Keynote

Chances and Challenges of Machine Control and Guidance Systems for Digital Agriculture Applications

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### Overview

#### Chances
- Costs for sensors, data storage and data processing decrease
- Accuracy and resolution of sensors improves (GNSS)
- Connectivity (5G & Sigfox)
- Image Processing & NIRS offer new opportunities
- Machine Learning provides new approaches to signal processing (CMS)
- Existing Yield Gap

#### Challenges
- Societal Challenges
  - Decreasing Workforce
  - Environmental Issues
  - Consumer Demand and Societal Issues
- Legal Issues and Liability
- Modular Approaches & Standards
- User
  - ROI
  - Resilience, Validity & Quality
  - Remote Service & Diagnostic Capabilities
  - User Experience (GUI, MMI)
Maslow's Hierarchy of Needs

https://me.me/i/maslows-hierarchy-of-needs-self-actualization-creativity-purpose-esteem-confidence-2226931
Maslow's Hierarchy of Needs - revisited

Agricultural production covers the basic needs of human beings.

https://commons.wikimedia.org/wiki/File:MaslowsHierarchyOfNeeds.svg
World population

- 10 Billion people by 2050
- World population has then increased **by factor 4 over the last 100 years**

Arable Land - World

https://data.worldbank.org
Arable Land - Europe

https://data.worldbank.org
Arable Land - Germany

https://data.worldbank.org
Arable Land – Germany (relative)

https://data.worldbank.org
Employees in Agriculture - World

https://data.worldbank.org

-39 %
Employees in Agriculture - Europe

https://data.worldbank.org

-57 %
Employees in Agriculture - Germany

https://data.worldbank.org
Seasonal Workers in Germany (2016 vs. 2010)

- Number of seasonal workers in Germany has decreased from 330,500 (2010) to 286,300 (2016).
- This equals to a reduction of 13.4%.
- During the same period the total area farmed has been almost stable (-0.2%).

Farm Sizes in Germany (2016 vs. 2010)

Germany: Farm Area by Farm Size

- Farm Size [ha]
  - > 200
  - 100 - 200
  - 50 - 100
  - 20 - 50
  - 10 - 20
  - 5 - 10

- Rel. Size Change 2016/2010
  - -15%
  - -10%
  - -5%
  - 0%
  - 5%
  - 10%
  - 15%
Farm Sizes in Germany (2016 vs. 2010)

Larger Farms

+ Less Employees

= Less Knowledge about Single Fields

+ More Demand for Data/Information
Environment: Nitrate Load in German Groundwater

- Less than 50 mg Nitrate/l
- More than 50 mg Nitrate/l
Required Reduction of Nitrogen Fertilization

Target Nitrate concentration:
37.5 mg/l

Required reduction in kg N/ha

0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-100
100-200

Quelle: Umwelt Bundesamt
Societal Issues: Agrochemicals

HERBICIDES

Study shows glyphosate may be killing honeybees

Glyphosate, the world's most widely used weed killer, has caused concerns over its potential risk to human health and the environment for decades. Now, new research shows that glyphosate may be indirectly killing bees.

Jury Orders Monsanto To Pay $289 Million In Roundup Cancer Trial
Climate Change

Seasonal Percent of Normal Precipitation (WMO)
Mar. 1 - Sep. 10, 2018

Precipitation in Germany between March 1st and September 10th 2018: 0% to 25% of long term average.
Solution (?): Bigger and more efficient machinery

Limits for Mechanical Engineering in Ag:

- length
- width
- height
- weight (roads and field)
- distribution accuracy
  - straw
  - fertilizer
  - agrochemicals

Legal Constraints

Application Constraints

Connectivity and Automatization still provide potential for leveraging efficiency in Farming.
Intermediate Conclusion

- Agricultural production covers basic human needs:
  - Food,
  - Feed for animals,
  - Bio Energy and
  - Raw Materials for the industry (e.g. clothing)
- The world population is growing.
- The area of arable land is stable or even decreasing.
- The amount of people involved in agricultural production is decreasing.
- Agriculture needs to adopt to environmental and societal challenges (reduction of agrochemicals).
- The size of machinery has reached its limits with respect to size and weight.

Summary
INCREASE PRODUCTION ON EXISTING AREA WITH LESS INPUT OF LABOUR AND MATERIAL.
Summary

INCREASE PRODUCTION ON EXISTING AREA WITH LESS INPUT OF LABOUR AND MATERIAL

Solution:
Increase productivity by increasing yield and making more out of existing labor force and material input while maintaining or reducing the size of machinery = Increase Efficiency

Options:
- Breeding, Genome Editing, e.g. Crispr/Cas
- Reduce meat consumption or replace meat by Cultured Meat/In Vitro Meat
- Introduce more autonomous and intelligent systems into agricultural production
Can we increase yield? Yield Gap (Wheat)

Data source: www.yieldgap.org
Open Software

- Linux
- ROS.org
- Java
- Python
- KNIME
- JASP
- R
- OpenCV
- PostgreSQL
- MySQL
- Hadoop
Open Data

GNSS-RTK: Prices

Auf dem anderen Ende der Skala stehen geodätische Empfänger für Vermessungsaufgaben, die je nach Ausrüstung bis über DM *100.000* kosten. Für die Zukunft wird ein rapide Anwachsen der Empfängerzah-

**1994:** 50000 EUR  
**2018:** 200 EUR

Muhr, T.; Demmel, M.; Auernhammer, H., 1994: Positionsbestimmung landwirtschaftlicher Arbeitsmaschinen für die Entwicklung ökologisch optimierter Anbauverfahren. Gelbes Heft 53; Bayerisches Staatsministerium für Ernährung, Landwirtschaft und Forsten (StMELF)(Ed.). AgTecCollection: FG Technik im Pflanzenbau TUM / Auernhammer, TU München  
http://mediatum.ub.tum.de/?id=1006062
Controllers

- Raspberry Pi 3 B+, 4x 1.4 GHz...
  - 33.90 €
  - reichelt.de
  - +5.60 € Versand
  - Von smec

- Raspberry Pi 3 Model B ARM...
  - 31.99 €
  - notebooksbillig.de
  - +3.00 € Versand
  - Von Google

- Raspberry Pi 3 Model B+ 1 GB...
  - 37.99 €
  - Conrad Electronic
  - Versand gratis
  - Von Google

- MEGA 2560 R3 ATmega2580-16AU...
  - 7.98 €
  - eBay
  - Versand gratis
  - Von Twenga

- LG K7 black 8GB EU [12,7 cm (5'') Display, 1,3GHz Quad-Core-Prozessor, 5MP Kamera, 1GB Ram]
  - 85,00 €
  - Liefertermine noch unbestimmt
  - In-Cell Touch Technologie
  - Selfie Backlight-Funktion
  - MicroSD Speicher-Slot für bis zu 32 GB
  - Festplattenspeicher 8 GB
  - 5 Megapixel Kamera, Tap & Shoot-Kameramodus

- Controller
- Telemetry
- IMU
- GNSS
- UI
Aerial Carrier Platforms for Sensors

How Much Does it Cost to Buy a Plane?

Operating Costs
$100-$200 per flight hour based on a single-engine Cessna 172.

Fuel
Up to $30 per hour; if you fly 200 hours in a year, it'll cost $6,000 in fuel alone per year.

Purchase Price
- Ultralight: $8,000 - $15,000
- Single-Engine: $15,000 - $100,000
- Multi-engine: $75,000 - $300,000

Storage
Average $275 per month and $100 for tie-downs.

Insurance
Between $1,200 and $2,000 per year.

Gas and Oil
$4 and $5 per gallon as of November 2015.

Maintenance and Inspections
From $600 to $1,200.

~ 50000 EUR
~ 1000 EUR

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Cameras
3D Reconstruction (Wear Analysis)

Bachelor Thesis Florian Baus
3D model parcel plot trial
Digital Farming: Connectivity

- **Cloud**
  - Yield
  - Nutrients
  - Task data
  - Expert systems (Big Data)
  - Soil data
  - Weather data

- **ISO 11783 / CAN**
  - ISO-VT Terminal
  - Implement

- **GNSS**

- **Telemetry**
  - GSM/GPRS
5G Mobile Networks: Volume, Density, Latency

5G Mobile Networks: eMBB, mMTC, uRLLC, NB-IoT

- **eMBB**: high data rates, up to 10/20 GBit/s
  - $10 \frac{MBit}{s \cdot m^2}$ or $1 \frac{TBit}{s \cdot km^2}$
  - Availability at high speeds (up to 1000 km/h)
- **mMTC**: massive Machine Type Communication
  - 1 million connections/km²
- **uRRLC**: ultra reliable low latency connection
  - Latency 1 ms (currently 30 to 50 ms)
- **Additional features**
  - **NB-IoT**: Long Range Low Power (LoRaWAN)
  - **D2D**: Device-to-Device Communication
  - Lower power consumption (per Bit)

LTE Coverage (2018)

https://opensignal.com/reports/2018/02/state-of-lte
LTE availability

https://opensignal.com/networks
LTE Coverage: 65% of population
LTE Coverage: 90% of population
LTE Coverage: 99% of population
Summary Mobile Networks: Demand → 5G?

**Coverage**
- Reliable access, anywhere

**Bandwidth**
- Process Data and Diagnostics

**Device to Device**
- Infield Communication

**Latency**
- Autonomous Operations

**LoRaWAN**
- Sensor Networks
3-Tier Architecture

- **User Interface**
- **Logic / Control**
- **Sensors**
GUI – Old Style
GUI – New Style

https://demo.365farmnet.com
Alternative MMI – Gesture Control

https://www.youtube.com/watch?v=7uQC1mH4x4E
Speech Control

Farm Management Information Systems document tasks performed in the field. They help to analyze productivity and discover weaknesses in the production system.

The market penetration is low. This is partly due to lacking motivation to enter data into the system.

Making data entry more attractive would help to increase market penetration.

Speech FMIS
User Context Analysis

- Roll
- Task
- Light
- Vibration
- Noise
- Age
- Skill
- Socio-Ethical Background
- Temperature

MMI

Display
Button
Alarms
Gloves
Heat Map: focus when actuating hydraulic actuators
3-Tier Architecture

Speech/Voice
   Worker

Tablet
   Group Leader

Smart Phone
   CEO

Logic / Control

Sensors/Data
Digital Farming: Connectivity

Cloud
- Yield Nutrients Taskdata
- Expert-Systems (Big Data)
- Soil Data Wheather Data

ISO 11783 / CAN
- ISO-VT Terminal
- Implement

GNSS

Telemetry GSM/GPRS
3-Tier Architecture

User Interface

Logic / Control

Logic / Control

Sensors
Missing Modularity: GNSS – avoiding Interfaces

Abundancy, no redundancy

GNSS
Steering System

GNSS
Section Control

GNSS
Variable Rate Control

GNSS
Data Logger
Modularity: GNSS

- Steering System
- Section Control
- Variable Rate Control
- Data Logger
Modularity: Telemetry

Telemetry
DGPS Data
Fleet Management
Remote Service & Support
Process Data
Interfaces Site Specific Farming (Variable Rate)
Interface – open and standardized
Interface: a Basis for Collaboration

No single entity or person is an expert on everything.
Intermediate Conclusion

We have…

- access to
  - massive amounts of data which is freely available.
  - cheap sensors that allow collecting additional data.
  - low cost hardware for data collection, processing and controlling actuators.
  - wireless networks for exchanging data and information in real time.
- standards for interfacing data and processing expertise.
- a demand for further interface standards and more discipline avoiding proprietary communication
- a challenge with deriving relevant information from data.
Light and Sound

Camera

Microphone/MEMS

Wavelengths x Pixels x Time

Frequency x Time

Multivariate Data
Spectrum of Corn Varieties
Frequency Analysis on Forage Harvester (Chopping Drum, Condition Monitoring)

Frequency Analysis

Frequency [Hz]

Amplitude [dB]
NIRS Spectroscopy
# NIRS applications in Agriculture

<table>
<thead>
<tr>
<th>Application</th>
<th>Stationary/Mobile</th>
<th>Carrier</th>
<th>Spatial Resolution</th>
<th>Spectral Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll, N-demand</td>
<td>Mobile</td>
<td>Tractor</td>
<td>6-8 m oof track</td>
<td>Multispectral VIS, NIR</td>
</tr>
<tr>
<td>Biomass, plant protection</td>
<td>Mobile</td>
<td>Tractor</td>
<td>6-8 m off track</td>
<td>Multispectral VIS, NIR</td>
</tr>
<tr>
<td>Biomass, chlorophyll, oil content, protein content</td>
<td>Mobile</td>
<td>UAS</td>
<td>0,5 to 5 cm</td>
<td>Multi- und Hyperspectral VIS, NIR</td>
</tr>
<tr>
<td>Germination, wild harm, ripeness</td>
<td>Mobile</td>
<td>UAS</td>
<td>0,5 to 5 cm</td>
<td>RGB</td>
</tr>
<tr>
<td>Biomass, chlorophyll</td>
<td>Mobile</td>
<td>Aeroplane</td>
<td>5 to 50 cm</td>
<td>Multispectral VIS, NIR</td>
</tr>
<tr>
<td>Biomass, chlorophyll, ripeness</td>
<td>Mobile</td>
<td>Satellite</td>
<td>5 to 30 m</td>
<td>Multispectral VIS, NIR, (SWIR)</td>
</tr>
<tr>
<td>Dry matter, raw protein feed</td>
<td>Stationary</td>
<td>Laboratory</td>
<td>-</td>
<td>Hyperspectral VIS, NIR, SWIR</td>
</tr>
<tr>
<td>Protein, oil content small grains and legumes</td>
<td>Stationary</td>
<td>Laboratory</td>
<td>-</td>
<td>Hyperspectral VIS, NIR, SWIR</td>
</tr>
<tr>
<td>Dry matter corn/ grass</td>
<td>Mobile</td>
<td>Forage Harvester</td>
<td>-</td>
<td>Hyperspectral VIS, NIR, SWIR</td>
</tr>
</tbody>
</table>
### NIRS applications in Agriculture (cont.)

<table>
<thead>
<tr>
<th>Anwendung</th>
<th>Stationary/ Mobile</th>
<th>Carrier</th>
<th>Spatial Resolution</th>
<th>Spectral Resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic Matter</td>
<td>Mobile</td>
<td>Soil Sensor</td>
<td>-</td>
<td>Multispectral VIS, NIR</td>
</tr>
<tr>
<td>Organic Matter, Water</td>
<td>Mobile</td>
<td>Satellite</td>
<td>30 to 60 m</td>
<td>Multispectral NIR, SWIR</td>
</tr>
<tr>
<td>Content</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilizer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-concentration liquid manure</td>
<td>Mobile</td>
<td>Liquid manure spreader</td>
<td>-</td>
<td>Hyperspectral VIS, NIR, SWIR</td>
</tr>
</tbody>
</table>
Multitemporal/Multispectral Data: Yield ~ NDVI
Artificial Neuronal Network: 1+1=3

Estimating yield based on satellite time series with an ANN
Tools for Multivariate Data Analysis and AI

- Artificial Neuronal Networks
- Random Tree Classification
- Decision Tree
- Partial Least Squares Regression
- Support Vector Machine (SVM)
- Tensor Flow (?)
- …
Future Science (Data Driven)

Remote Sensing
Sensor Telemetry
AI Model
AI Training
Model Application
Institutional Science vs. Commercial Science

**Systematic Approach**
- Understanding
- versus
- mere **Data Mining**

**Quality Assessment**
- and
- Transparency of Methods
- versus
- Black Box Results

Knowledge as **Common Property**
- (publications)
- versus
- Knowledge as **Proprietary Property**
Data Quality – Garbage in, Garbage out

Data cleaning, the unsexy but essential aspect of data science

There’s an aspect of data science, though, that is ‘unsexy’ but a requisite to actually developing those predictive models. It’s called data cleaning or data curation.

Depending on the quality of a data set, data cleaning takes up between 60 percent and 80 percent of a data scientist or a data analytics team’s time. Daniel Jimenez, who leads the CIAT data team, attributed the lengthy time to clean agriculture data to the lack of standardization of common terms used in the field.

Yield Map with Quality Assignment

Quality Assignment instead of Filtering

yield increasing ~ symbol size
degree of belief
~ 0 to 1
~ red=low to green=high

low yield, high belief

high yield, high belief
Summary

- **Agriculture** is a core field for meeting the **basic needs of human mankind**. Agriculture has issues in the **productivity** domain as well as **environmental and societal** issues that need to be resolved.

- Digital Systems like **Sensors, Telemetry Systems, Image Processing Systems and NIRS and AI** are affordable and helpful tools which offer many **chances** to tackle some of the issues.

- The **core challenges** when applying digital technologies are:
  - Using or developing **standardized and open interfaces**
  - Including the needs of users into the **UI & MMI Design**
  - **Deriving information from data** using artificial intelligence whilst keeping the results and methods public and transparent