
Global Production of Agricultural Machinery 2005

- North America: 30%
- Eastern Europe: 4%
- Others: 7%
- Latin America: 8%
- Japan: 4%
- India: 5%
- European Union: 42%
- World leading position of Europe (and the USA) can only be maintained when products are
  - of high quality,
  - high tech,
  - possible to integrate in any tractor-implement combination

Standards are essential!

Source: Estimations VDMA Agricultural Machinery, Frankfurt
Agricultural BUS Systems by DIN 9684 and ISO 11783

LBS established 1987 – 1997 in Europe (predecessor and initiator of the ISOBUS)

ISOBUS established from 1994 by Europe, USA and Canada (still under development / extension)

Electronic communication, sensors and actuators and location systems allow for “Intelligent machinery” → Intelligent Farming → Precision Farming

Electronic communication, sensors and actuators and location systems allow for “Intelligent machinery” → Intelligent Farming → Precision Farming
Precision Farming is more than only “Site-specific Farming!"
1. Agriculture in Europe

2. Precision in the past and today

3. Guidance systems in autonomous vehicles

4. Guidance systems in driver operated vehicles

5. Assessment of driver operated guidance systems

6. Conclusions
Requirements:

- **New track has to be placed in the previous track**, distance error $\leq \frac{1}{2}$ wheel width $= \leq 3$ cm
- Tracks have to be **absolutely straight** (ones must be able to shoot through it)
- In sugar beets a so called **“Blind hoe”** is allowed when following the seeding track

Therefore: **Seeding was done with three people**

- One responsible for the drawing animals
- One doing highly accurate steering of the sowing machine
- A third one watching the seed distribution behind the sowing machine
Changing to tractor operated seeding in the 50th

Tractor instead of animal drawing,

- Roller markers at tractor and adopted seeding technology

- Still accurate steering by humans on low mechanized small farms

- Technical assistance for parallel tracking in tractor mounted seeding units
Tram lines in grain production since the 70th

Appearance at early state

Appearance before harvesting

- Used for fertilization (2 to 3 passes) and spraying (1 to 2 passes) operations mainly, sometimes also for harvesting in “skipped passes” (when tram line distances correlates with multiple harvester working widths)
- Less overall soil compaction
- No significant reduction in yield
Investigated Tram Line Interspaces on Farms

Own investigations 1991
Set-distance 12 m
Region Freising (Germany), 61 fields

Investigation by SCHICK 1990
Set-distance 20 m
Region Schleswig-Holstein (Germany)

- All tram line distances are too narrow → Overlapping!
- Slope has a significant influence → Human reaction is limited!
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6. Conclusions
This driverless tractor was evolved at Reading University 1959, and it follows a cable buried under the Soil below cultivation depth. Picture by kind permission of Keith Morgan, Reading University.

- Shown for seeding purposes too
- Usable only after establishment of infrastructure
- Developed in a time when enough labourer were available

Source: GROWER 1982, Dec. 16, p 23
EICHER autonomous Plough (D) in 1964

**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: Archive Landtechnik Weihenstephan (992ab058)

- Use of available tractor parts (engine, power transmission)
- Created as a small unit for 24-hour-work
- Ploughing does not need constantly manual attention and monitoring
Modular unmanned tractor for agricultural applications (SF)

Developed in Finland in 1992 with 2 different sizes to stop the ongoing enlargement of tractors.

- Platforms with RTK-GPS auto guidance systems
- Two-way use with different implements, using the 3-point-linkage!
- Rubber wheels in the larger, rubber-tracked crawler in the smaller unit

Overall steering and control device for use in autonomous tractors, established by GoeTec, Hallbergmoos (Germany).

- **Only a few units were sold** (around 50,000 €/unit under discount conditions for research purposes)
- **Full operational capability was demonstrated**
- **No real market under the given European conditions at that time**

Source: Ehrl, M., Stempfhuber, W., Demmel, M., Auernhammer, H.: AutoTrac - accuracy of a RTK DGPS based autonomous vehicle guidance system under field conditions. Kyoto 2004
Autonomous Christmas tree weeder 2004

Based on a platform from a self-propelled 4-wheel grass mower, established by Simon Blackmore and others (Denmark).

- Used for weeding only
- Additional sensors and sensor fusion required
- Obstacle detection and safety requirements another challenge

Source: www.unibots.com/ACW.htm
Important attempts to autonomous vehicles at a glance

- **‘50**
  - Mechanics and hydraulics

- **‘60**
  - Mechanics and hydraulics

- **‘70**
  - Mechatronics

- **‘80**
  - Mechatronics

- **‘90**
  - Mechatronics and GNSS

- **‘00**
  - E²tronics, smart sensors, ..

- **June 17, 1995**
  - FOC of GPS-NAVSTAR
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6. Conclusions
First announced in 1977

“One row” sensing device

Meanwhile more than 10,000 systems in use, extra equipment >70%
Row guidance in sugar beet combine harvesters

- Visual “backsight” to pull into the row at the headland
- “Three row sensing device”
- Secure guidance (basic accessory unit since more than 10 years)
Guidance in grain combine harvesters

- First announced in 1999
- “One edge” sensing device (often two devices installed)
- Meanwhile more than 15,000 systems in use, extra equipment >50%
First announced in 1998
“Four sensor” adaptable device unit
Mainly offered and used for swath guidance (round and square balers, … )
- First announced in 2006
- “3D-Camera” sensing device
- About 100 systems in use, mainly in horticultural row crops
Guidance systems (schematic)

- **Field relation**
  - **Field points**
    - Mechanics
    - Optics
    - Acoustics
  - Field independent

- **Physical principle**
  - Mechanics
  - Optics
  - Acoustics
  - Electromagnetics

- **Detected objects**
  - Row (corn, sugar beet, ...)
  - Canopy edge, swath, furrow
  - Canopy edge, swath, furrow
  - Planned path

- **Primary sensors**
  - Levers, sticks, plates, ...
  - Laser
  - Images
  - Ultra sonic
  - GNSS

All systems are offered and used on field level - are specialized for certain tasks - need no infrastructure - can simply be added to existing machinery

Source: Koch P., Munich-Weihenstephan 2007, modified
Today parallel-tracking gets more and more popular

Guidance aid

System signals the distance to an ideal driving lane by a visual device.

Steering assist

Assistant performs steering functionality and can be used on different machines.

Automatic Guidance

Automatically steers the tractor via hydraulic valve and becomes part of the machine.
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## Accuracy requirements of guidance systems

<table>
<thead>
<tr>
<th>Required accuracy</th>
<th>Field operations (examples)</th>
<th>Rough rating</th>
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<tbody>
<tr>
<td>±20 to ±30 cm</td>
<td>Operations on stubble fields or on grass land, Soil tillage, Distribution of organic matters, Distribution of mineral fertilizer, Plant protection measures (spraying), Liming</td>
<td>Normally large working width of the implements (e.g. &gt; 6 m)</td>
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<tr>
<td>±5 to ±10 cm</td>
<td>On-land ploughing, Seeding, Tillage-seeding-combinations, Planting, Mowing, Harvesting</td>
<td>Working width of the implements up to ~ 6 m</td>
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<tr>
<td>±2 cm</td>
<td>Seeding, Mechanical weed control, Seeding and husbandry of special crops, Controlled traffic</td>
<td>High precision field work</td>
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</table>

Source: Koch P., Munich-Weihenstephan 2007, modified
## Expected benefits of guidance systems

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Benefit</th>
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<tr>
<td><strong>Reduction of overlapping</strong></td>
<td>Savings of seed, fertilizer, plant protectants</td>
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<tr>
<td></td>
<td>Increased working capacity</td>
</tr>
<tr>
<td></td>
<td>Prevention of double applications</td>
</tr>
<tr>
<td><strong>Hard facts (measurable)</strong></td>
<td>Increased working speed</td>
</tr>
<tr>
<td></td>
<td>Reduced fuel consumption</td>
</tr>
<tr>
<td></td>
<td>More accuracy even with larger working widths of implements</td>
</tr>
<tr>
<td></td>
<td>Operation with less trained people</td>
</tr>
<tr>
<td></td>
<td>Extended field working time (evening, night, fog, dust, ...)</td>
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<tr>
<td></td>
<td>Cheaper Implements (abandonment of markers, foamers, ...)</td>
</tr>
<tr>
<td></td>
<td>Eventually reduction of additional tractors/implements</td>
</tr>
<tr>
<td><strong>Reduced labour costs and higher labour capacity</strong></td>
<td>等携戔惩う络まし履脕谰</td>
</tr>
<tr>
<td><strong>Soft facts (not measurable)</strong></td>
<td>Improved appearance of agriculture to the community</td>
</tr>
<tr>
<td></td>
<td>Doing better than the neighbor</td>
</tr>
<tr>
<td></td>
<td>Avoiding of mistakes (nonattention, work overload, ...)</td>
</tr>
<tr>
<td><strong>Working conditions</strong></td>
<td>More comfort</td>
</tr>
<tr>
<td></td>
<td>More time for implement control</td>
</tr>
<tr>
<td></td>
<td>Reduced work fatigue</td>
</tr>
<tr>
<td><strong>Image</strong></td>
<td>Improved repeatability of working operations</td>
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<td></td>
<td>Improved conditions for mechanical husbandry measures in row crops</td>
</tr>
<tr>
<td></td>
<td>Optimized management of field works</td>
</tr>
<tr>
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<td>Documentation of field working conditions</td>
</tr>
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<td>Efficient contribution to &quot;Precision Farming Practice&quot;</td>
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</table>
Increased productivity of guidance systems 2007 (±5 – 10 cm)

Wheat: 24.49 €/ha

Increased productivity of guidance systems 2007 (±5 – 10 cm)

Wheat: 24.49 €/ha

- Tillage: 3.48 €; 14%
- Seed bed preparation: 3.25 €; 13%
- Fertilizing: 2.19 €; 9%
- Plant protection: 2.58 €; 11%
- Seeding: 4.40 €; 18%
- Liming: 6.13 €; 25%

Summer barley: 24.49 €/ha

- Tillage: 3.48 €; 17%
- Seed bed preparation: 3.25 €; 16%
- Fertilizing: 2.19 €; 11%
- Plant protection: 2.17 €; 11%
- Seeding: 3.64 €; 19%
- Liming: 2.75 €; 14%

Rape: 21.61 €/ha

- Tillage: 3.48 €; 16%
- Seed bed preparation: 3.25 €; 15%
- Fertilizing: 2.19 €; 10%
- Plant protection: 1.72 €; 8%
- Seeding: 4.77 €; 22%
- Liquid manure: 3.73 €; 17%

Silage mais: 20.24 €/ha

- Tillage: 1.20 €; 6%
- Seed bed preparation: 3.25 €; 16%
- Fertilizing: 2.19 €; 11%
- Plant protection: 5.08 €; 25%
- Seeding: 4.56 €; 23%
- Liming: 2.70 €; 13%
- Round up: 1.27 €; 6%

Cost – benefit relation of guidance systems 2007 (±5 – 10 cm)

Guidance benefit in a crop rotation of:
- Wheat 48 %
- Corn 20 %
- Rape 22 %
- Barley 10 %

Benefit changes of guidance use 2007

Benefit of guidance use [€/ha•a]

Crop rotation of:
- Wheat 48 %
- Corn 20 %
- Rape 22 %
- Barley 10 %

Price Development of Input Costs

- \( \text{P}_2\text{O}_5 \)
- \( \text{N} \)
- \( \text{K}_2\text{O} \)
- \( \text{CaO} \)

Source: Koch, P., Mannheim 2008
More and more cultivated crops are used for energy production.

Price levels for production factors are increasing (labour, fuel, fertilizer, crop protection, rents….)

To produce 1 ha (~ 2.4 acre) of wheat:

- Production costs in 2002: 445 €/ha
- Production costs in 2007: 724 €/ha
  
  Production costs increased by +62%.

- Benefits auto guidance in 2002: ~ 25 €/ha
- Benefits auto guidance in 2007: ~ 35 €/ha

Benefits auto guidance increased by +40%.

Source: Koch, P., Mannheim 2008
Influence of direct costing to the „Break Even Point“

**Economic Assumptions:**
- Depreciation: 5 a
- Interest rate: 6 %
- Field size: 20 ha
- Accuracy: ±5 cm
- Terminal: GS 2600
- Overlapping: 8 %
- Crop rotation:
  - Wheat: 48 %
  - Corn: 20 %
  - Rape: 22 %
  - Barley: 10 %

- Higher direct costs reduces the “Break Even Point”
- Higher direct cost increase the benefit of guidance systems

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Guidance systems in a farm based conclusion

**Guidance Systems**

- Field independent
- Field points

**Field relation**

**Physical principle**
- Electromagnetics
- Mechanics
- Optics
- Acoustics

**Detected objects**
- Planned path
- Row (corn, sugar beet, ...)
- Canopy edge, swath, furrow
- Canopy edge, swath, furrow

**Primary sensors**
- GNSS
- Levers, sticks, plates, ...
- Laser
- Images
- Ultra sonic

Example: Winter barley follows winter wheat

Field points available

Only GNNS-based guidance systems fulfill all requirements (and allow the use of other systems during the growing period!)

All guidance systems fulfill the requirements under regular conditions!

Sensor fusion allows highest benefits!!!
Conclusions

- Guidance in Europe (and in other continents too) have experienced highest attention during animal drafted field operations.
- The move to tractor drawn implements induced a loss in precision.
- First improvements produced fully automated tractor or field robot guidance systems (unreliable, expensive, unsophisticated, ) and were niche products only.
- Automatic row guidance of self propelled choppers took a wide acceptance for the first time and is standard in newly sold machines for more than 15 years.
- Also row guidance systems in sugar beet harvesters came early and are standard in all today used machines.
- Laser-based guidance systems in combine harvesters were established, when header widths increased to more than 5 meters and are standard now in 7.5 and 9 m cutting width .
- Ultra-sonic and optical guidance systems are on the market available too, but have not earned great importance so far.
- GNNS-based guidance systems have an increased importance to farmers. The fast acceptance is mainly driven by cost:benefits and by comfort reasons.