56th Photogrammetric Week

September 11-15, 2017, University of Stuttgart

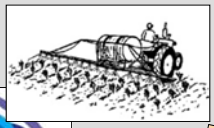
Imaging Sensor Systems – Key Technology for Innovative and Sustainable Agricultural Systems


Arno Ruckelshausen

University of Applied Sciences Osnabrück, Germany / Faculty of Engineering and Computer Science

COALA - Competence Center of Applied Agricultural Engineering

Agriculture 2017+



Supported by technology and interdisciplinary cooperation

Global Relevance:

- Food
- Energy
- Ressources
- Landscape preservation

Challenges:

- Increase of production
- Reduction of environmental burdons
- Saving of ressources
- Optimization of logistics
- Social aspects

Sources: United Nations Development Programme / Sustainable Development Goals, 2015
Sources: UN World Population Prospects, May 2011; : http://www.aces.edu/pubs/ systemsview.wordpress.com , MSClipArt (2011)

Overview

Technology meets Nature

Image-based Sensors in Agriculture

Modeling Environment

Alternative (Technological) Concepts for Agriculture

Overview

Technology meets Nature

Image-based Sensors in Agriculture

Modeling Environment

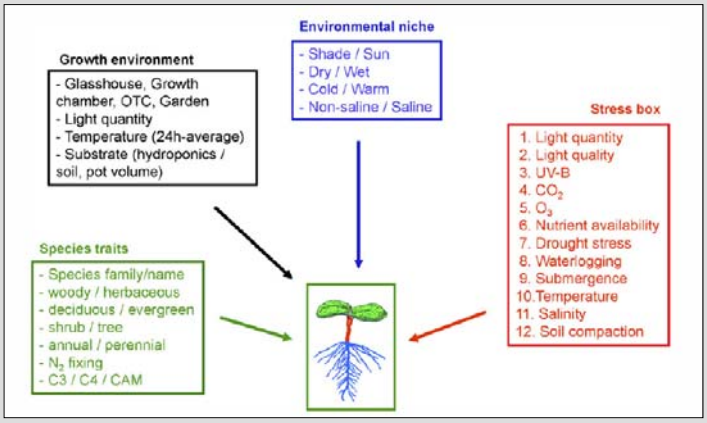
Alternative (Technological) Concepts for Agriculture

Technology meets nature …

Sources: University of Applied Sciences Osnabrück , agrarheute.com

Plant production

Question: How does a plant grow ?



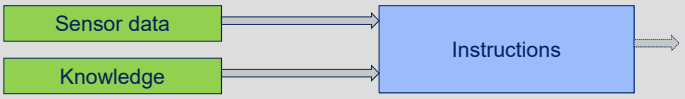
Answer: It depends on …

Source: H.Poorter et al. , Journal of Expoerimental Botany, Vol. 61, No.8, pp.2043-2055, 2010

Crop sensors (examples)

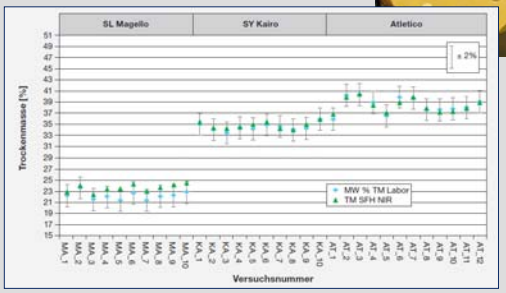


…



Sources: Claas, Agricon, FarmFacts

1D-Moisture Sensor (NIR) for Maize (harvest)

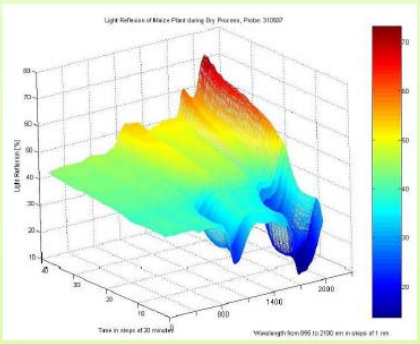


KRONE

Hochschule Osnabrück

COALA nature · technology · food

1D-Moisture Sensor (NIR) for Maize (harvest)



3D Trocknungsverlauf als Funktion der Wellenlänge, Zeit und Intensität;
Durch Auswahl selektiver Spektralbereiche können Abhängigkeiten zur Feuchte korreliert werden.

NIR-Sensor (Fa. Krone)

Realisierter „Messkopf" NIR-Sensor

Sensor systems: fertilization, crop protection (examples)

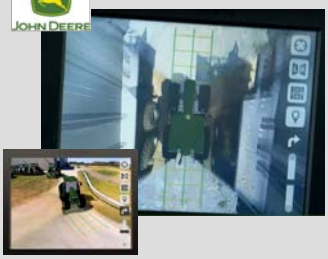
Non-image-based sensors

Image-based sensors

Sources: Garford, AgriCon, Claas

Out in the field …

Agritechnica 2015: Imaging goes Agriculture



Overview

Technology meets Nature

Image-based Sensors in Agriculture

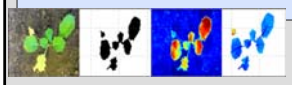
Modeling Environment

Alternative (Technological) Concepts for Agriculture

Imaging

Image-based technologies:

- Color and grey scale imaging (1D, 2D)
- Shadow imaging
- Highspeed imaging
- 3D-imaging (laser, stereo, time-of-flight, ,,,)
- Multispectral imaging
- Hyperspectral imaging
- Thermal/UV imaging
- Others (x-ray, THz, ultrasonic, NMR,…)



Imaging concepts:

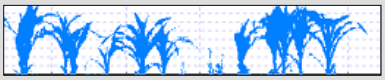
- Image processing (robustness)
- Sensor and data fusion
- Smart sensors
- Simulation technologies
- Human machine interface
- Remote imaging
- Low cost Imaging

Shadow Imaging (1)

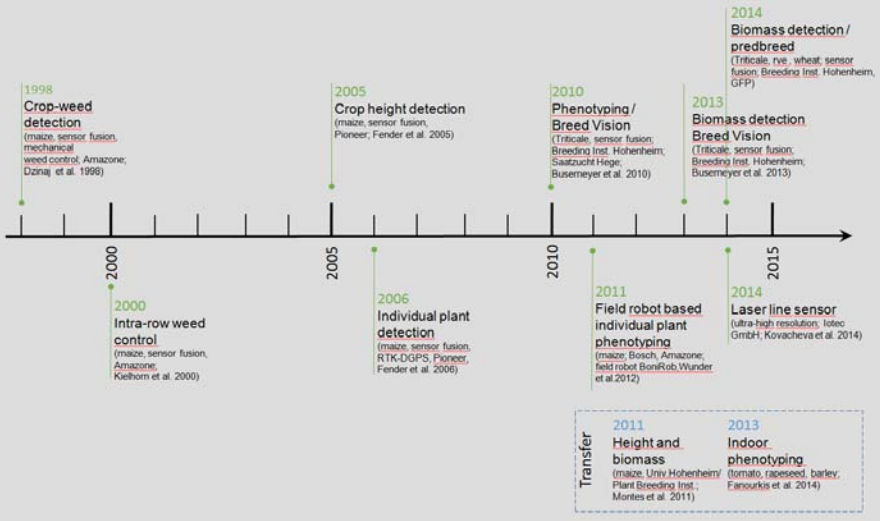
Light curtains, laser-line sensors → "1-bit-imaging"

Lab

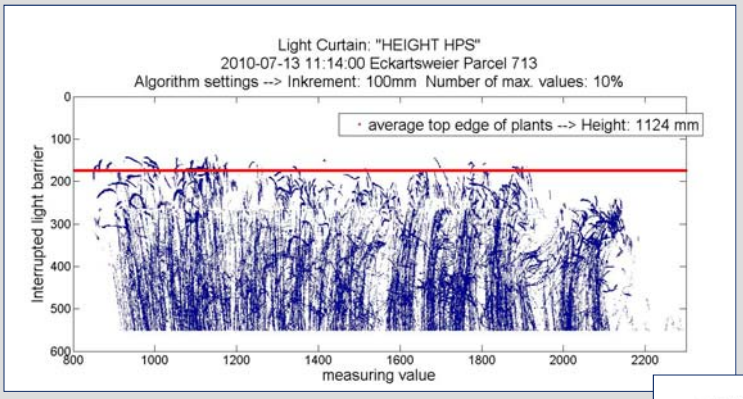
Field

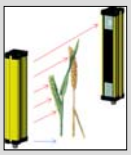


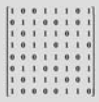
Shadow Imaging (2)

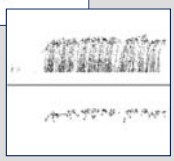


Shadow Imaging (3)

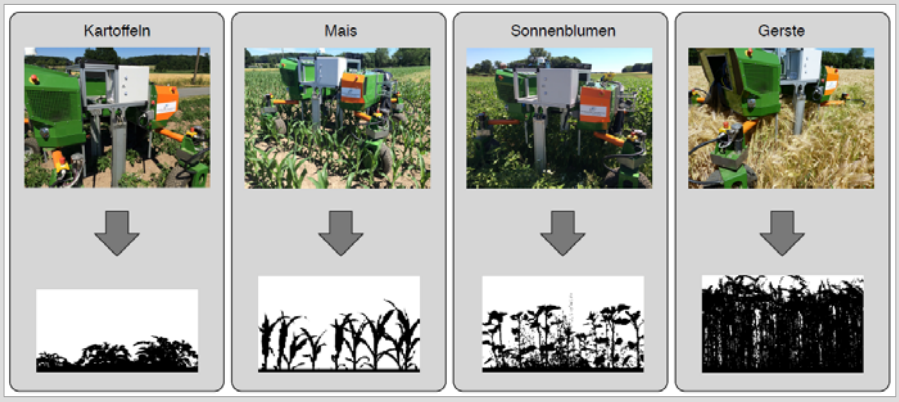




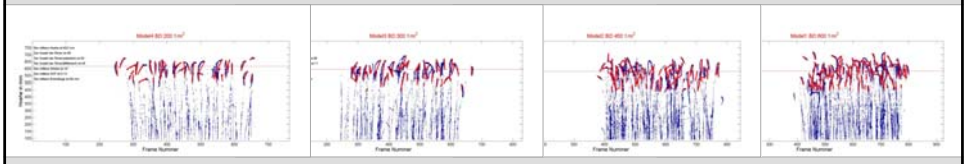


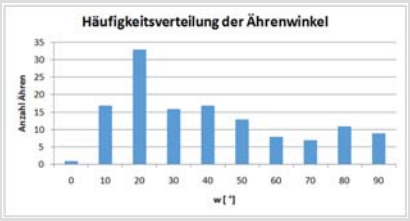


Shadow Imaging (4)



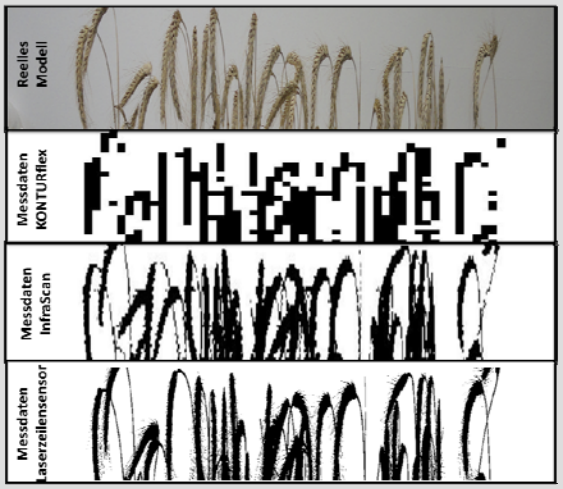
Shadow Imaging (5)





Source: Ivana Kovacheva, University of Applied Sciences Osnabrück, Master Thesis (2013), CBA-Workshop (2014)

Shadow Imaging (6)



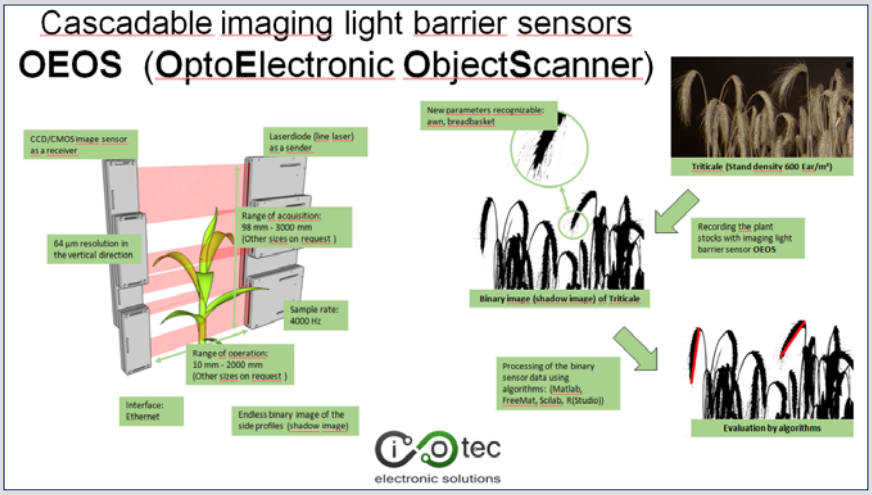
Rough shape information
(low resolution light curtain)

Stalk and ears of corn
(high resolution light curtain)

Stalk, ears and awns
(ultra-high resolution laser line sensor)

20

Shadow Imaging (7)



Shadow Imaging (8)

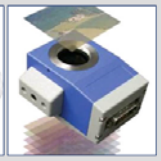
Source: Dominik Nieberg, Master Thesis (2015), Osnabrück; *The Plant Accelerator, University of Adelaide*

Hyper/multi-spectral imaging (1)

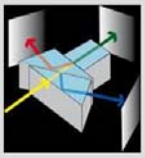
Technological solutions for image-based spectroscopy

Full Frame

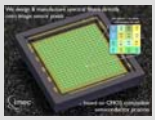
Filter wheel



Programmable filter



Multi-chip camera



Filter matrix

Line-based system

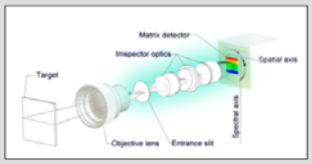
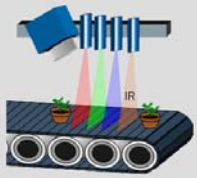


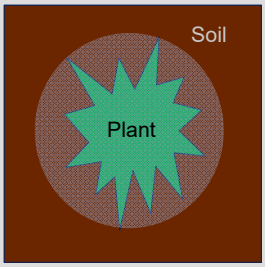
Image-based spectrometer

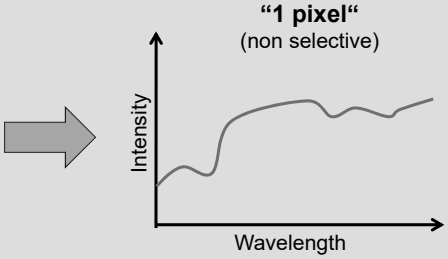


Multiwavelength Laser Line Profile Sensor (MWLP)

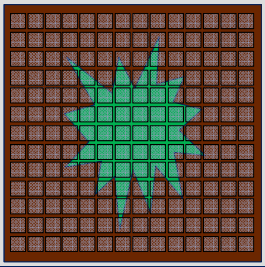
Hyper/multi-spectral imaging (2)

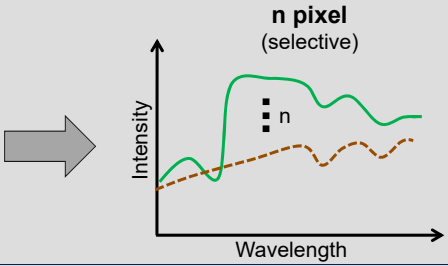
Miniature spectrometer





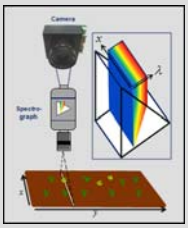
Spectral Imaging

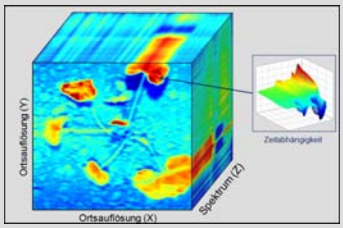


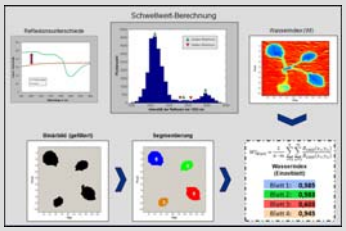


Hyper/multi-spectral imaging (3)

Spectral Imaging (Technology) ⇨ Spectral Cube (Data) ⇨ Moisture parameter (Algorithms)

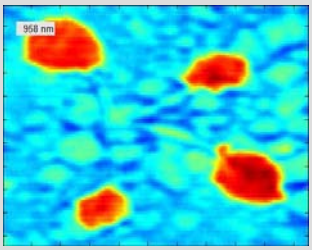


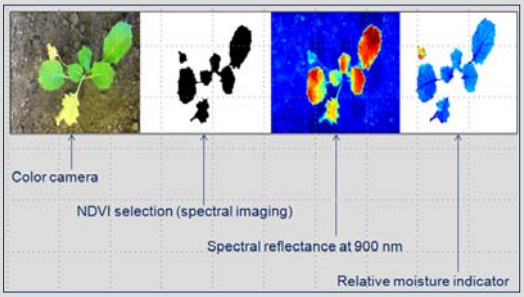




Soruce: Marius Thiel, Hochschule Osnabrück, PhD (in preparation, University Hanover)

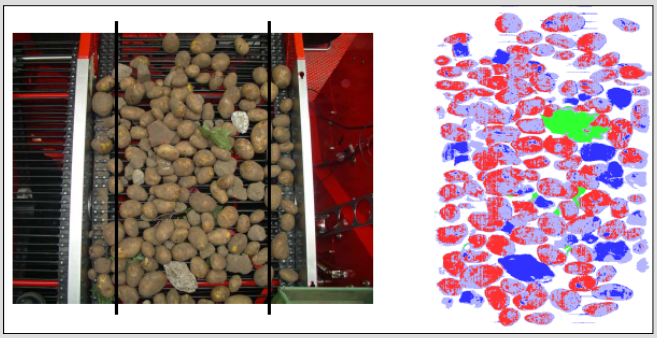
Hyper/multi-spectral imaging (4)





Hyper/multi-spectral imaging (5)

Example: Detection of potatoes and impurities (harvest)

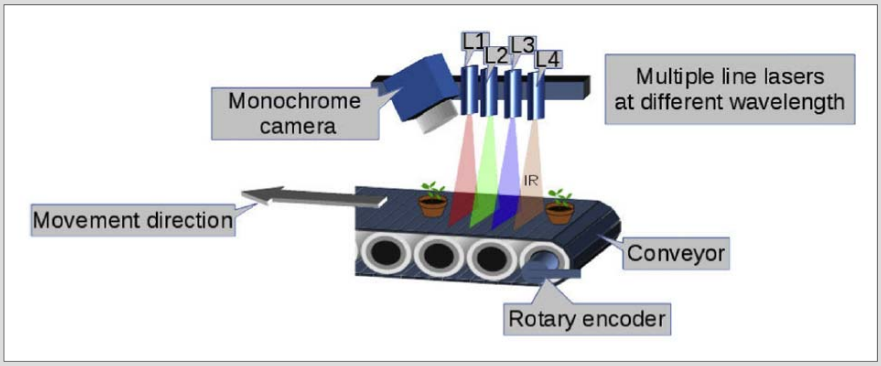


Harvest machine

Pointwise spectral analysis and image processing (online)

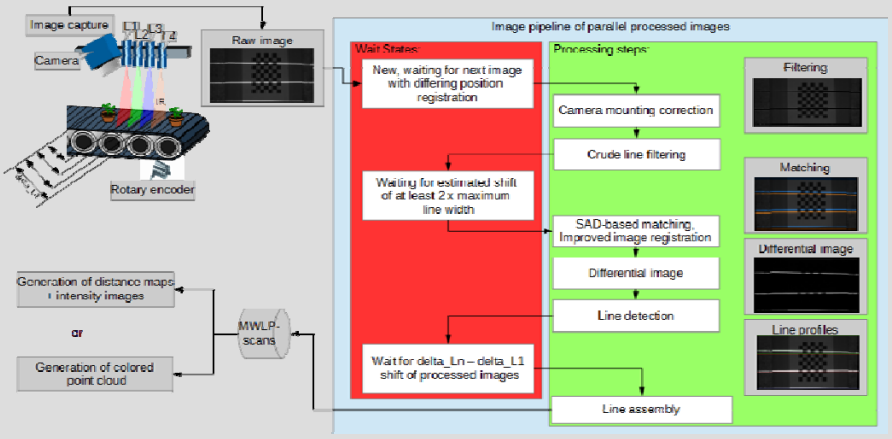
„Multiwavelength Laser Line Profile Sensing - MWLP“ (1)

Combination of 3D and spectral imaging in one sensor



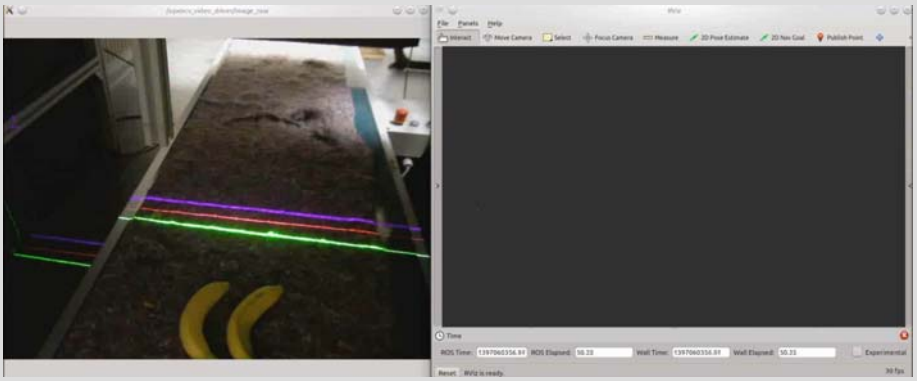
Source: Strothmann, W., Ruckelshausen, A., Hertzberg, J., Scholz, C., & Langsenkamp, F. (2017). Plant classification with In-Field-Labeling for crop/weed discrimination using spectral features and 3D surface features from a multi-wavelength laser line profile system. *Computers and Electronics in Agriculture*, *134*, 79-93.

„Multiwavelength Laser Line Profile Sensing - MWLP“ (2)



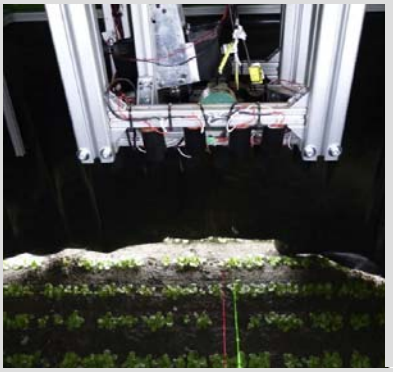
Source: Wolfram Strothmann ; Arno Ruckelshausen and Joachim Hertzberg: "Multiwavelength laser line profile sensing for agricultural crop characterization ", Proc. SPIE 9141, Optical Sensing and Detection, 2014, http://dx.doi.org/10.1117/12.2052009

„Multiwavelength Laser Line Profile Sensing - MWLP“ (3)



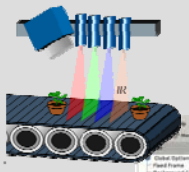
Movie

„Multiwavelength Laser Line Profile Sensing - MWLP“ (4)

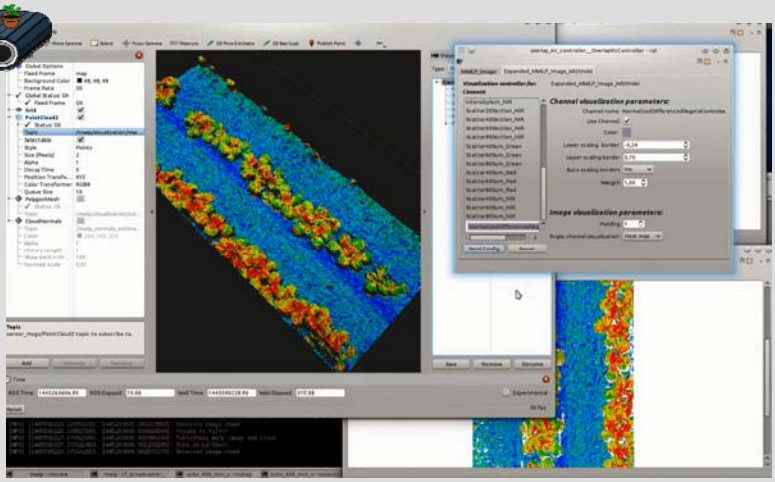


Movie

„Multiwavelength Laser Line Profile Sensing - MWLP“ (5)

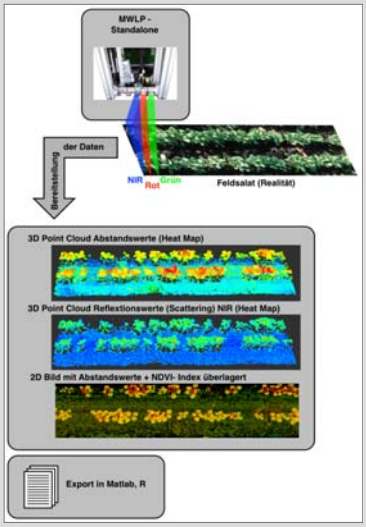


3D-NDVI-Imaging

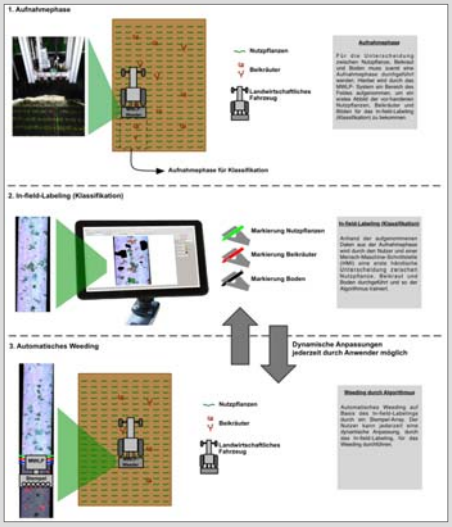


„Multiwavelength Laser Line Profile Sensing - MWLP“ (6)

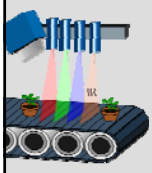
3D / NDVI – Vegetation Index



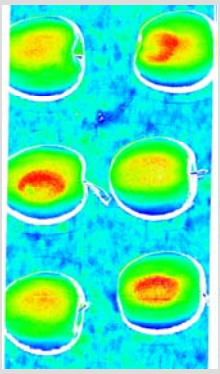
Process integration of MWLP-system



„Multiwavelength Laser Line Profile Sensing - MWLP“ (7)



Scattering example: apples dropped from 60 cm height



MWLP system, scattering feature of NIR laser @ 850nm, immediately after drop

Photo of scene, immediately after dropping / damaging the apples

Phenotpying platforms / outdoor (selection)

Soruces: Schmidhalter/TU München, Bayerische Landesanstalt für Landwirtschaft, Lemnatec, N-Tester/landwirt.com, Sengis/Uni Hohenheim, Imko, AgriCon, satimagingcorp, HS Osnabrück

Sensor and data fusion

Said the **eye** one day, "I see beyond these valleys a mountain veiled with blue mist. Is it not beautiful?"

The **ear** listened, and after listening intently awhile, said, "But where is any mountain? I do not hear."

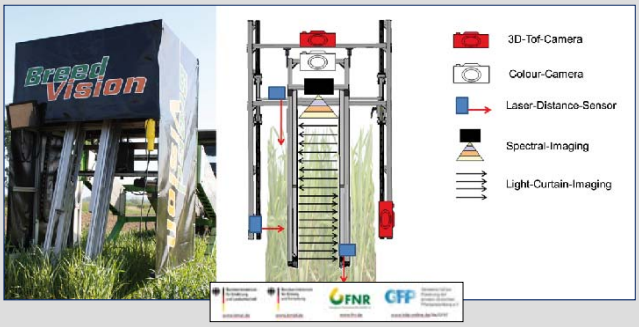
Then the **hand** spoke and said, "I am trying in vain to feel it or touch it, and I can find no mountain."

And the **nose** said, "There is no mountain, I cannot smell it."

Then the eye turned the other way, and they all began to talk together about the eye's strange delusion. And they said, "Something must be the matter with the eye."

K.Gibran: „The Madman" (1918)

Sensor-Fusion / Phenotyping



Projects: BreedVision, predbreed, BoniRob (BMEL,BLE, BMBF)

Concept „BreedVision“ (plant breeding)

Technische Daten — BreedVision

Trägerfahrzeug Zürn Z550GT
- *Dimensionen (in m)*
  - B x L x H (min – max)
    - 1,5 x 5,0 x 2,0 – 2,5 x 5,0 x 3,0???
  - Spurbreite (min - max)
    - 1,3 – 2,5???
  - Durchfahrtshöhe (min - max)
    - 1,3 – 2,1
- *Eigenschaften*
  - Leistung: 50kw???
  - Antrieb: hydraulisch
  - Geschwindigkeit (min – max)
    - 1 - 20 km/h
  - Leergewicht: 4,2t
  - Zuladung (max): 1000kg

Sensorik
- *Plattform*
  - GPS
  - Rotationsencoder
  - Gyrosensor
  - RGB Kamera
  - Multireflexions-Ultraschall
- *Sensormodul*
  - Lichtgitter
  - Spectral-Imaging System
  - Multireflexions-Ultraschall
  - 3D Kamera
  - 2 Lichtfeldkameras (RGB+NIR)
  - 3 Triangulationssensoren
  - ...modular erweiterbar

Kulturarten
- *Referenziert*
  - Triticale
  - Weizen
  - Roggen
- *geplant*
  - Gerste
  - Hafer
  - Mais

Nicht invasive Pflanzenparameterbestimmung
- Wuchshöhe
- Feuchtbiomasse
- Trockenbiomasse
- Ähreneigenschaften

Durchsatz
- ca. 2000 Testparzellen/Tag

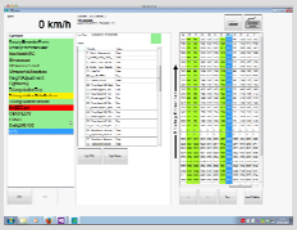
Flexibilität, Modularität und Wartung
- Modularer Hardwareaufbau mit *Industriestandardkomponenten* der Firma Beckhoff
- Datenbank-Infrastruktur
- Hochaufgelöste Zeit- und Ortsstempel zur Sensor- und Datenfusion
- 10 am Fahrzeug verteilte Use Cases bieten Schnittstellen zum Anschluss weiterer Sensoren
- Software Fernwartung und Support über LTE und VPN

Beteiligte Einrichtungen und Unternehmen im Projekt „predbreed“

Hochschule Osnabrück University of Applied Sciences

Ultra-high spatial and temporal resolution (data management)

- Self engineered software for simultaneous recording of all connected sensors
- Integrated field plan and sensor status view
- Database-infrastructure
- High resolution time (1ms) and position (< 1mm) – based recording
- Prerequisite for (multi-)sensor fusion
  - Statistical but also concrete!
  - Pointwise overlay of different sensors
- Generating more accurate values (eg. height)
- Determination of complex key figures (e.g. biomass)



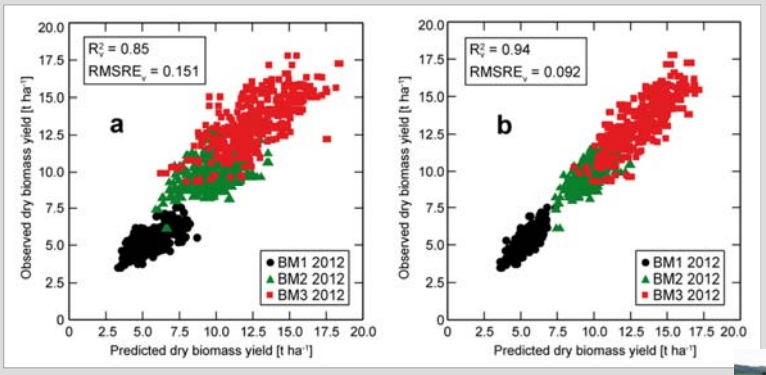
BreedVision

Juli 2015

Biomass detection (field trials) based on sensor fusion

Ignore water content

Take into account water content (+Spectral Imaging)



Busemeyer et al., BreedVision – A MultiSensor Platform for Non-Destructive Field-Based Phenotyping in Plant Breeding, Sensors, 2013, Vol. 13, pp. 2830-284.

Busemyer. Lucas, PhD Thesis, 2013 (University Stuttgart-Hohenheim / Univerrsity of Applied Sciences Osnabrück)

Busemeyer et al., Precision phenotyping of biomass accumulation in triticale reveals temporal genetic patterns of regulations, Nature Scientific Reports 3, Article Number 3442, 2013.

Overview

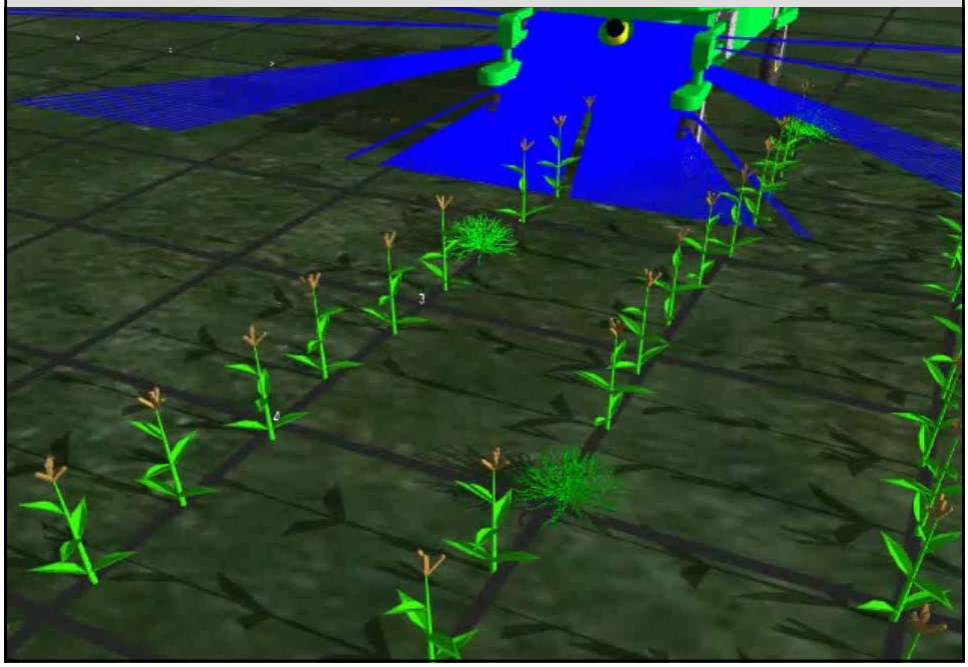
Technology meets Nature

Image-based Sensors in Agriculture

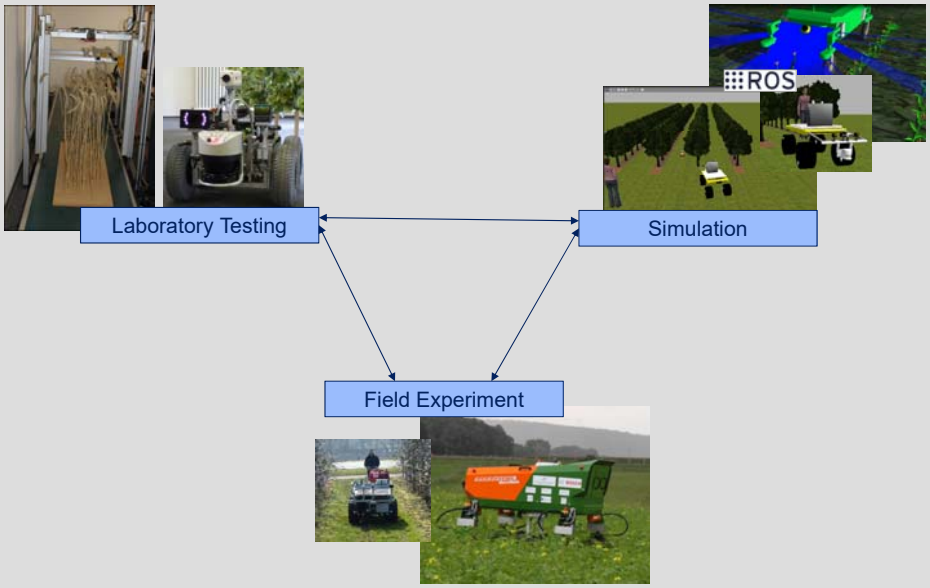
Modeling Environment

Alternative (Technological) Concepts for Agriculture

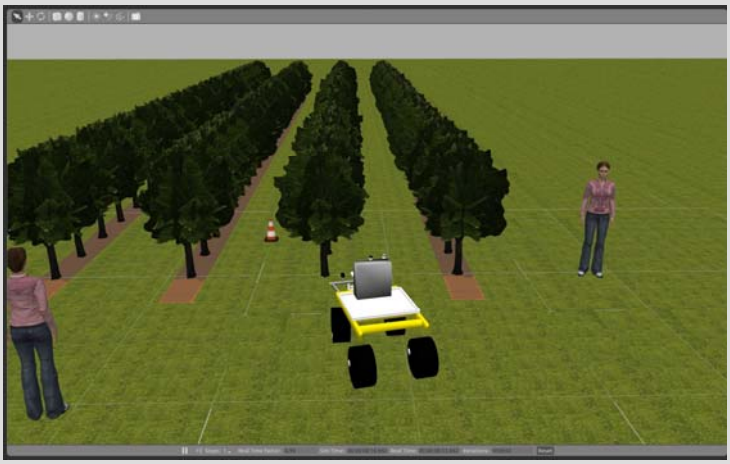
Key technology: simulation (process integrated imaging)



Lab testing – simulation – field trial: “nature in the loop“



Simulation for reality

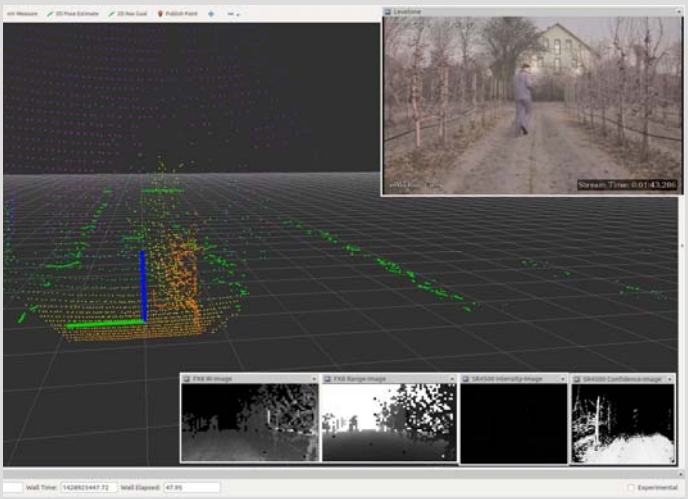


Project: elWObot/BMEL-BLE; Andreas Linz/HS Os

Data acquisition

Autonomous field robot Cäsar (Raussendorf, projekt elWObot)

Reality for simulation



elWObot-Inbetriebnahme

elWObot

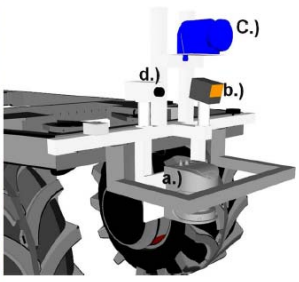
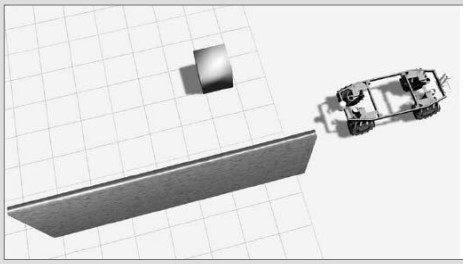
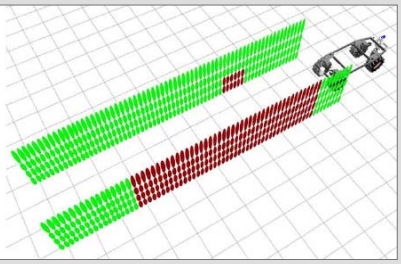


Figure 4 elWObot in the simulation environment Gazebo (left). Sensor fixture (simulation): a.) Horizontal laser scanner b.) 3D laser scanner c.) Vertical laser scanner d.) Webcam (right).

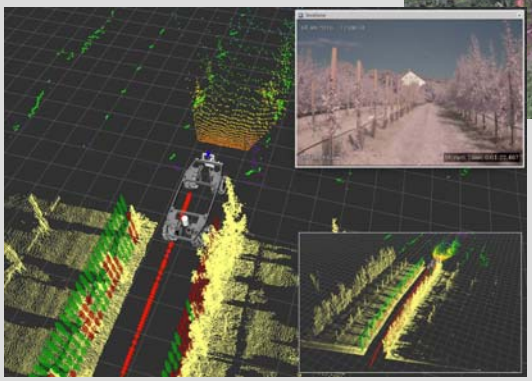


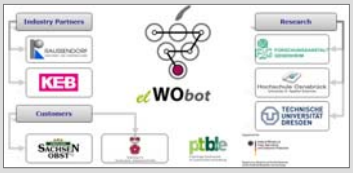


Autonomous electrical robot for orchards and wine yards (elWObot)

Simulation-und-Feld

Feld





Linz., A., Brunner, D., Fehrman, J., Herlitzius, T., Keicher , R., Ruckelshausen, A., Schwarz, H.-P.: Modelling environment for an electrical driven selective sprayer robot in orchards. In: Proceedings of the 11th European Conference on Precision Agriculture, Advances in Animal Bioscience 8(2), pp. 848–853, ISSN 2040-4700, 2017.

International Field Robot Event

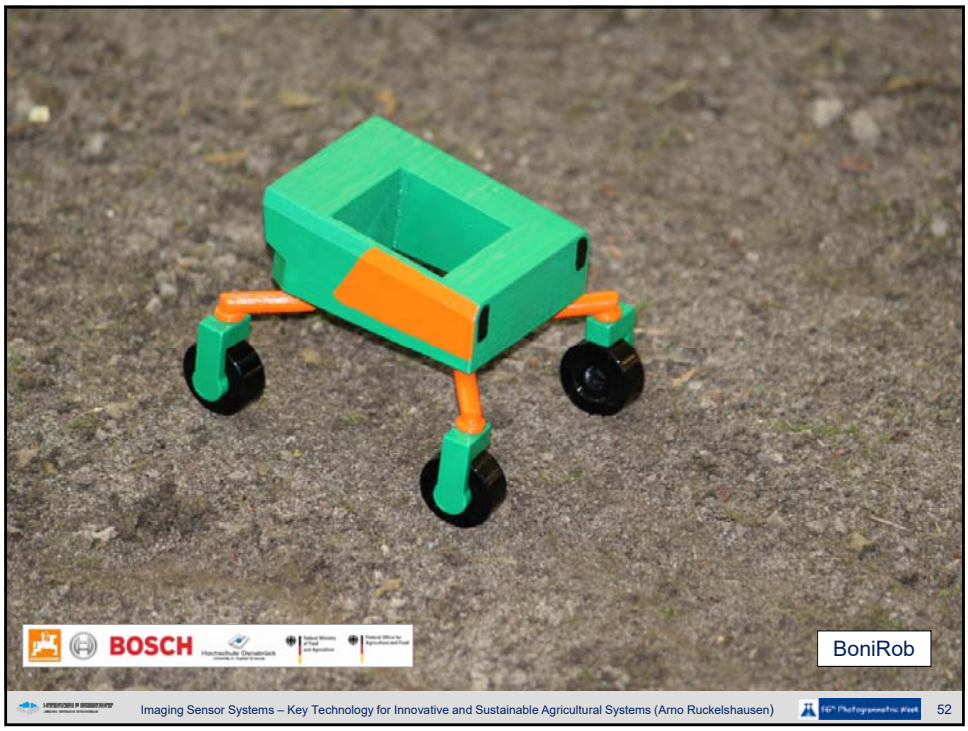
Overview

Technology meets Nature

Image-based Sensors in Agriculture

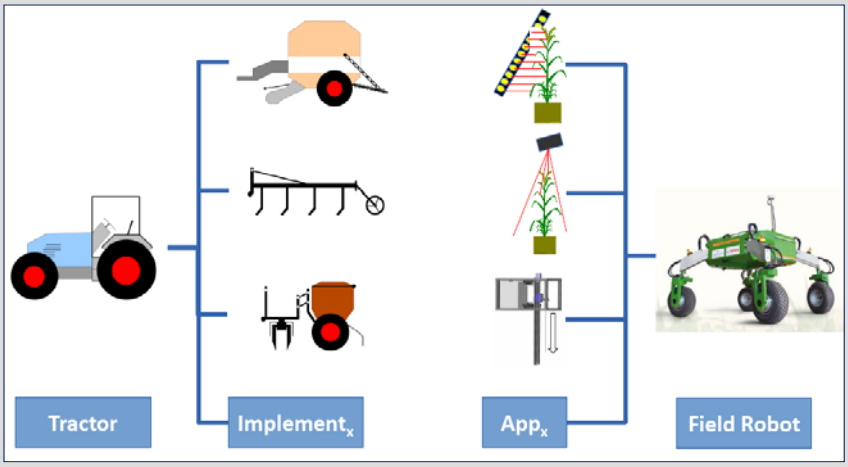
Modeling Environment

Alternative (Technological) Concepts for Agriculture

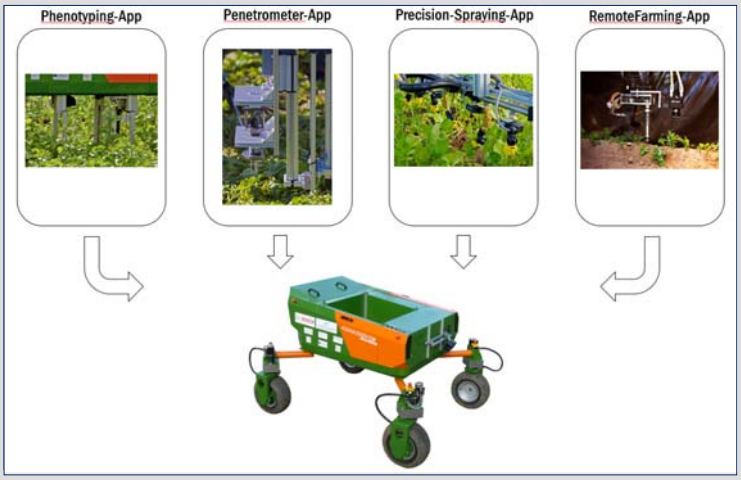


BoniRob / changing apps

Tractor-Implement - Field Robot-App

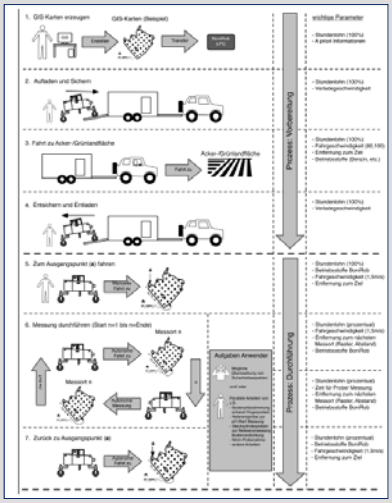


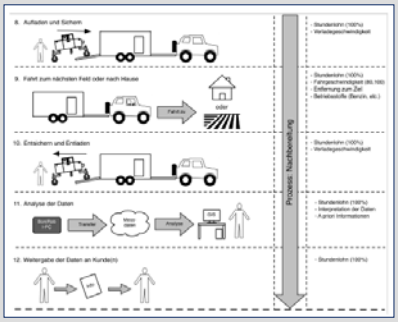
„App-Concept“ for field robotics



BoniRob-Phenotyping

Autonomous robots: economical aspects

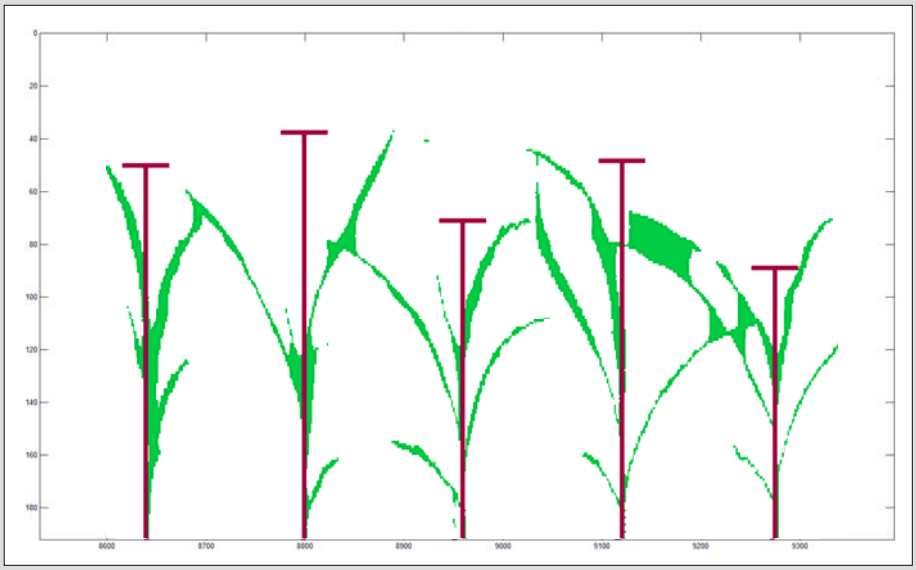




Wirtschaftlichkeit zur Feldroboter-basierte Bodenparameter-Bestimmung (Christian Scholz, Masterarbeit HS Osnabrück, 2015)

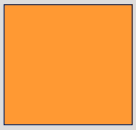
View in the future: individual crop farming

Field measurements (platform BoniRob, light-shadow sensors/light curtain)

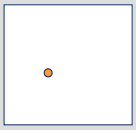


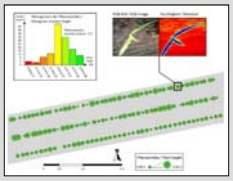
View in the future: individual crop farming

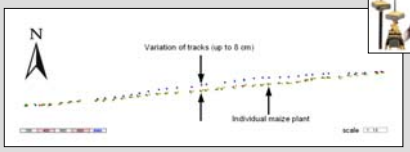
Field



Plant







View in the future: “Remote Farming“

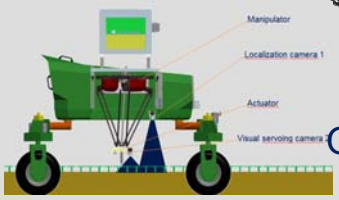
Status quo – mechanical weed control in ecological farming

(ca. 100-400 h/ha)

View in the future: “Remote Farming“

BoniRob with mechanical weed control App

UMTS Module



On-field

Webinterface with marker tools

Server

Mobile Networks

Human remote worker

Off-field (remote)

View in the future: “Remote Farming“

Interesting meeting on the field …

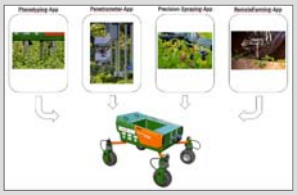
This vehicle is called „self-propelled“.

This vehicles propells itself.

View in the future: autonomous systems

„Family“ (BoniRob)

„App-Concept“ (BoniRob)

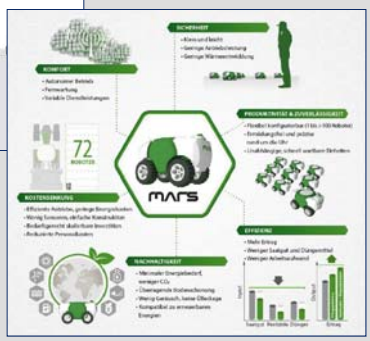


Sources: Deepfield Robotics - Robert Bosch Start-up GmbH, University of Applied Sciences Osnabrück, Amazonen-Werke, 2016/2017

Autonomation of existing machines

Precision Makers/Fendt, profi 10/2016: Strautmann 2017

Autonomous systems: logistics



Source: Fendt/Benno Pichlmaier

Imaging in Agriculture

- Imaging is a key component for the digital transformation in agriculture
- Multiplicity and complexity of variables in agriculture is high
- Selection of application-specific robust imaging systems is of high relevance
- Applications of imaging: navigation, processing, safety, quality, documentation
- Imaging strongly supports sustainable innovative agricultural processes
- Important topics for the digital transformation in agriculture: data management, human machine interface, sensor data fusion, „Work 4.0“, sustainability, internalisation of external costs

☺ Imaging and robotic technologies are supporting tools for a sustainable combination of economical, ecolological and social aspects in agriculture

☺ Interdisciplinary cooperation