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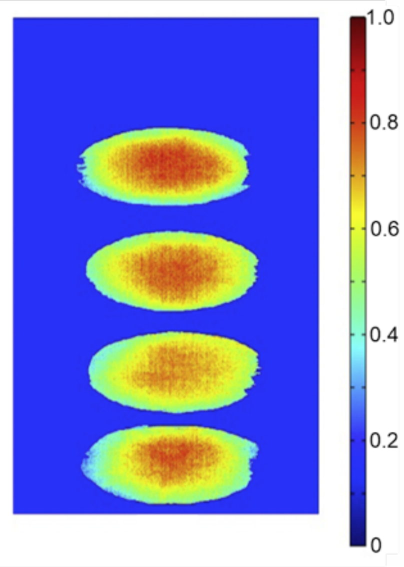
Digitisation in Agriculture and Food Processing

Principles, Concepts and Applications



MSc. Michael Hesse
Department of Agricultural and Biosystems Engineeing

https://i.ytimg.com, http://www.oberhoff.com

Digitisation:

- the transformation of analogue values in digital formats
- needs data (input parameter)
- has to be measurable
- today often a buzzword for all we automatise, operate, regulate, measure etc.

The 4th agricultural revolution

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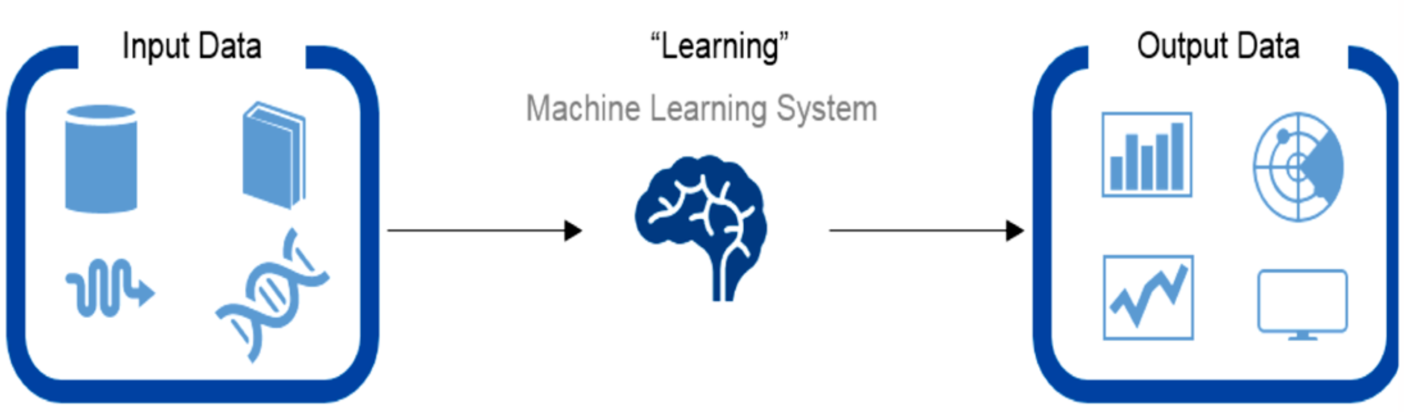
Heinrich Prankl

The vision…

https://doi.org/10.1016/j.biosystemseng.2017.09.007

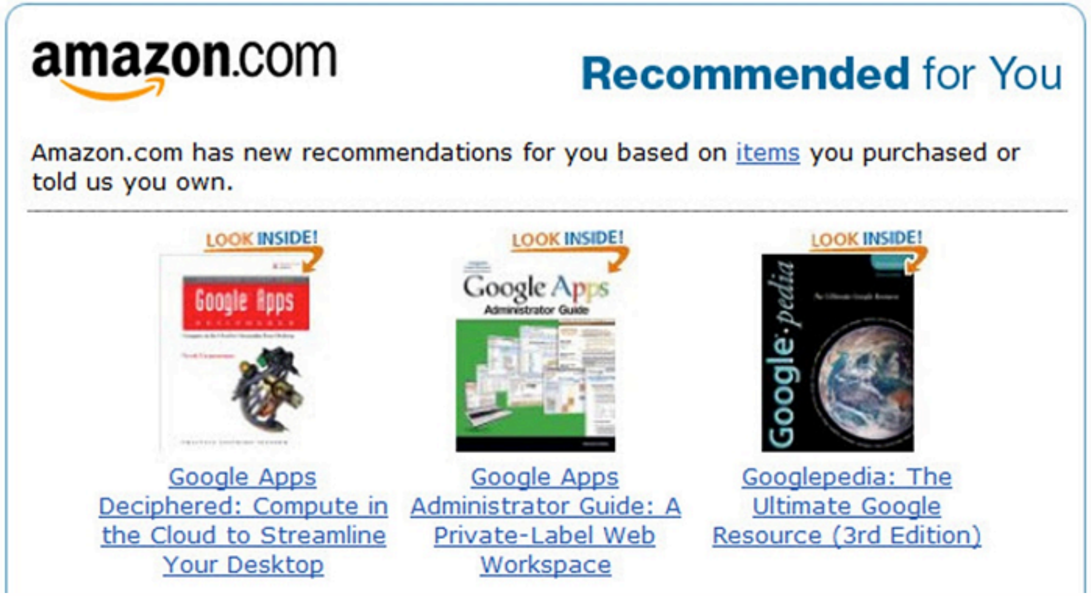
Machine learning

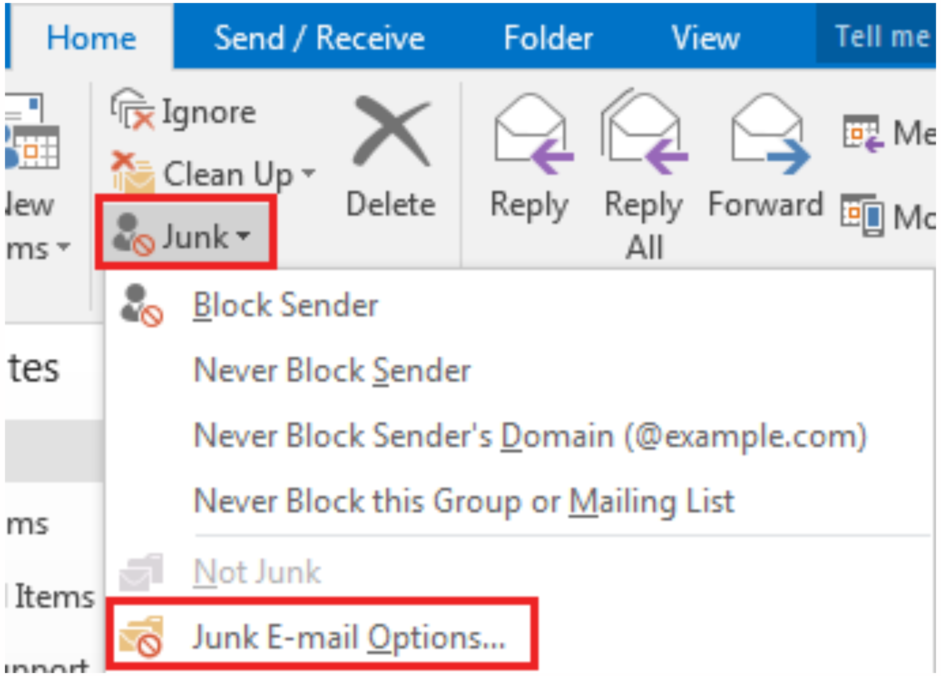
- **Extracts data knowledge without explicit programming**
- **Classification, Data Mining, pattern recognition…**



➔ Causality vs collinearity (correlation)!

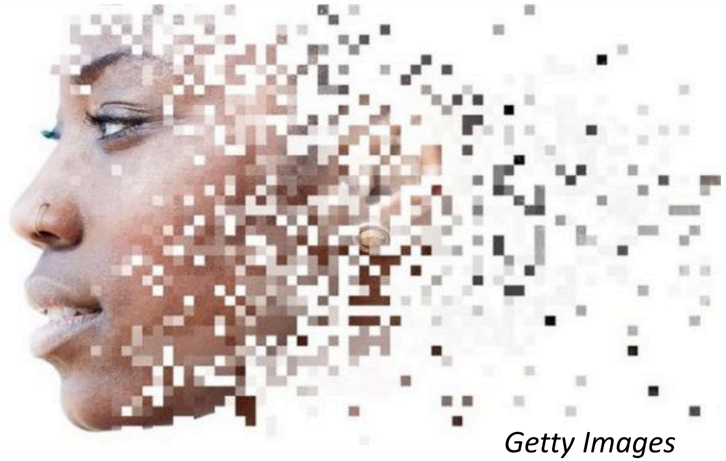
State of the art – opportunities

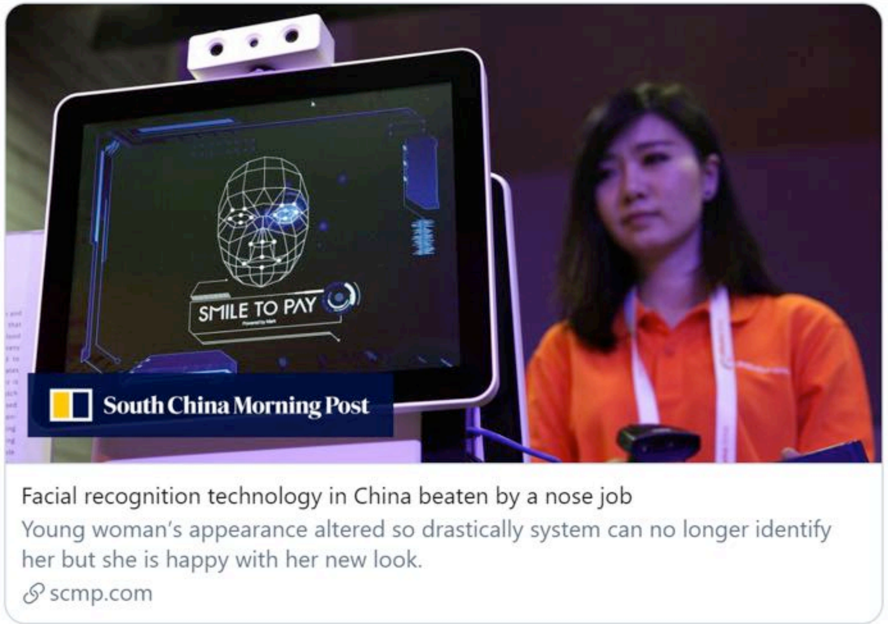




kb.wisc.edu/helpdesk/page.php?id=52445, https://www.mageplaza.com/blog/product-recomendation-how-amazon-succeeds-with-it.html

State of the art – risks


Getty Images



Stephen Brashear | Getty Images

bbc.com/news/technology-49961089; Cbsnews.com

Sensors:

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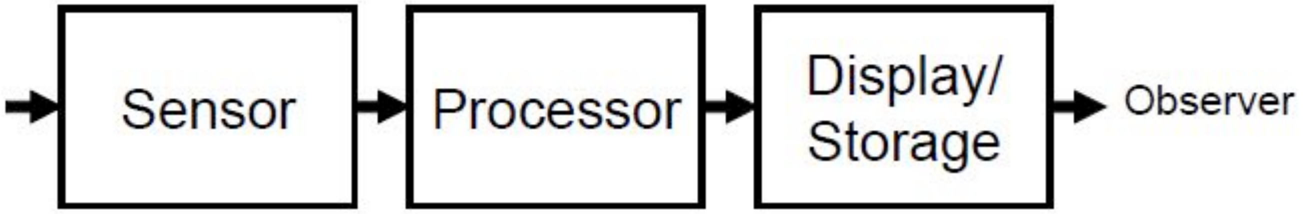
- Basically sensors copy our sensory perception:
- They are part of a wiring as switch-key, probe or transducer
- Sensors convert a measured physical value into an output signal (mostly electrical: volt)
- "Sensor" is a frequently and often imprecise used term, mostly as „something to measure, often with a cable outlet"
- The term „detector“ is used synonymous to „sensor“

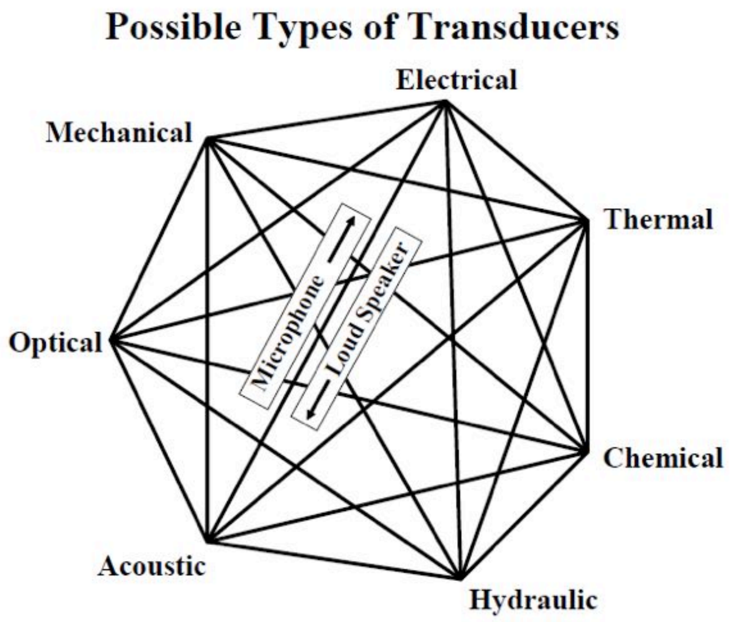
Sensor selection

- **To choose the instrument most suited for a particular measurement application, we have to know the system characteristics.**
- **The performance characteristics may be broadly divided into two groups, namely ‘*static*’ and ‘*dynamic*’ characteristics.**
- **Static characteristics**
  - the performance criteria for the measurement of quantities that remain constant, or vary only quite slowly.
- **Dynamic characteristics**
  - the relationship between the system input and output when the measured quantity (measurand) is varying rapidly

Generalised instrument system

- **Primary element (sensor)**
  - In contact with process.
- **Transducer**
  - converts one type of energy to another for various purposes including measurement or information transfer.
- **Transmitter**
  - Converts signal
  - Filter and amplification of measurement signal





Systematic characteristics

- Range
- Span
- Linearity
- Sensitivity
- Environmental effects
- Hysteresis
- Resolution
- Death space

Properties of a measurement instrument

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- **Range:** Set of values of the process attribute that can be measured by the sensor. For example 50ºC-150ºC. Sensor output e.g. 4-20 mA
- **Reach:** Difference between the upper and lower limits of the range. For example, 100ºC.
- **Margin of error:** Difference between the measurement obtained from the sensor and the real value of the process attribute. It can be static or dynamic.
- **Accuracy:** Maximum margin of error under nominal operating conditions.
  - Absolute value
  - % Reach
  - % Upper range limit
  - % Measured value
  - % Full scale

Properties of a measurement device

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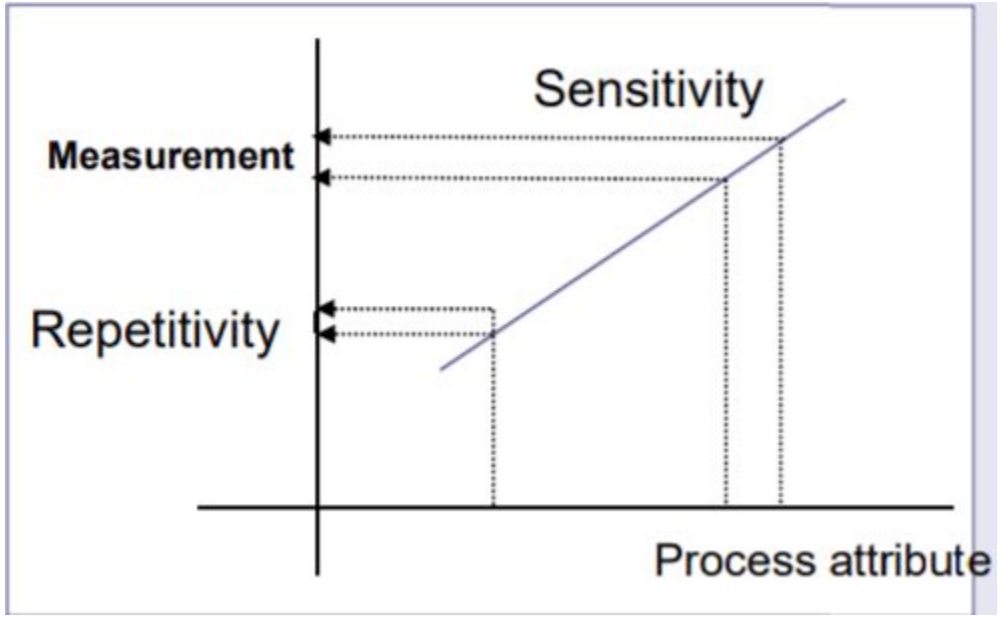
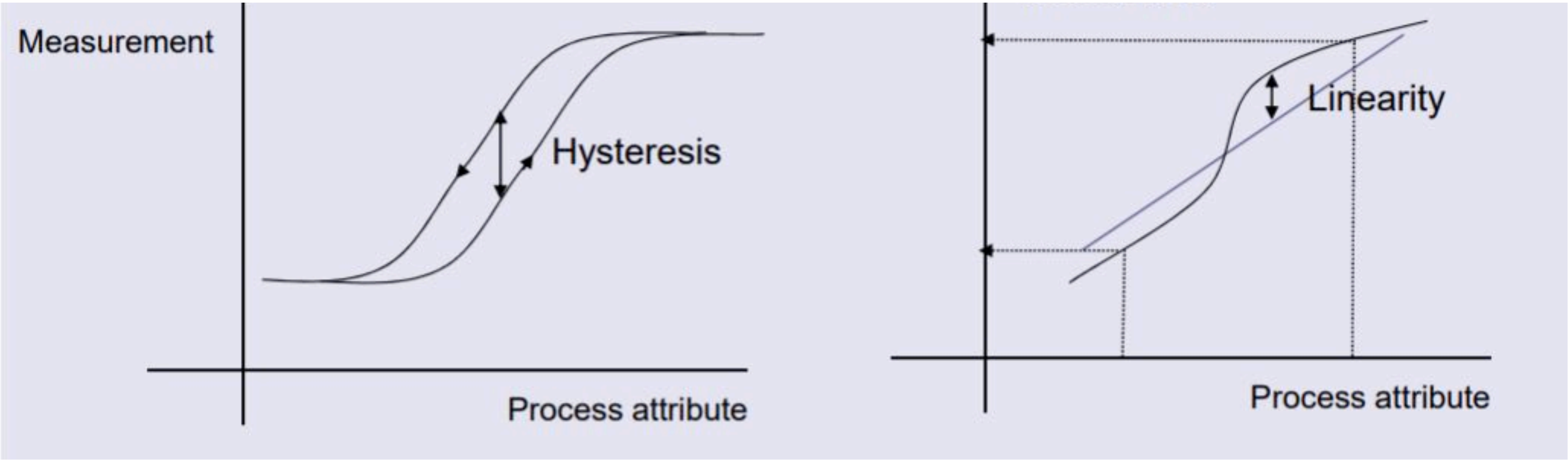
- **Dead-zone:** Range of variation of the process attribute that does not produce a change on the measured variable. It is related for example to the static friction. (%Reach).
- **Repetitivity:** The sensor is able to obtain the same measurement for the same process attribute (%Reach).
- **Sensitivity:** Relation between the increment of the measured signal and the increment of the process attribute. (slope).



Properties of a measurement device

- **Resolution:** Minimum increment in the process attribute that generates a change in the measurement signal. It is related to the Dead-zone and Sensitivity (Absolute or %Reach)
- **Hysteresis:** Maximum value of the difference between the measurements obtained in increasing and decreasing sense. (%Reach)



- **Linearity:** Maximum linear approximation error.

Classification of measurement devices

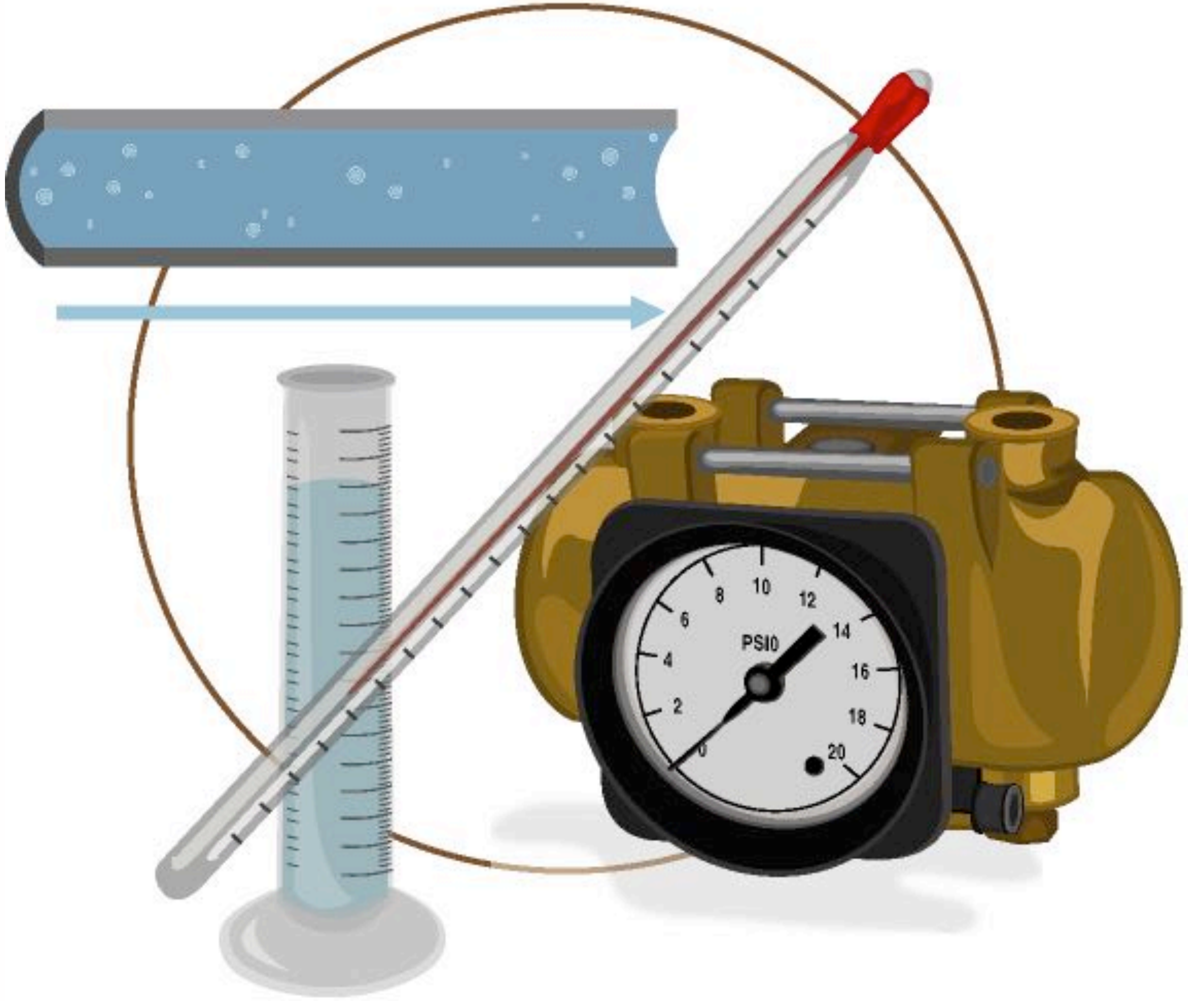
- **Energy**
  - Passive: Use the energy from the process.
  - Active: Use of an external energy source.
  - Measurement value:
    - Analog: Measurement takes value on a infinite set of values.
    - Digital: Measurement takes value on a finite set of values.
- **Presentation of the information**
  - Blind: No information is visible.
  - Indicators: The measurement is visible to the operator.
  - Recorders: The measurement is recorded by the instrument.

Classification of measurement devices

- **Function:**
  - Primary element: In contact with the process.
  - Transmitter: Signal transmission.
  - Transducer: Converts one type of energy to another for various purposes including measurement or information transfer.
  - Controller: Local or remote Actuators

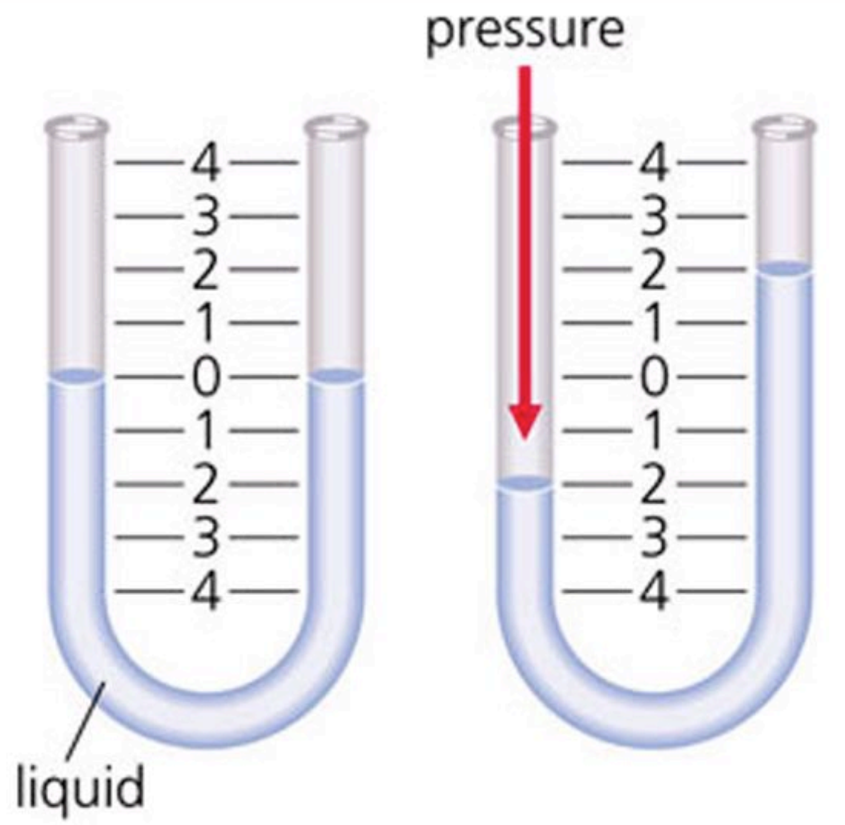
Process variables

■



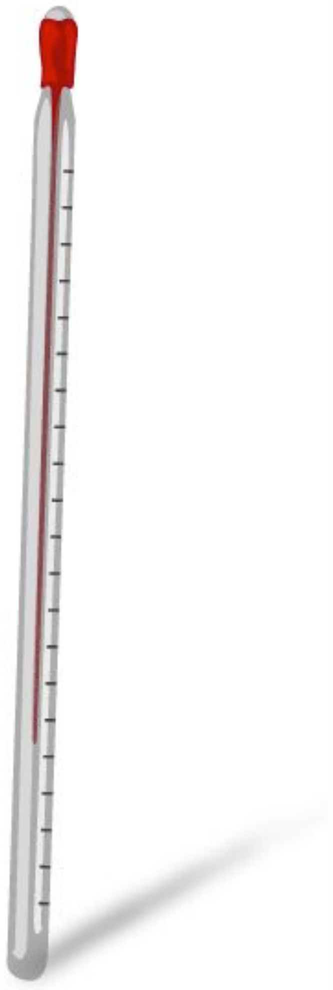
Process variables – Pressure

- The force applied to a unit of area. Gases and vapors apply force uniformly over all surfaces. While liquids apply force in accordance to their depth and density.



Process variables – Temperature

- Temperature is defined as a measure of the average kinetic energy (hotness or coldness) of a substance as indicated on a reference scale.
- Process plants control temperature in almost every major process vessel.



Process variables – Level

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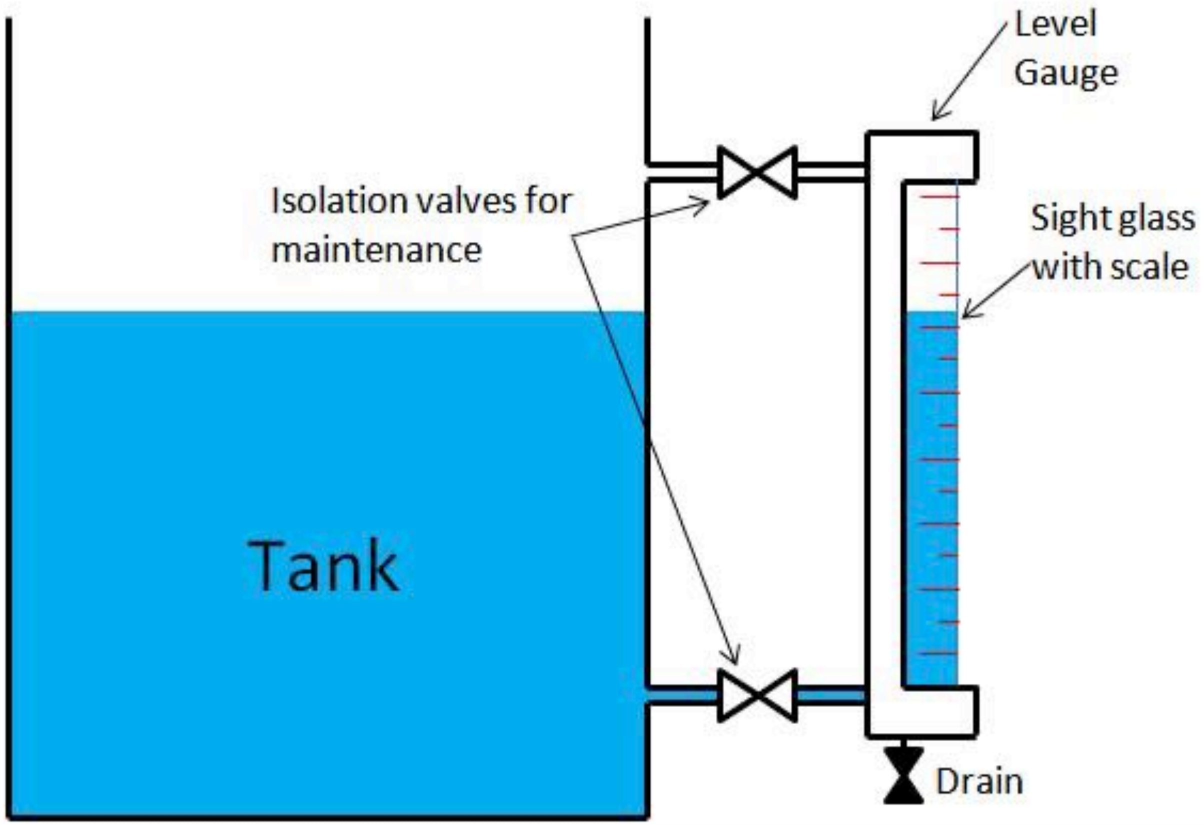
- Level is defined as the position of either height or depth along a vertical axis. In industry the term level specifically means the surface position of a material in a vessel.
- For example, checking levels is very important when controlling a liquid phase reactor where there is a need for a continuous flow of reactants into the vessel and a continuous flow of reacted product leaving the vessel.



Process variables – Flow

- In process industries the word flow is used interchangeably with the term flow rate.
- Flow rate can be defined as the quantity of fluid that moves through a pipe or channel within a given period of time.
- Flow rate is usually expressed in volume or mass units per unit of time, such as gallons per minute or cubic metres per hour.

Instruments and their functions

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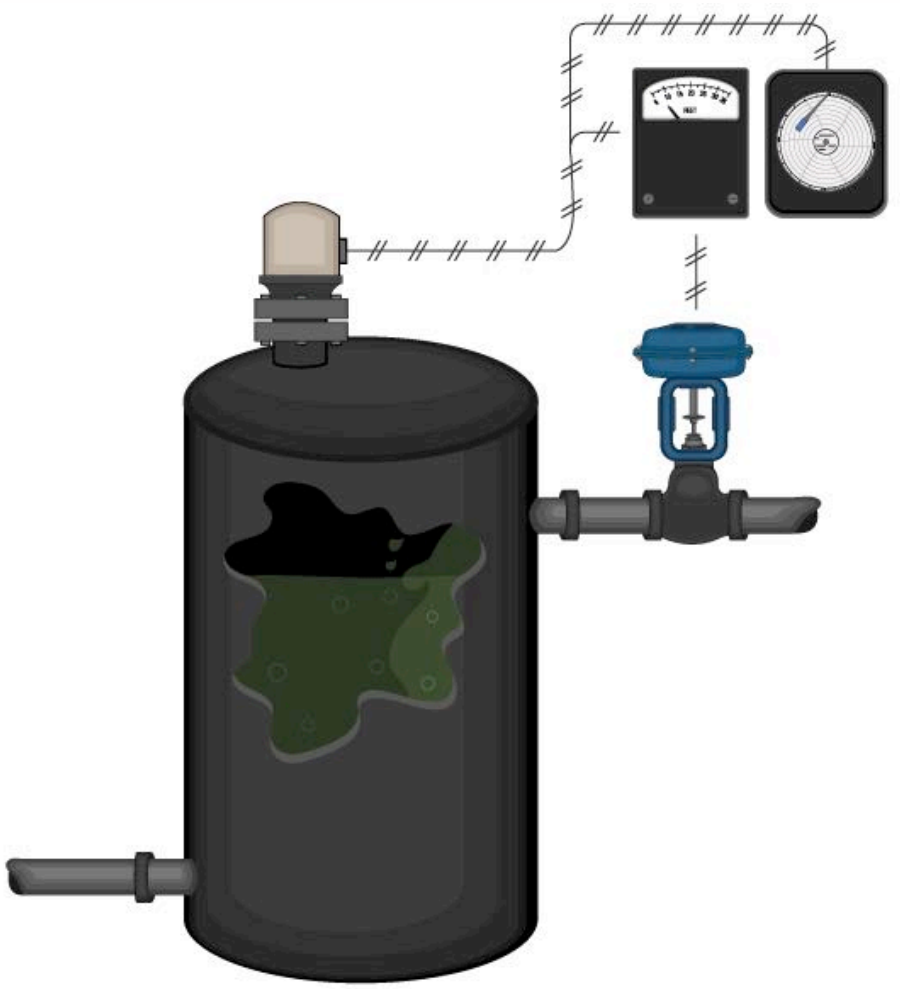
- Sensing, indicating, transmitting, comparing, and/or controlling. The sensing or measuring or transmitting device is the first instrument in the loop.
- Once it measures the process variable, it then must communicate that value to the next instrument in the loop, typically the controller.
- The controller would have to interpret that incoming signal, compare it to a setpoint, process the difference, and then produce an output signal that indicates to the final controlling element, usually a control valve to open more, close more or just stay the same.



Why is there a need for advances in mechatronics?

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- **Increased scale of operation**
  - Automation
  - Complexity of systems
  - Contract work
  - Need for systemic decision support
- **Tightening legislation**
- **Niche sector demands**
  - Diversified production
  - Systemic sustainability
- **"Food 2030"**
  - Guiding concept for Framework Program 9

➔ **Integrative, knowledge based system development**

Optical sensors

principles, concepts and applications

https://i.ytimg.com, http://www.oberhoff.com

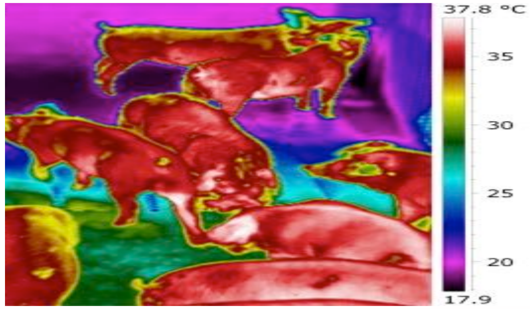
Where do optical sensors come in?

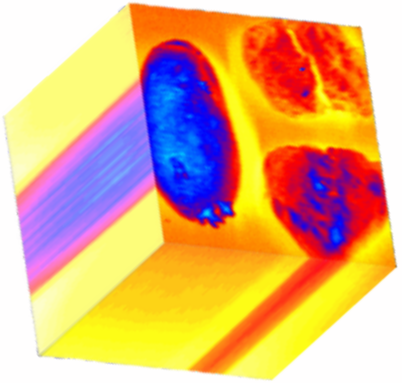
- **Multitude of different objects and objectives**
- **Need for deeper understanding of processes**
  - Commonly indirect and insufficient sensing
  - Insufficient accuracy of available process data
  - Direct observation
  - Optimisation based on post process evaluation
- **Need for direct continuous measurement of characteristics**
- **Need for sensor information fusion**

➔ Combination of fundamental and applied research

Principles of broadly used optical sensors

- **Non-destructive (non-contact)**
- **Feature analysis**
  - Physical
    - Shape, size, texture…
  - Chemical and biotic factors
    - Component
    - Microorganism counts…
- **Measurement principles**
  - Direct or indirect attribute determination
  - Visible light (colour and black & white)
  - Mono-, Multi- and Hyperspectral
  - Thermal
- **Spot, 2-, 3-dimensional, time of flight, plenoptic**

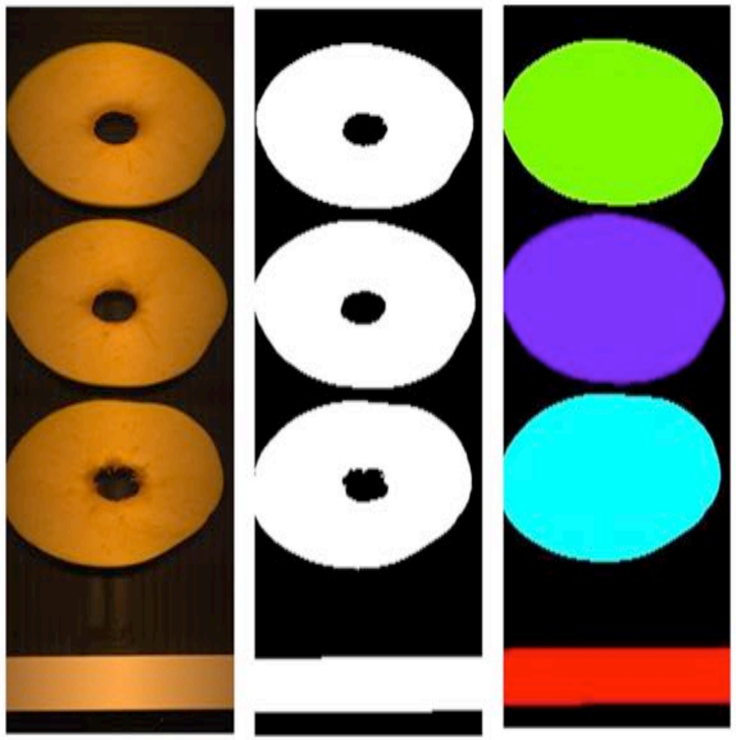




http://www.perception-park.com/uploads/1/1/2/0/11207127/6181200.png; Brown-Brandl et al., 2013

Focus of the presented studies

- **Non-invasive optical examination using**
  - Hyper- and multispectral systems
  - RGB and BW imaging
  - Colorimetry
  - Thermography
- **Development of**
  - Data analysis and classification algorithms
  - Data reduction algorithms
  - Real-time measurement systems
  - Sensor and information fusion
  - Transfer to less complex systems
  - Control system set-ups



Pre processing apple slice hypercubes

Crichton et al. (2017). Drying Technology (10.1080/07373937.2017.1356847)

Case 1: Optical sensors in sugar beet harvesting

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https://grimme.com

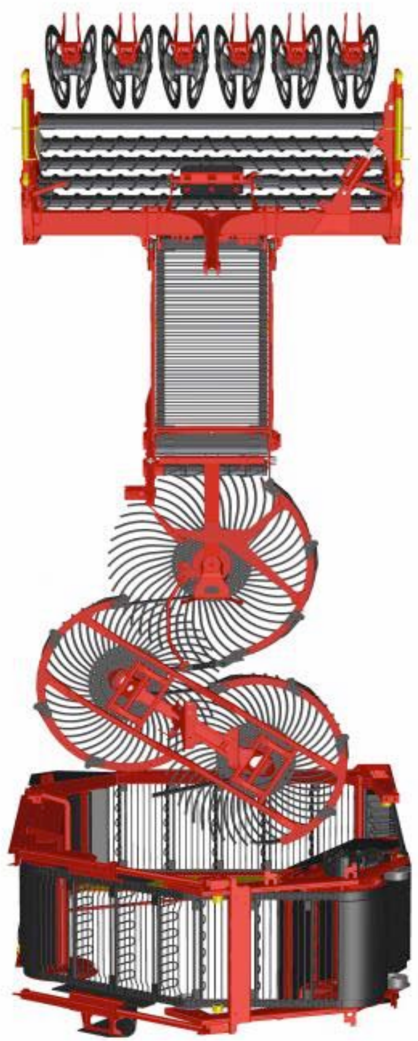
Case 1: Problem statement

- **Current situation**
  - De-regulation of market
  - Extended storage time

➔ **Long term impact on quality**

  - Respiration
  - Inverted sugars production
  - Microbial degradation
  - Pests

- **Research goals**
  - Artificial sugar beet for process assessment
  - Camera based machinery assessment and control
  - Camera based assessment on heap



Internal set-up sugar beet combine harvester

https://grimme.com

Case 1: Common types of damages

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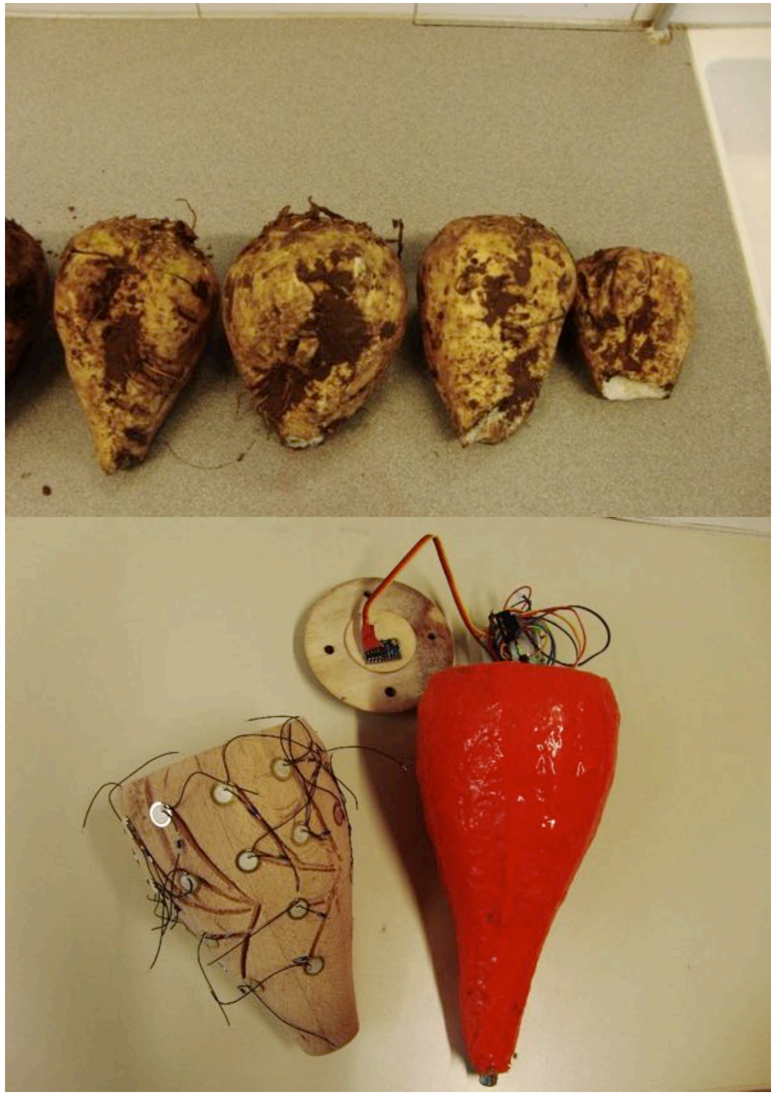
- Cut off (head) position too low
- Root breakage
- Cuts
- Internal bruising
- Skinning injuries



Case 1: Harvesting and quality

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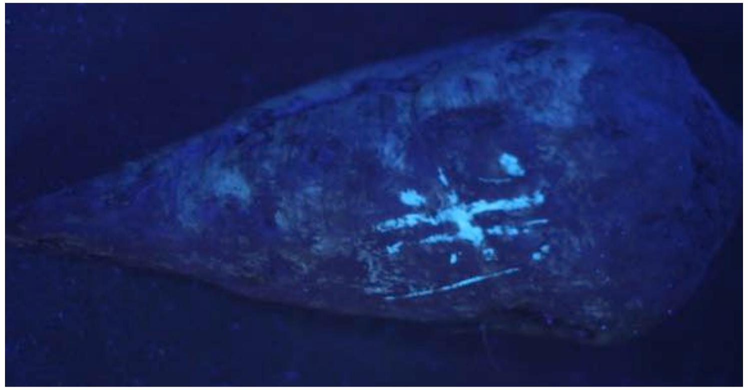
- **Process diagnostics**
  - Data analysis
  - Audio-visual diagnostics
- **Damage in harvested produce**
  - Mechanical stress
  - Physiological damage
  - Storage losses
- **Technology development**
  - Real-time control of harvest operation
  - Storage damage prediction

Case 1: Optical damage analysis

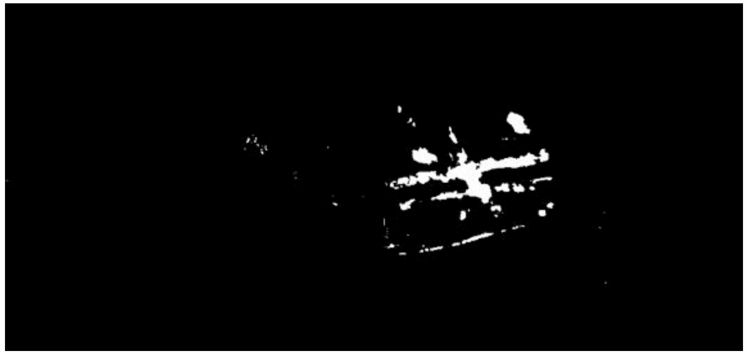
- **Adaption of lighting system**
  - UV, VNIR
- **Video analysis**
  - In process, real-time
- **Damage development analysis**
  - Defined damages
    - Analysis of development
    - RGB imaging
    - Multi & Hyperspectral imaging
- **Control and evaluation**
  - Real-time control of harvest operation
  - On heap damage prediction

RGB

UV



Binary

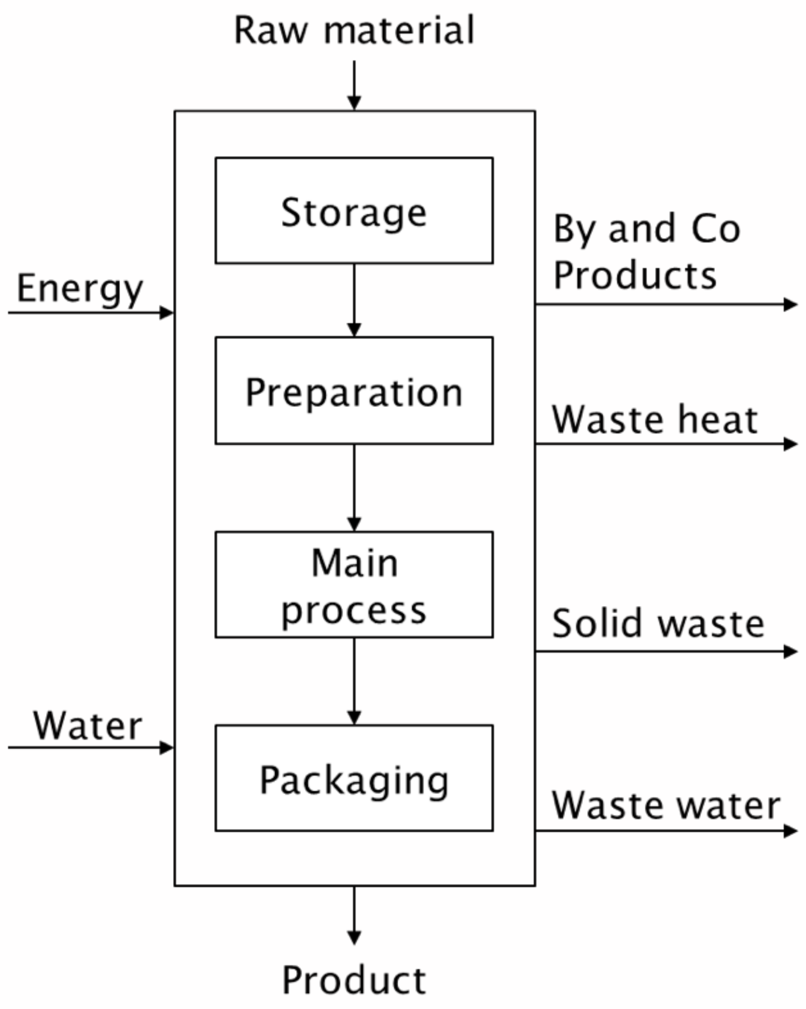


Case 2: Optical sensors in food processing



Problem statement: food processing systems

- **Current systems**
  - Fluctuations in raw material quality
  - Multiple products
  - Process settings and technologies outdated
  - Need for customisation/adaption
  - Many processes black-box
  - Dependency on oil and gas prices
- **Goals**
  - Targeted control of processes
  - Technically easy to implement solutions
  - Increased capacity or smaller devices
  - Flexibility in production
  - Reduction of energy costs and demands



Adapted from Sturm (2018). In Intelligent Control in Drying, Martynenko & Bück (Eds.), CRC Press

Raw material status and quality analysis in meat

- **Majority of standard methods invasive**
  - Loss of monetary value of tested muscle
  - Random sampling
- **Continuous monitoring limited**
  - Authenticity
  - Quality
- **Process control**
  - Black box approach is common
  - Integration of quality aspects very limited
- **Lack of integration**
  - Sensory attributes into standard quality parameters

http://www.vinothek.info; https://s3-us-west-2.amazonaws.com

Case 3: Optical sensors in pig rearing



http://idspigs.co.uk, http://kilimo.biz, https://www.youtube.com/watch?v=3CiqBZww23U

Case 3: Problem statement

- **Current systems**
  - Simple control systems
    - Temperature, CO_2, NH_3
    - Fan control
  - Insufficient sensor data correlation
  - Animal performance not considered
    - Direct observation
  - Physical set-ups suboptimal
- **Research goals**
  - Automated observation of animal behaviours
  - Warning systems
  - Integration of thermal welfare in control system

Case 3: Image processing

Background subtraction

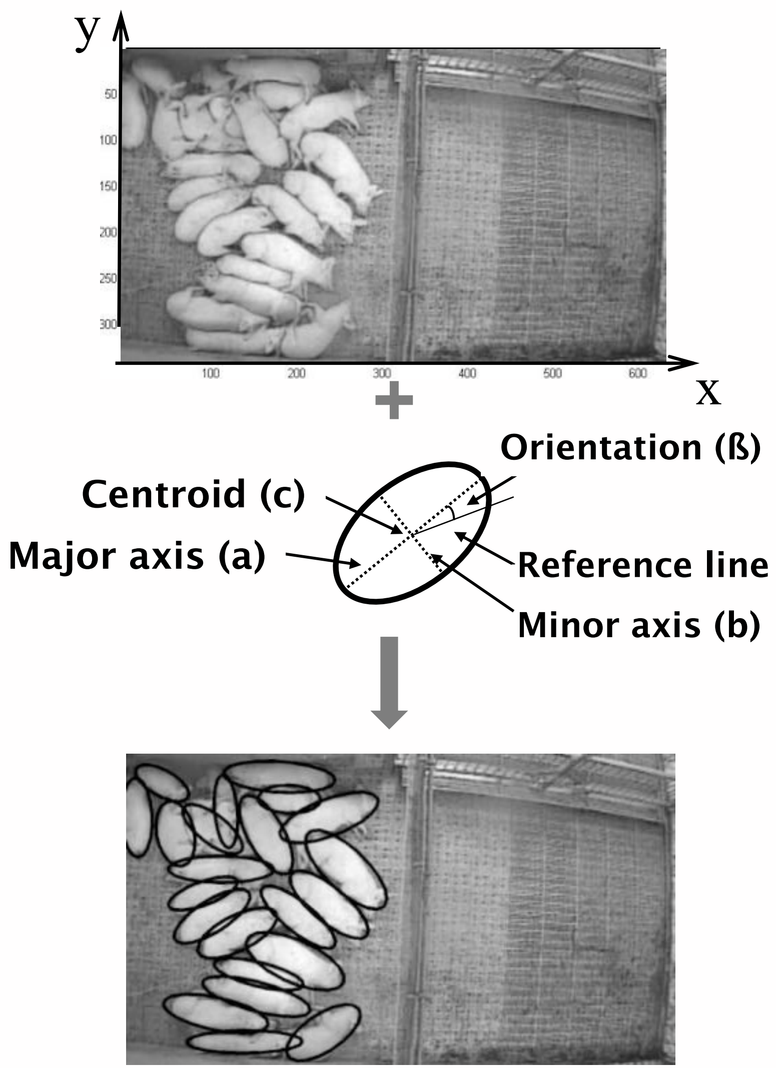
Grey image into binary

Removal of small objects

Separation of touching pigs

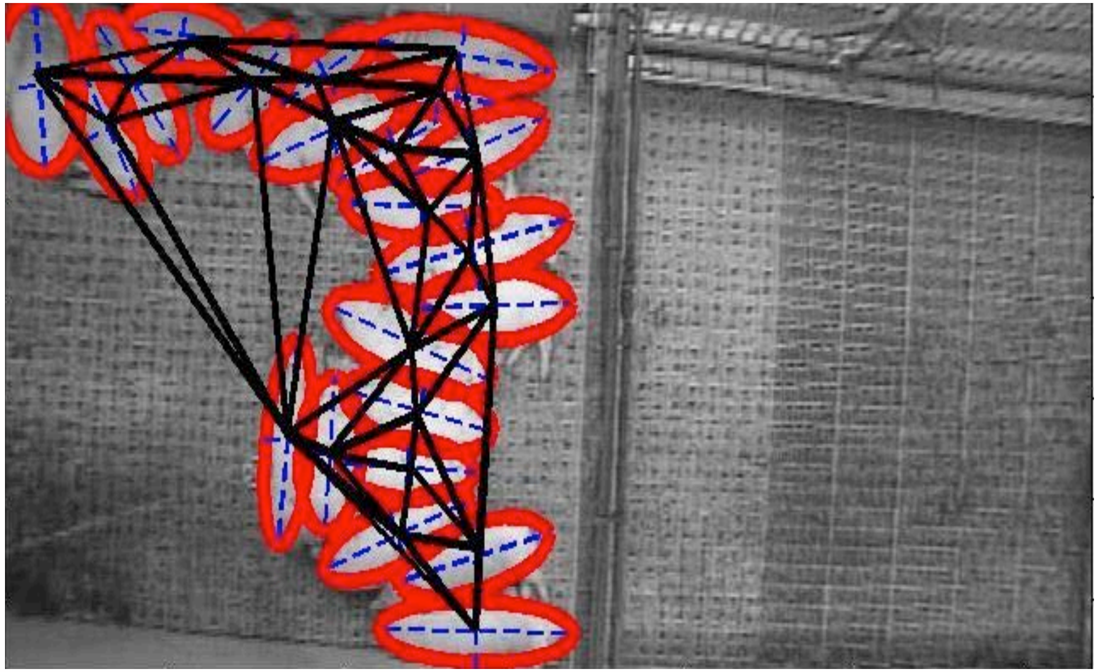
x-y coordinate determination

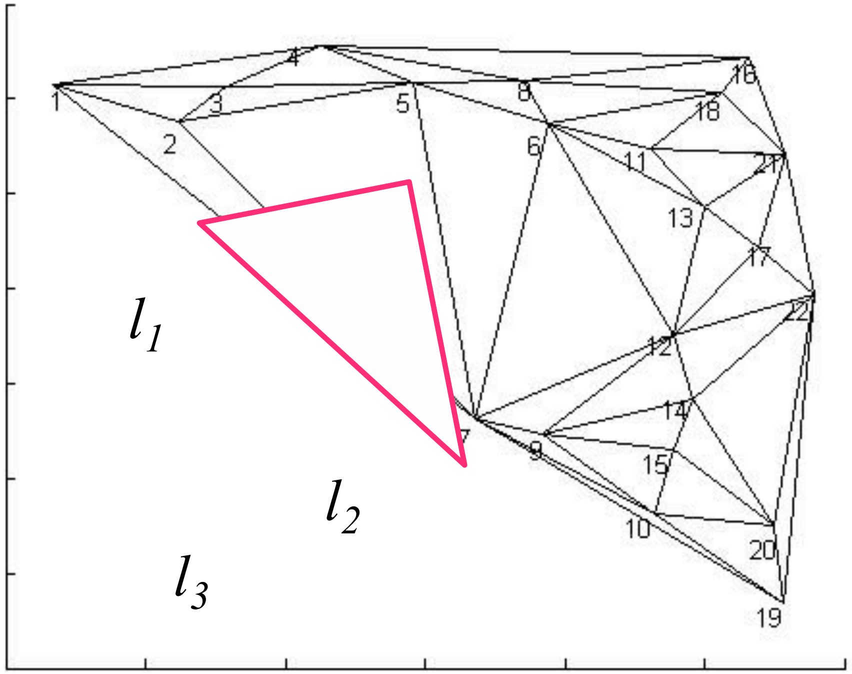
Ellipse fitting



Nasirahmadi et al. (2015). Computers and electronics in Agriculture 119, 184-190

Case 3: Delauney triangulation

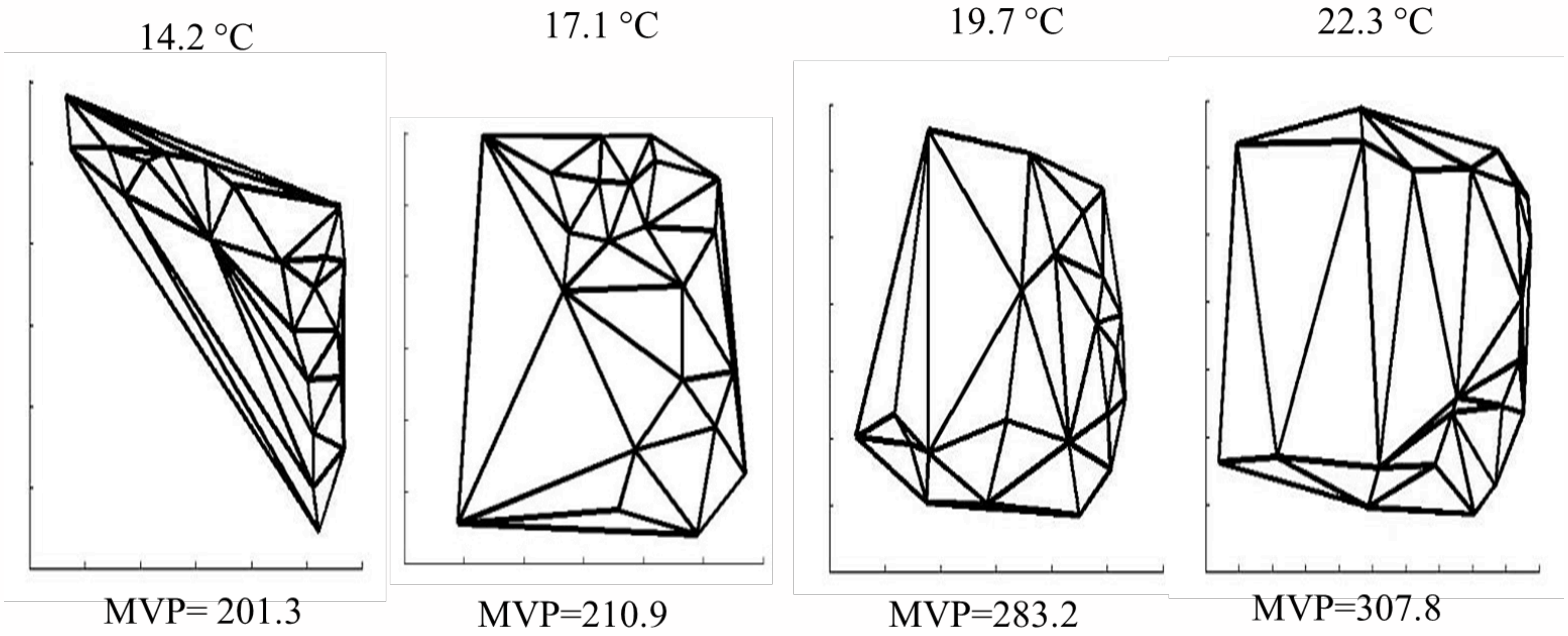




$$\text{Perimeter(P)} = l_1 + l_2 + l_3$$

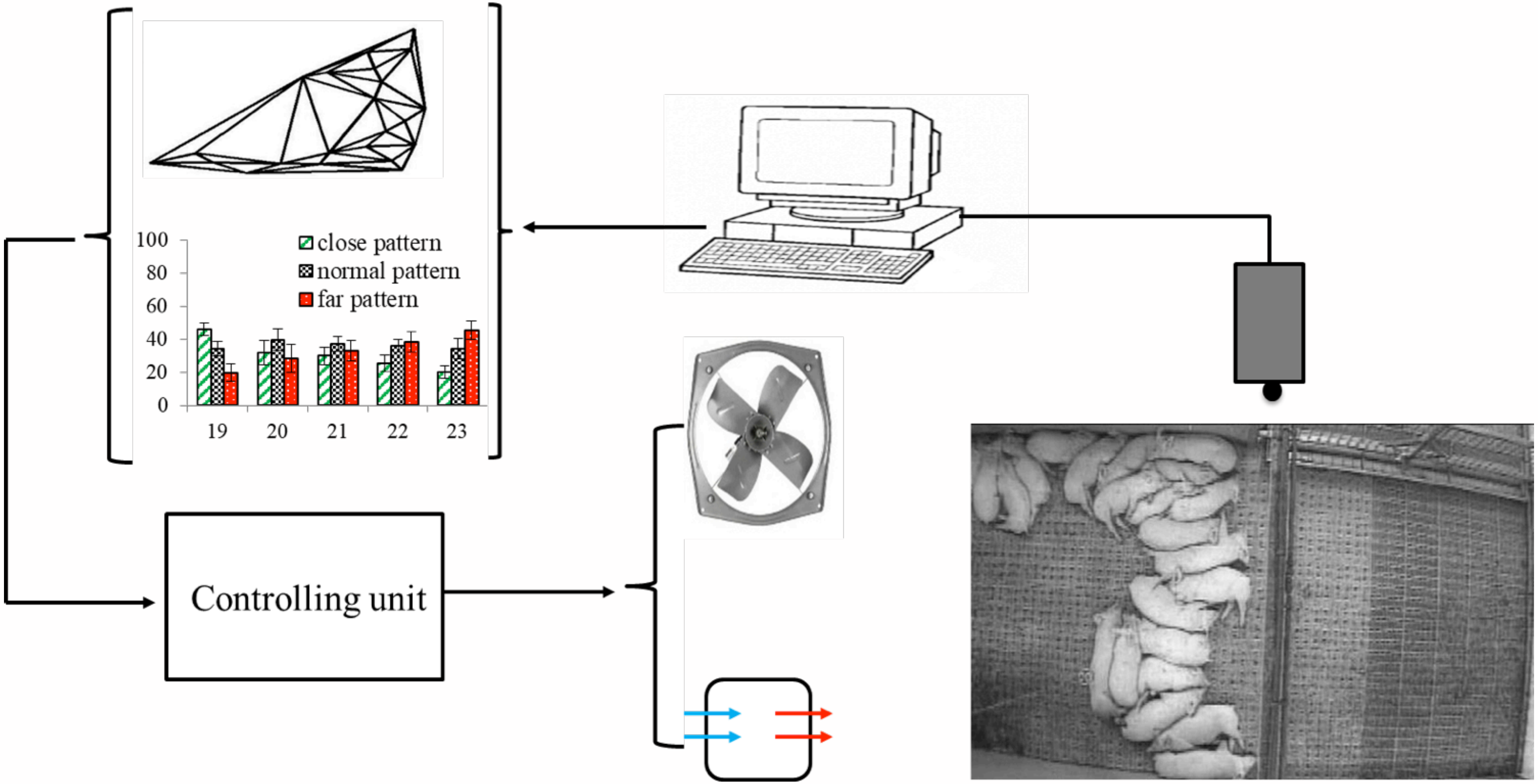
MVP: mean value of perimeter

Case 3: Temperature dependent lying patterns



Nasirahmadi et al. (2015). Computers and electronics in Agriculture 119, 184-190

Case 3: Lying pattern based control

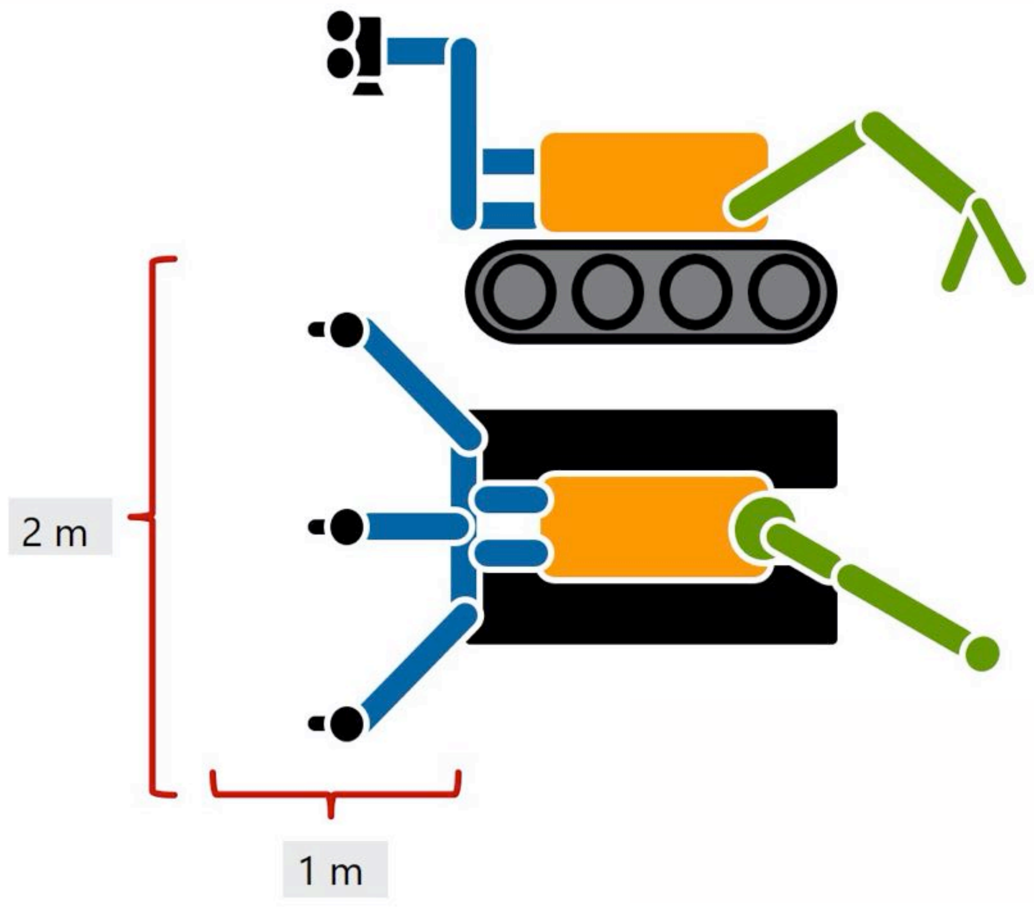


Nasirahmadi et al. (2017). Animal 11, 131-139

Case 4: Optical sensors for slug detection

Case 4: Problem statement

- **Current situation**
  - Economically important pests
    - Spanish slug (Arion vulgaris), gray field slug (Deroceras reticulatum)
  - Seedling stage
    - Rape, broad bean, beets, soy
  - Soil compaction needs to be avoided
- **Research goals**
  - Autonomous robot
  - Optical slug detection
  - Elimination of individuals



Case 4: Robot pathway determination

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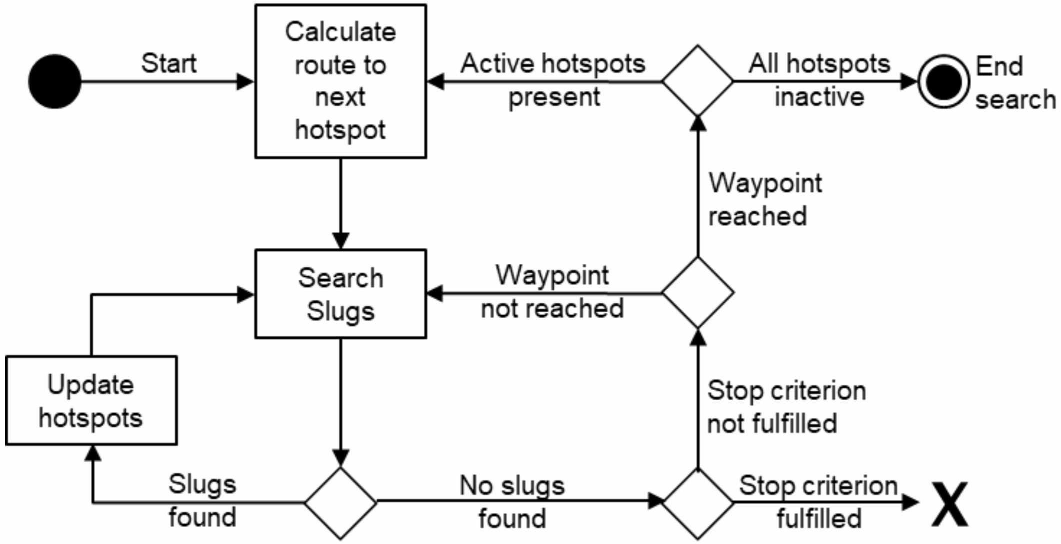
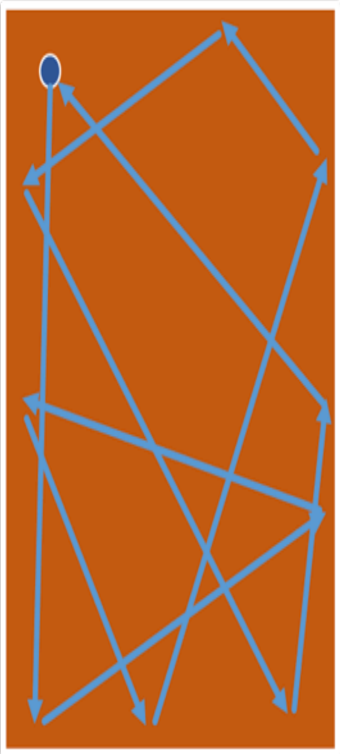
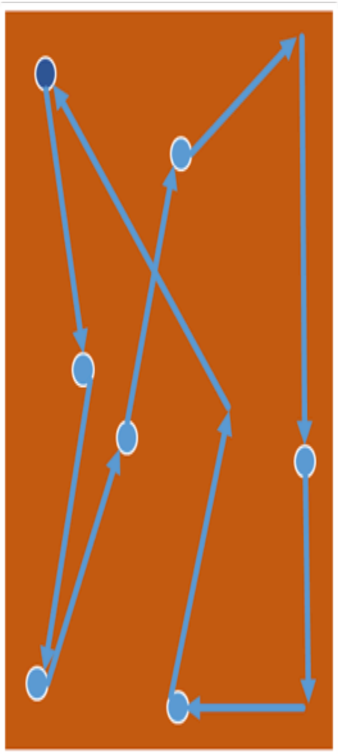


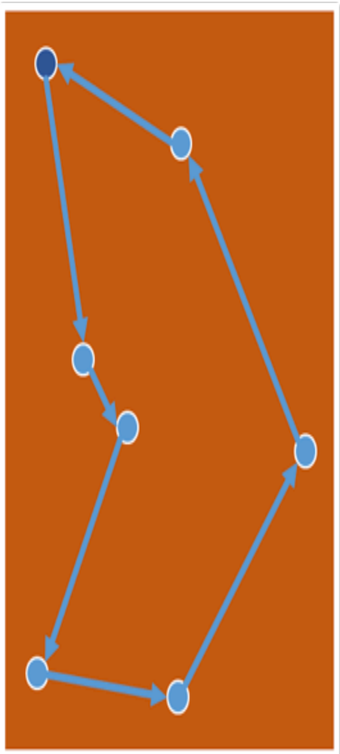
Control code working mode



Random mode: robot moves chaotically over whole field

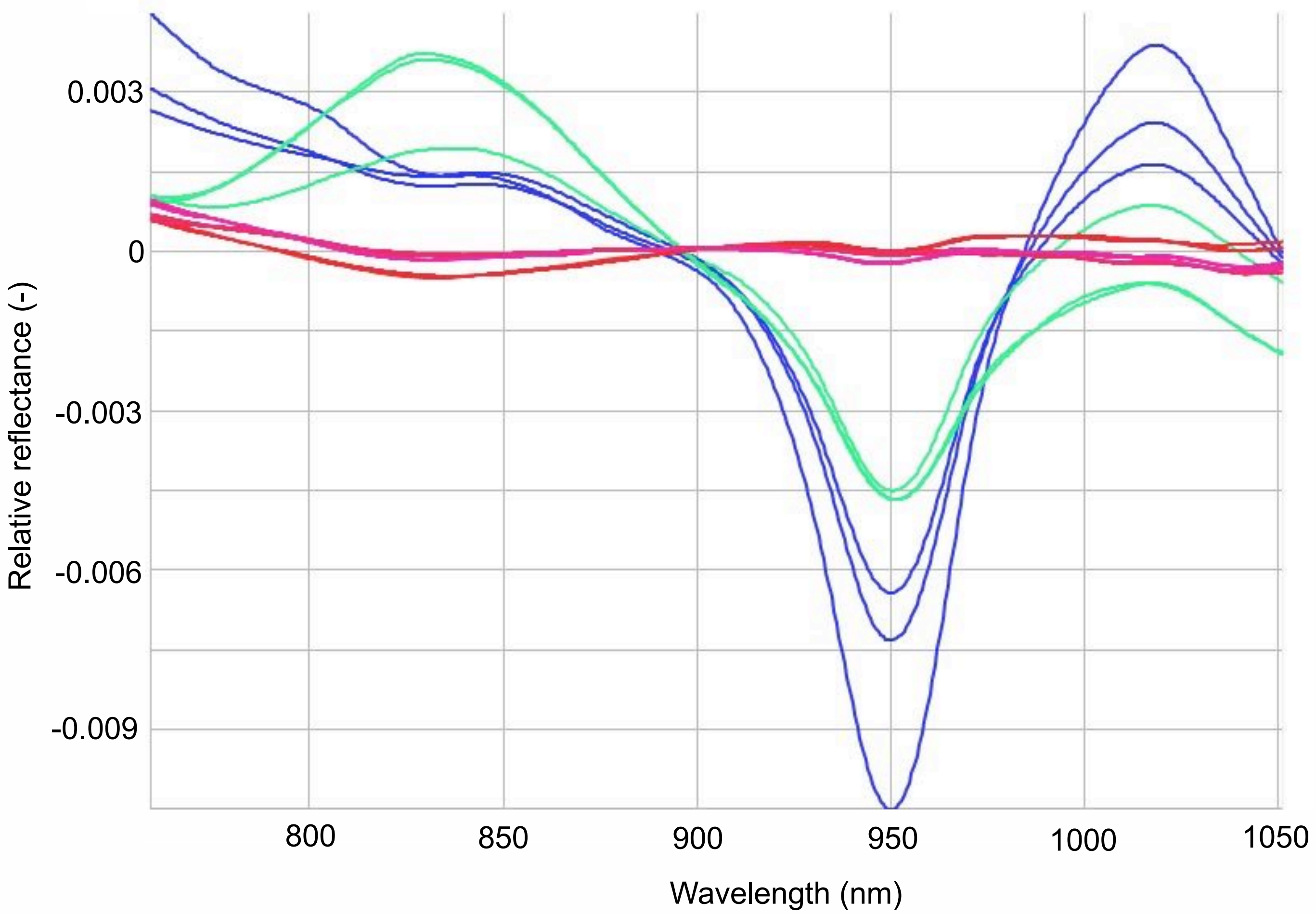


Exploration mode: robot moves on an expansive route



Working mode: robot takes shortest route between hotspots

Case 4: Optical methods for slug detection



Conclusions for optical sensor integration

- **Great opportunities / potentials**
  - Novel applications
  - In depth evaluation of current processes
  - Resource and process efficiency
  - Product quality / animal welfare
  - Development of systemic solutions
  - Simplification of sensor and control systems

- **Close collaborations are vital**
  - Animal and plant science
  - Physical systems design
  - Fluid and thermodynamics
  - Automation and control

http://grimme.com, http://idspigs.co.uk,

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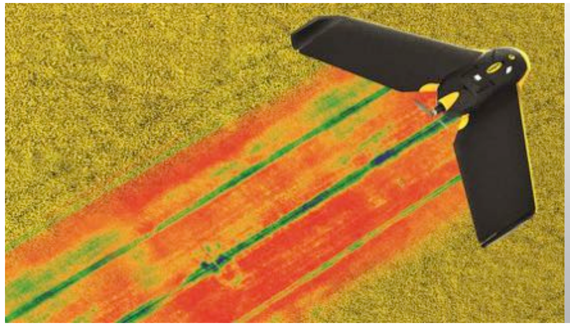
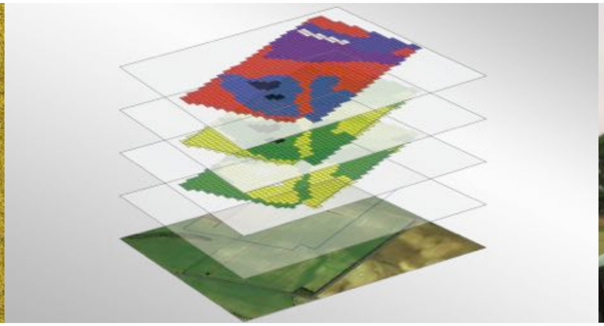


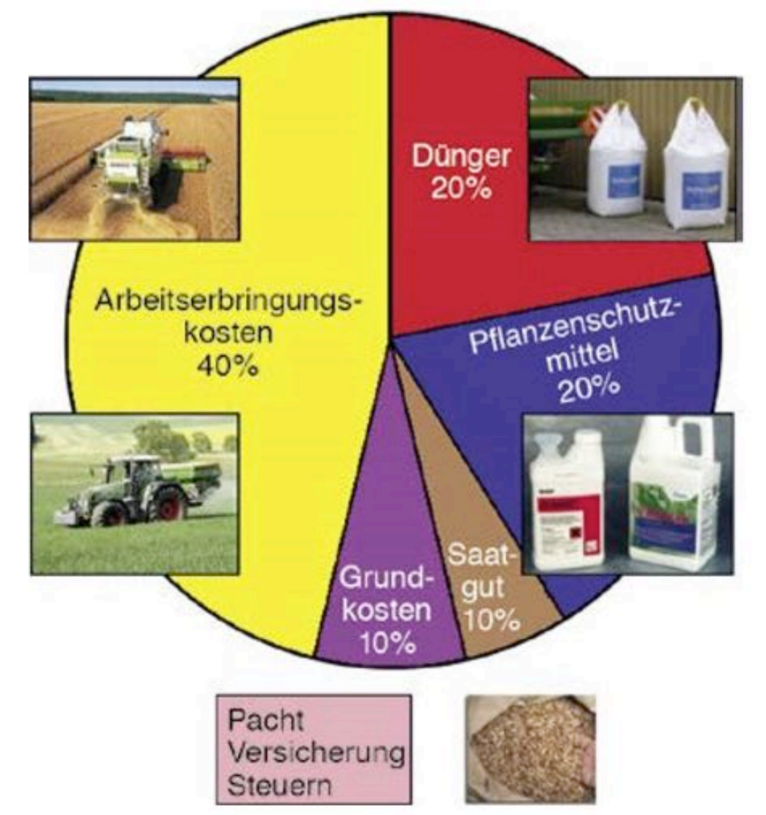


Sensors in demand driven fertilisation

https://i.ytimg.com, http://www.oberhoff.com, yara.de, rauch.de

Relevance

- **Economic efficiency**
  - Up to 30% of production costs
  - Potential for yield increase
- **Sustainability**
  - Leaking of nutrients in ground and surface water
- **Production management**
  - Punctuality
  - Nutrient demand planning
  - Consideration of spatio-temporal differences
- **Precision tools**
  - Sensor driven
  - Application maps
  - Sensor-information-map-overlay

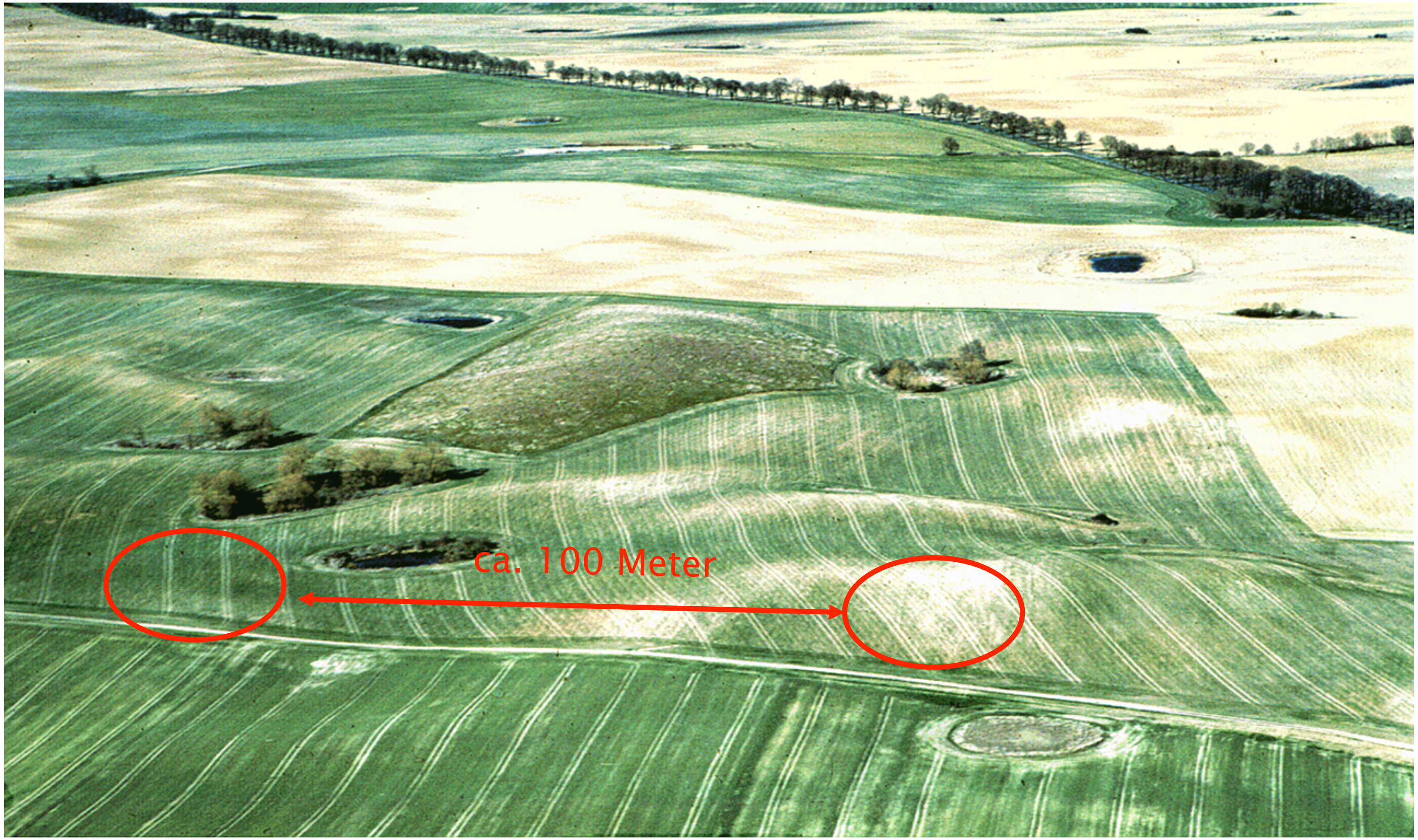


DLG (2017). Merkblatt 410

Influencing factors – example wheat

- **Production targets**
  - ➔ Quality wheat, feed wheat, biomass production
- **Variety**
  - ➔ Stock or single ear type
- **Location**
  - ➔ Soil type, yield potential, hilltop or valley, climate and weather, water available to plants...
- **Type of fertilizer**
  - ➔ Ammonium or nitrate form
- **Number and timing of fertilizer application**

How even are conditions?



What are the temporal changes?

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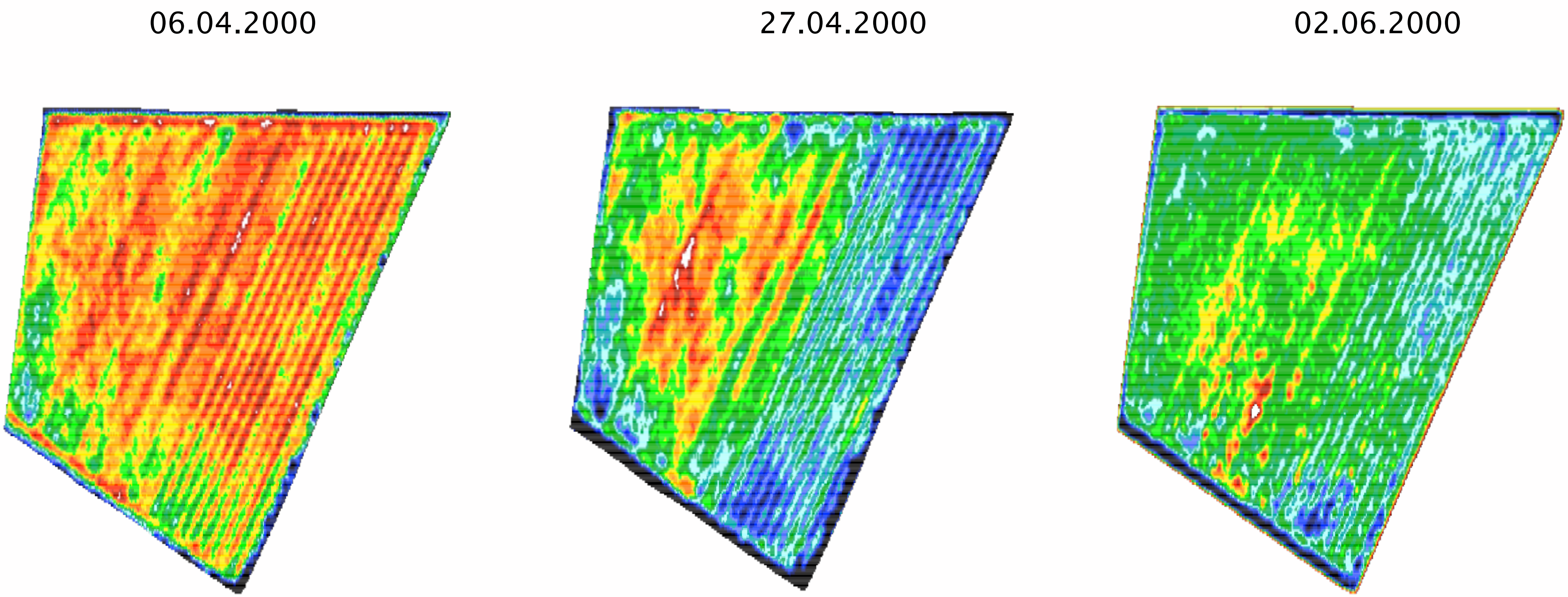

Agro Sat (2000)

Partial area specific fertilisation

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- **Online-Method (real-time)**
  - Determination of current status in plant population
  - Implementation of the operating resource application coordinated with measurement results and target values
  - ➔ Sensors

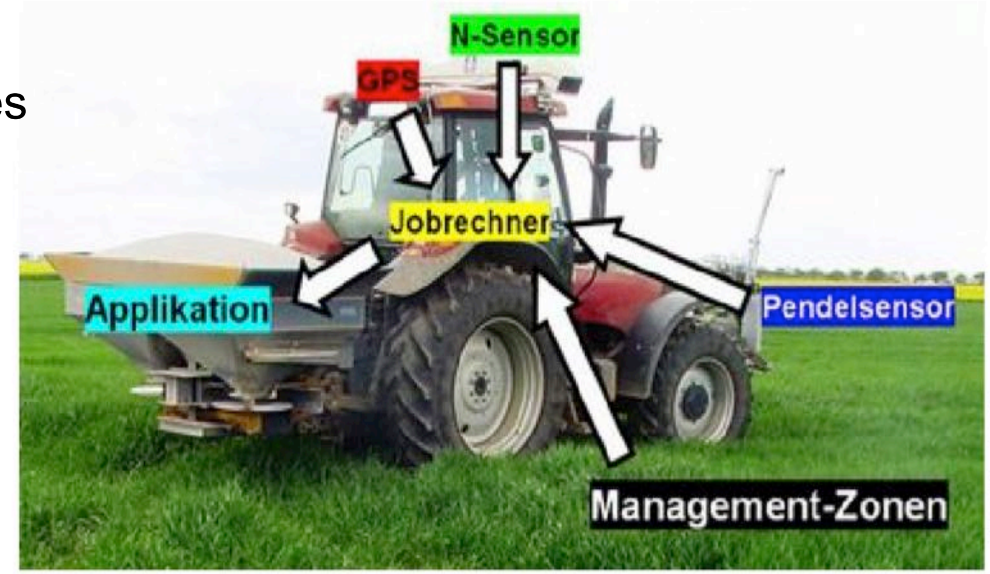

Bild: Pößneck 2011

- **Mapping (offline-method)**
  - Application map (Basis: location- and population information
  - Processing by on-board computer according to GPS coordinates
- **Combination (Map-overlay)**
  - Combination online- and mapping approach
  - Creation of management zones = partial areas with the same characteristics

Nach Pößneck (2011) und Hüter (2005)

Function principle N-sensors

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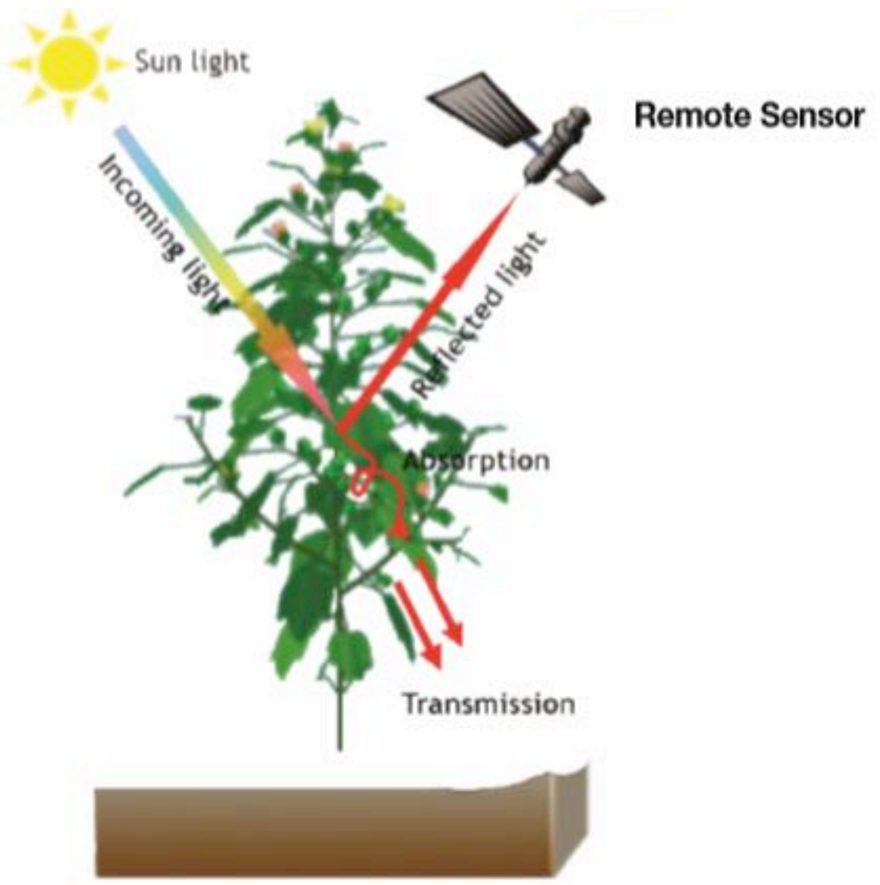

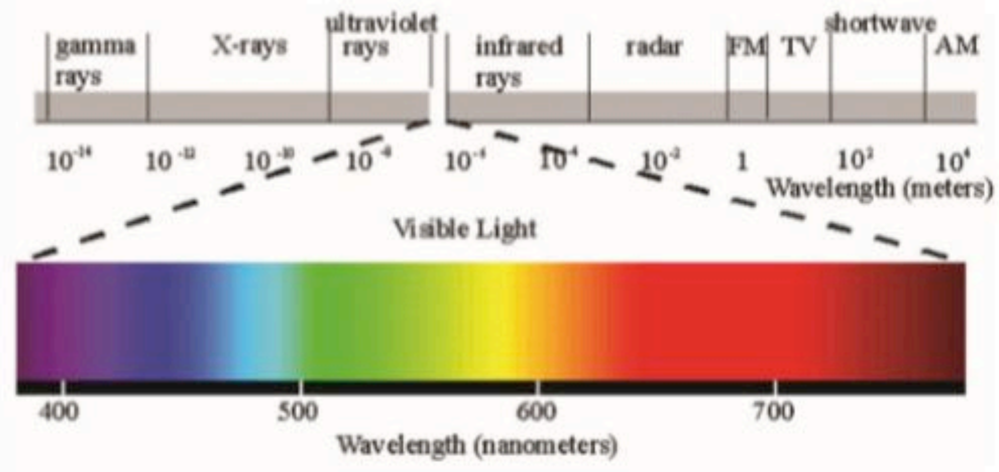

Ortiz et al. (2011)

Passive and active sensor systems

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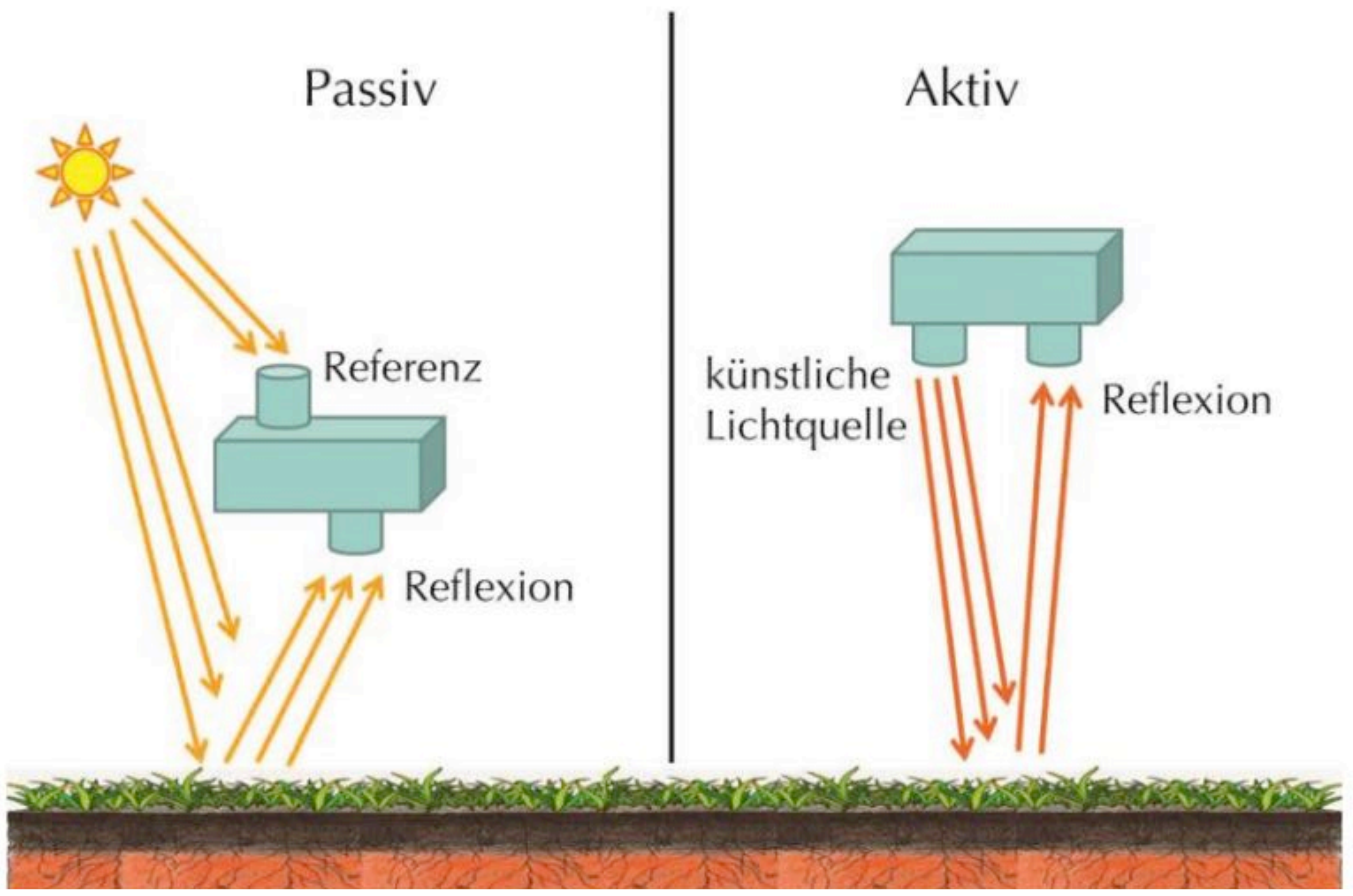
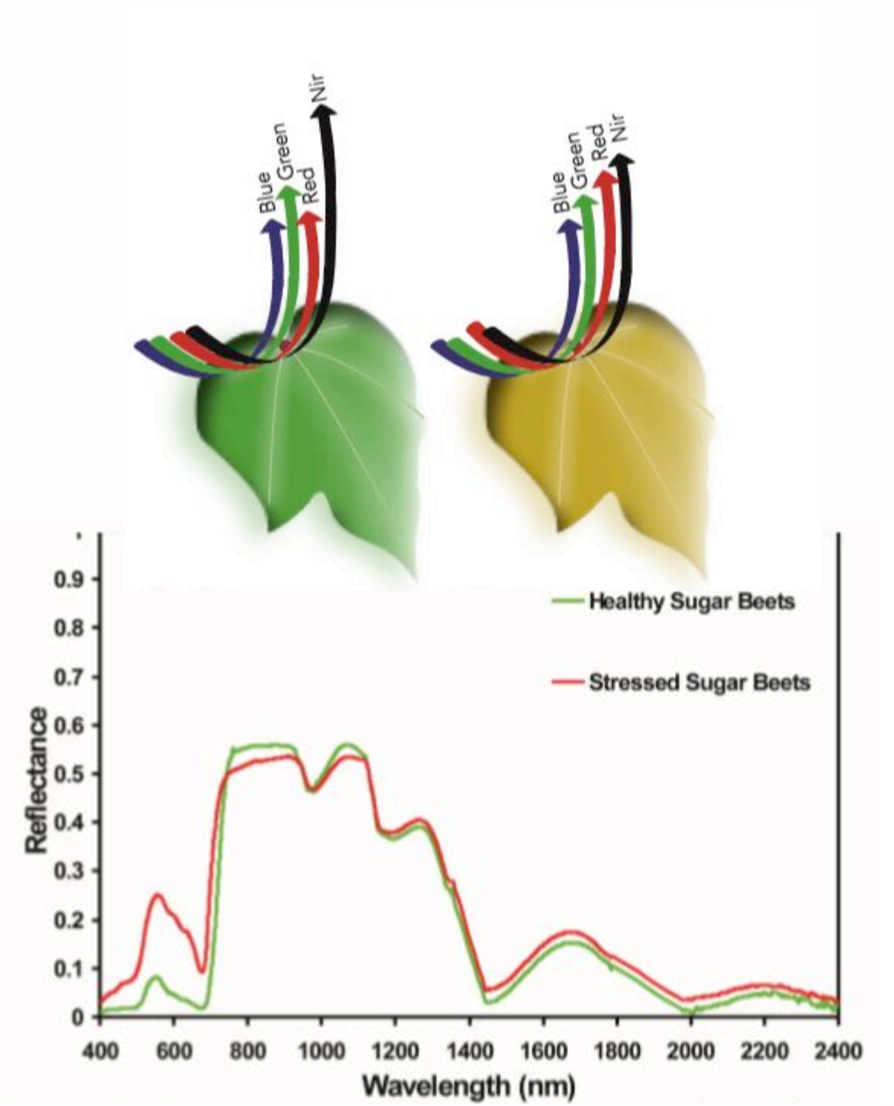
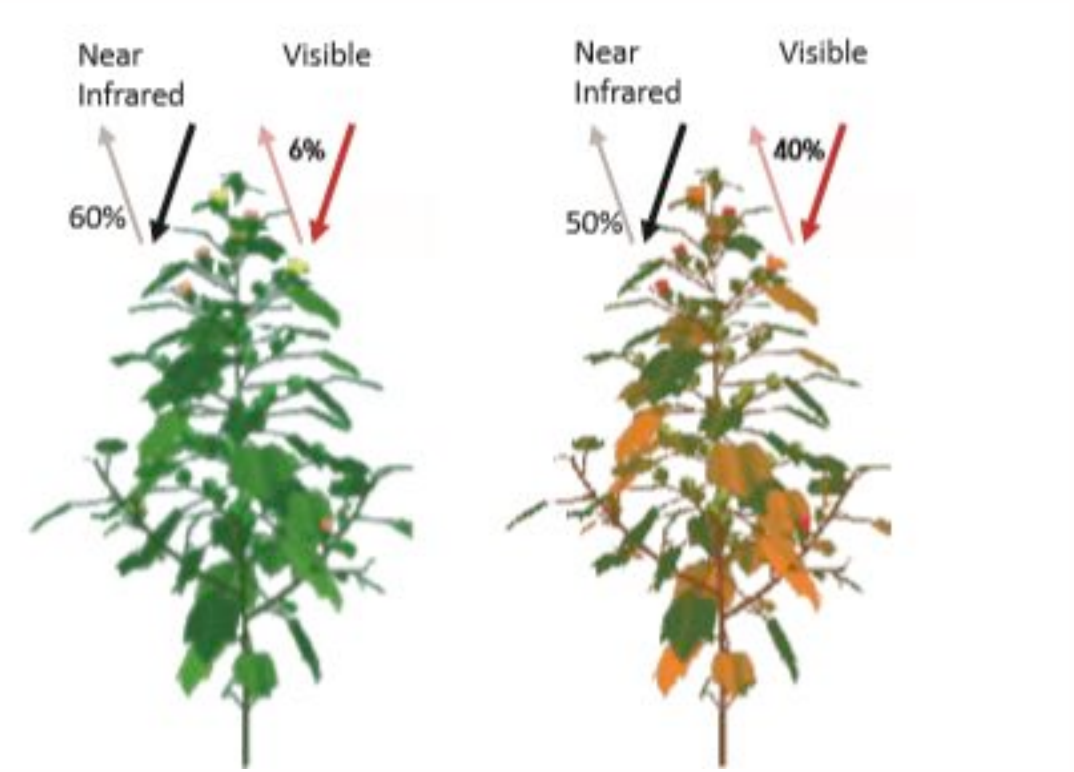


Erdle (2013)

Determination of NDVI



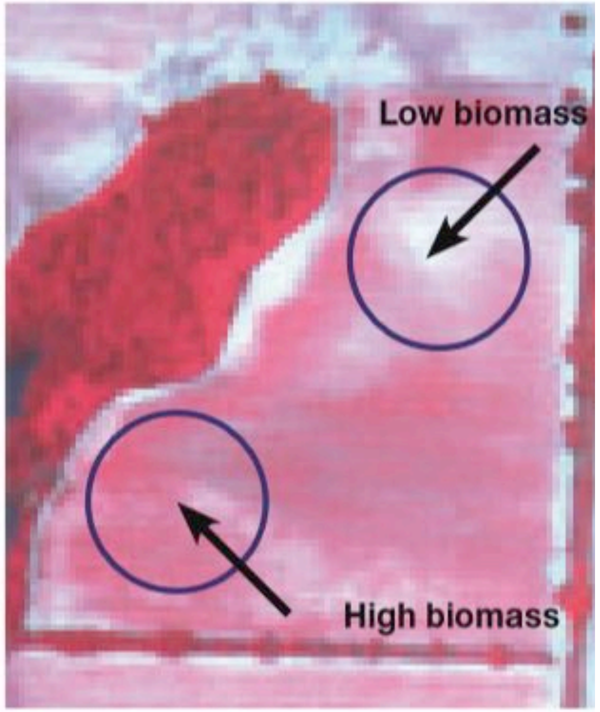


$$NDVI = \frac{0,60 - 0,06}{0,60 + 0,06} = 0,82 \qquad NDVI = \frac{0,50 - 0,40}{0,50 + 0,40} = 0,11$$

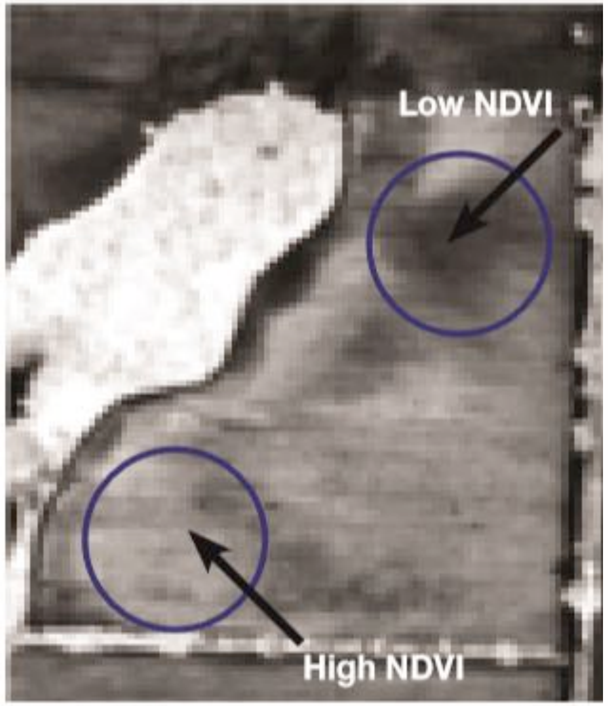
$$NDVI = \frac{NIR - Red}{NIR + Red}$$

Ortiz et al. (2011)

Determination biomass classes



Satelite- / aerial photo



Vegetation index display of different biomass classes

Vegetation index based display of biomass classes

Ortiz et al. (2011)

Widely used sensors for N-Management

Abbildung 5: ISARIA (© Fritzmeier Umwelttechnik)

Abbildung 6: Crop Sensor (© Claas Agrosystems)

Abbildung 4: GreenSeeker (© Land-Data Eurosoft)

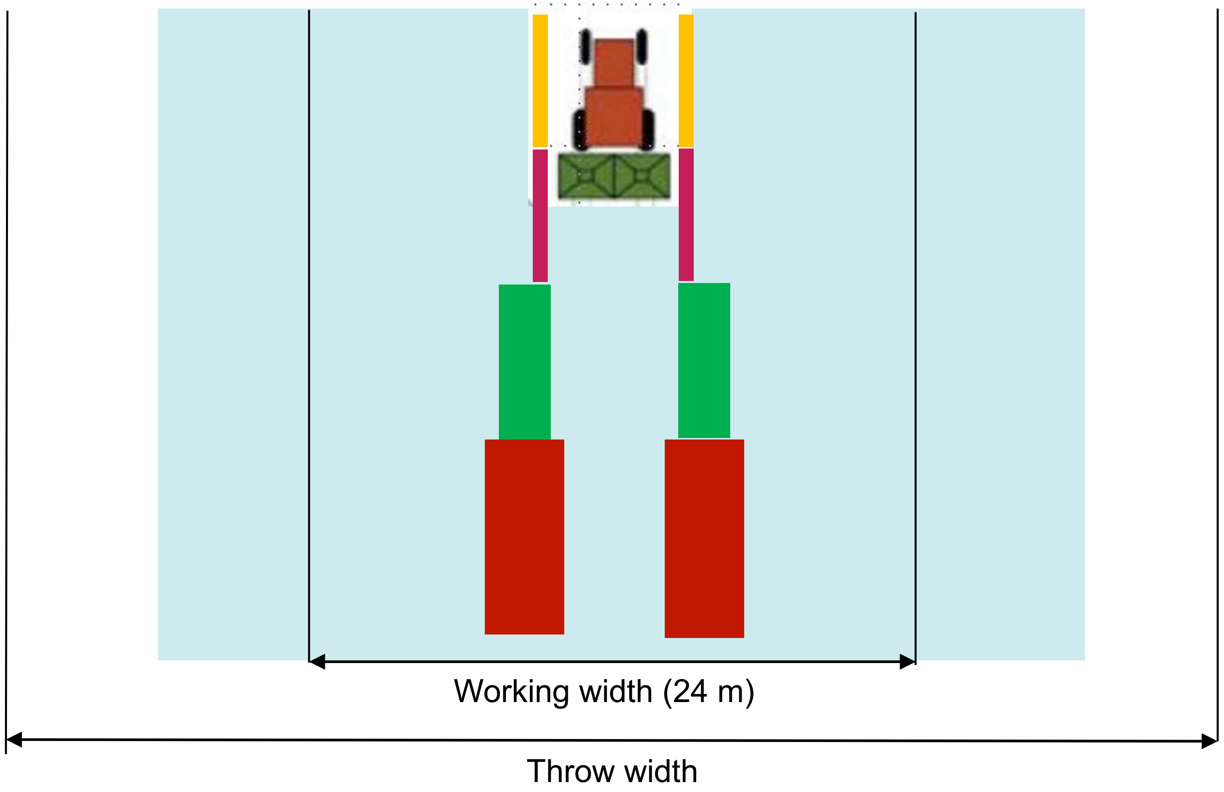
Abbildung 10: N-Sensor ALS (© YARA)

Abbildung 7: OptRx (© Ag Leader)

http://www.greenseeker.nl/

Sensor selection

- **Measurement principle**
  - All systems based on reflexion
- **Representation**
  - Measuring range values
- **Installing options**
  - Roof vs. flexible mounting
- **Recommendations for use producers**
- Calibration
- Deposited control algorithms
- **Resulting system cost**



Map – overlay approach - Fritzmeier ISARIA

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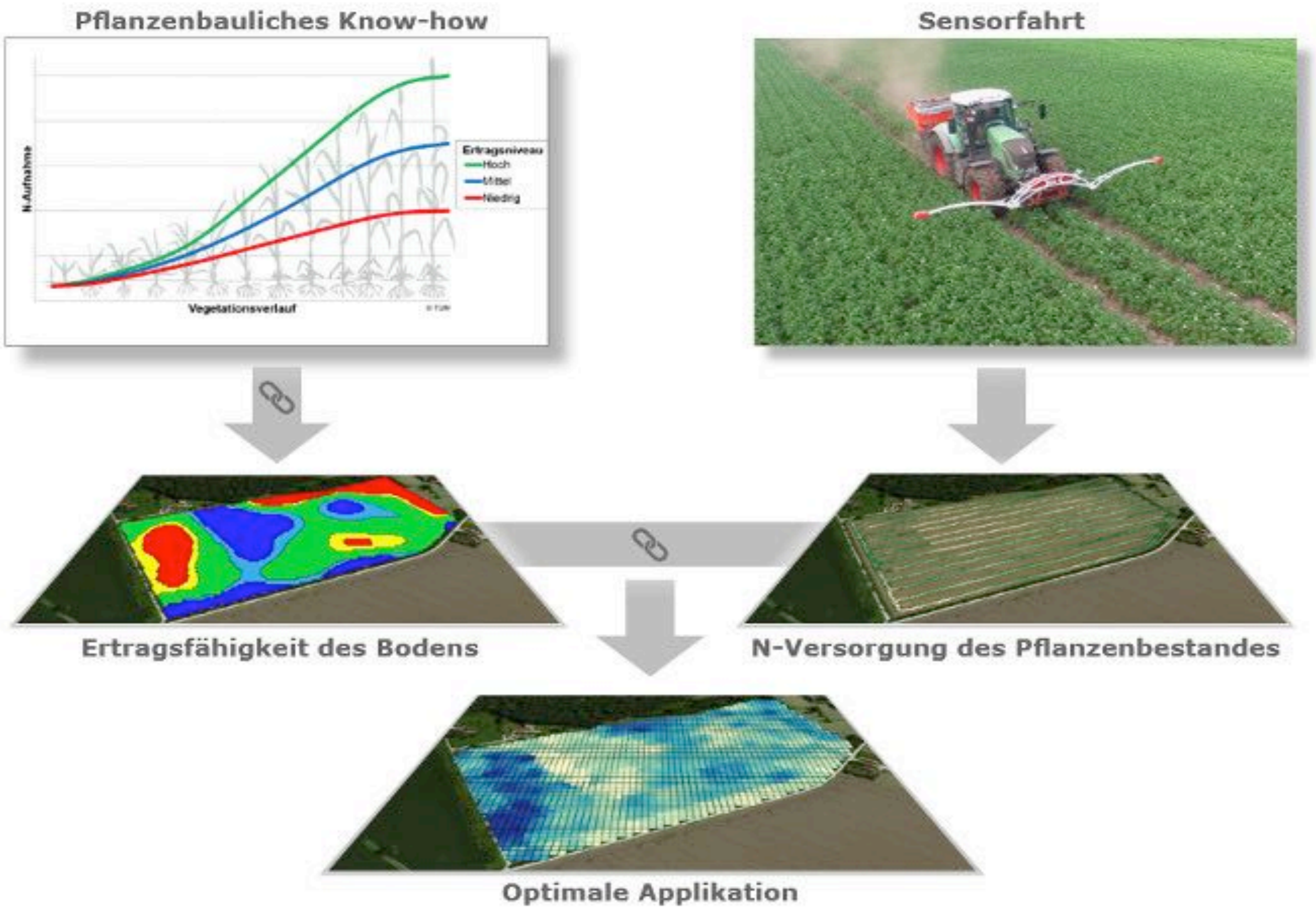
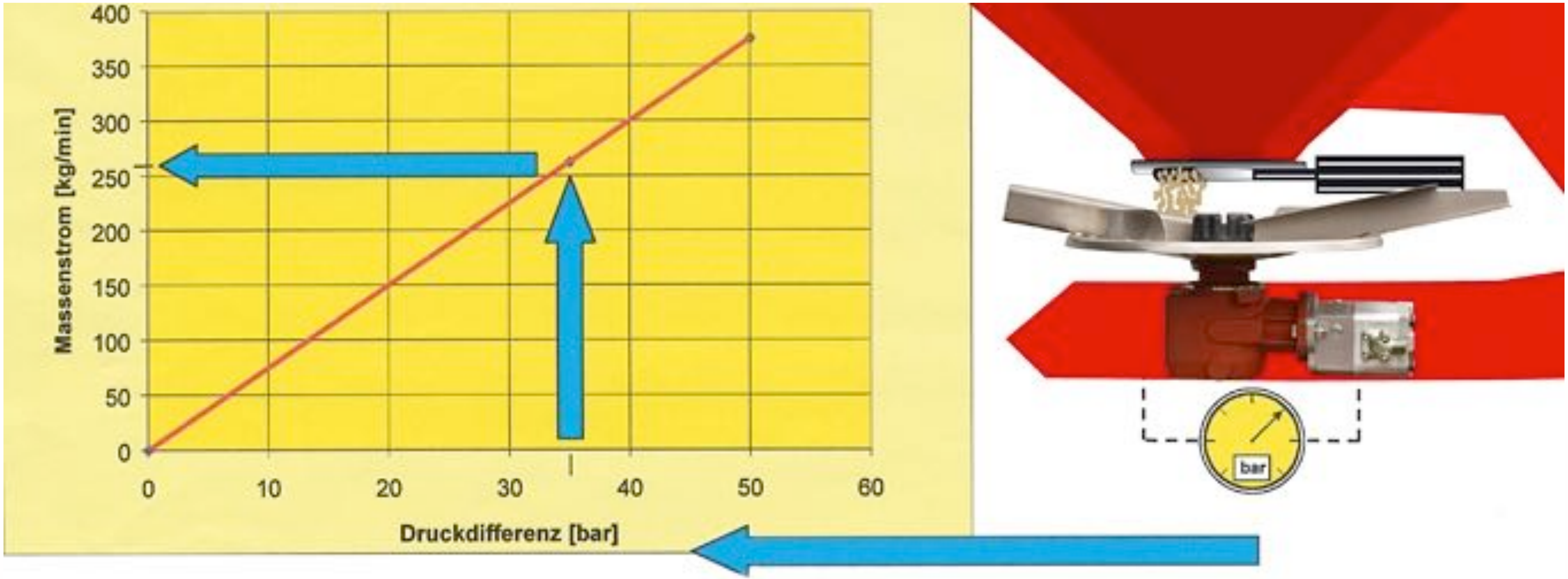


http://fritzmeier-umwelttechnik.com/isaria/

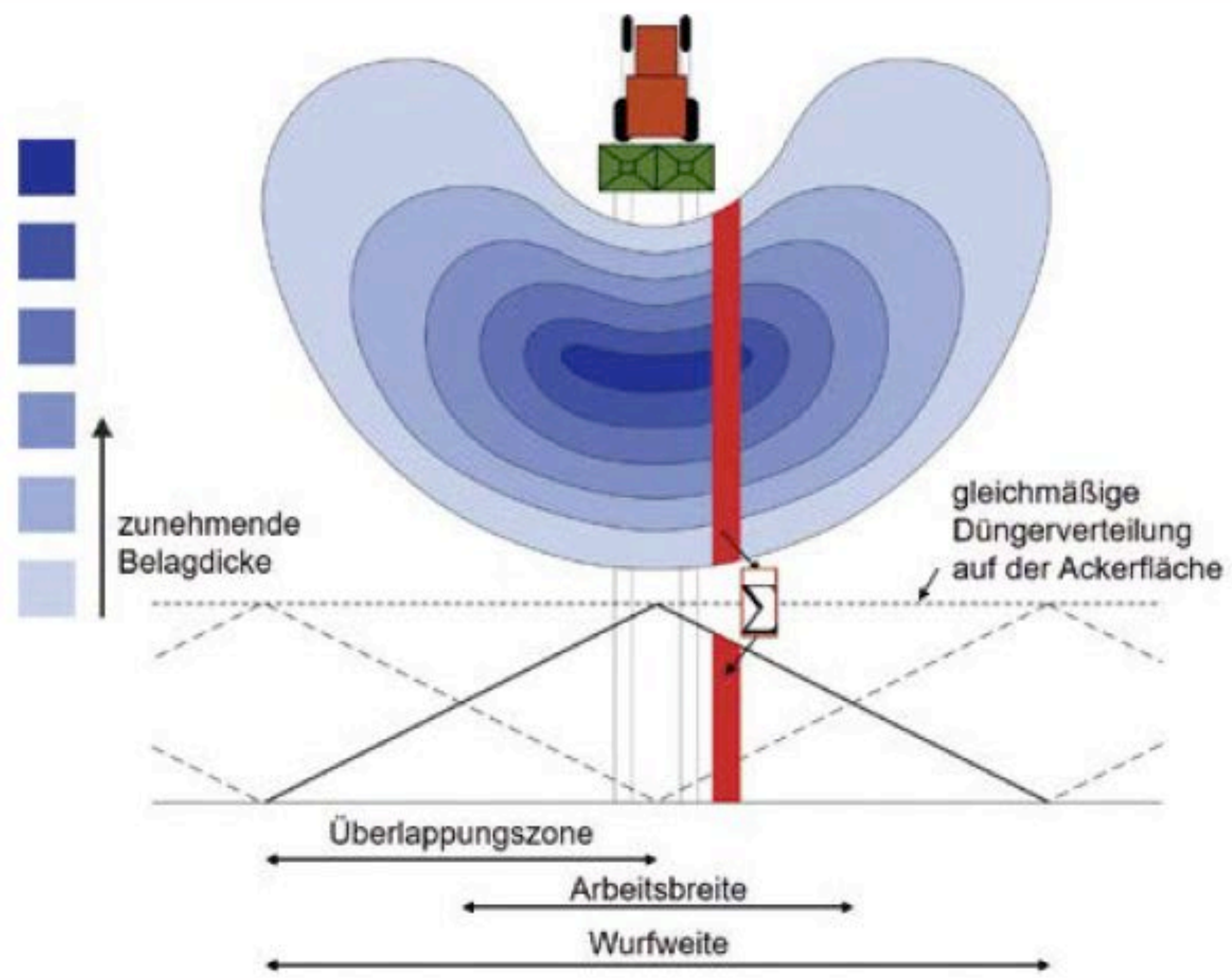
Throw spreader – Electronic mass flow control

-



Rauch.de

Throw spreader – Throwing characteristics



Throw spreader - Pneumatic spreader

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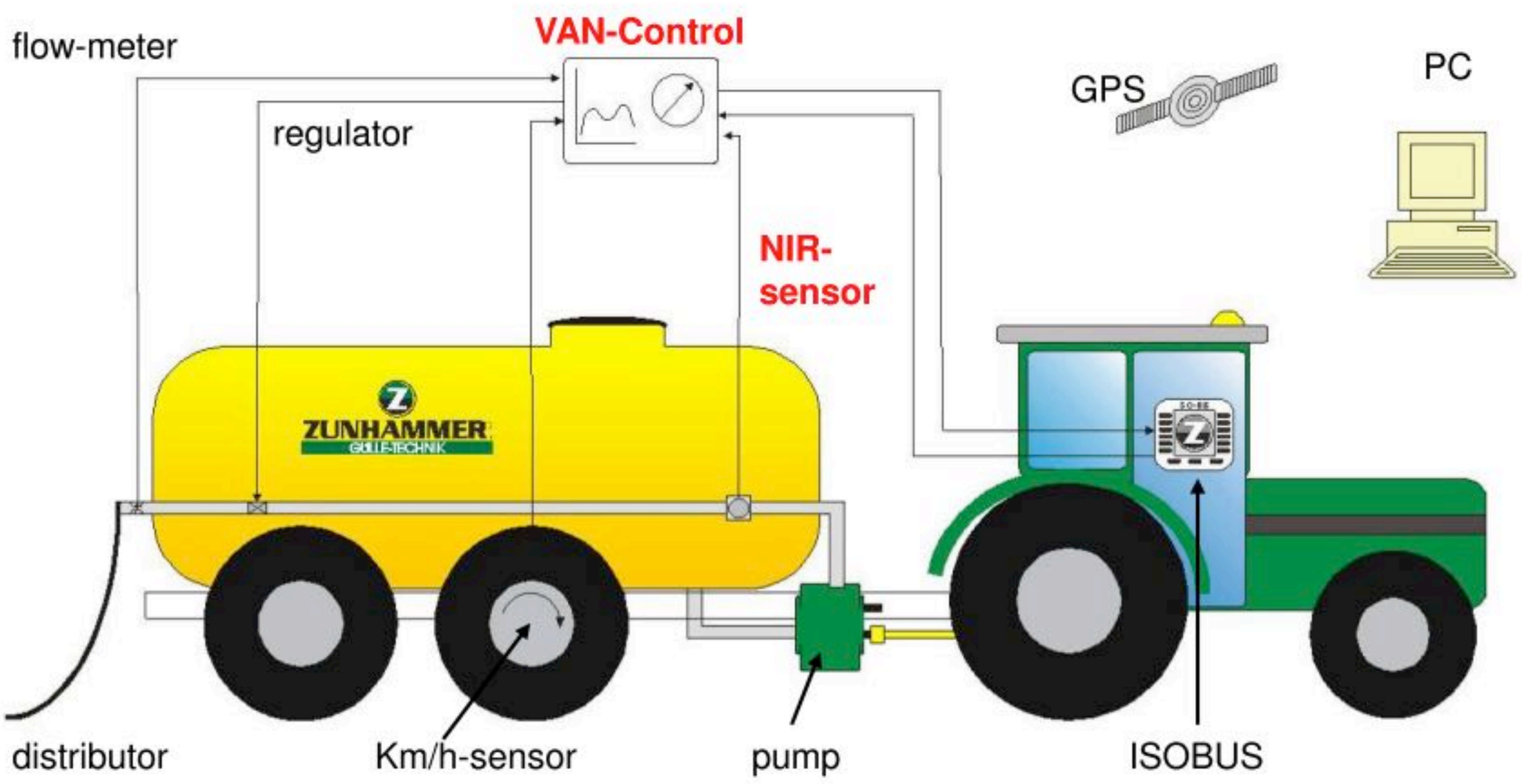
- Rods with elbows and plates
- Dosing device with cam wheel rollers
- Blower technology for pneumatic conveying
- 6-fold part width section control

Rauch.de

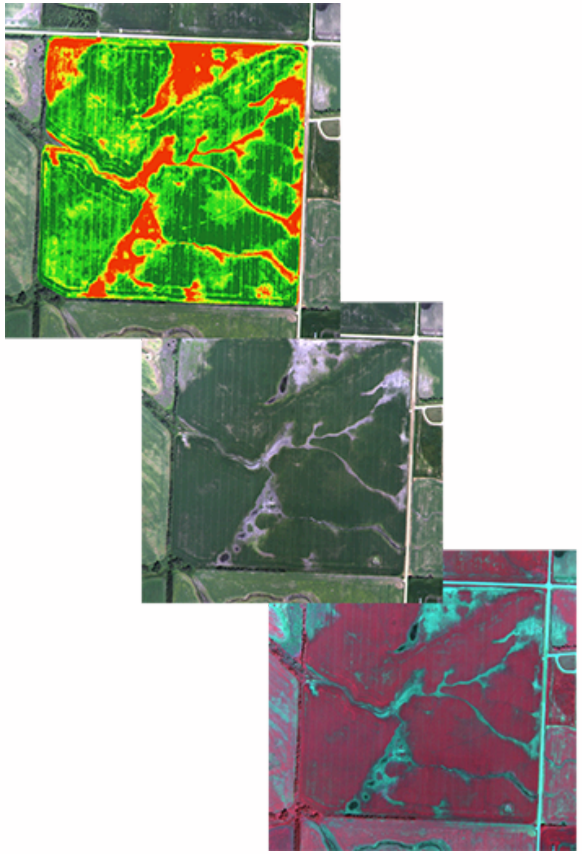
Sensor- / Actuator system



Zunhammer.de

Overview Vis/IR sensor application

- **N-Management**
  - Vis and NIR
  - Min. twice per growth period
- **Irrigation**
  - Vis, NIR, MIR, Thermographie
  - Daily to weekly
- **Yield prediciton**
  - Vis und NIR
  - Min. twice per growth period
- **Plant diseases**
  - Vis, NIR, MIR, Thermographie
  - Daily to weekly
- **Soil mapping**
  - Vis und NIR
  - Weekly to monthly

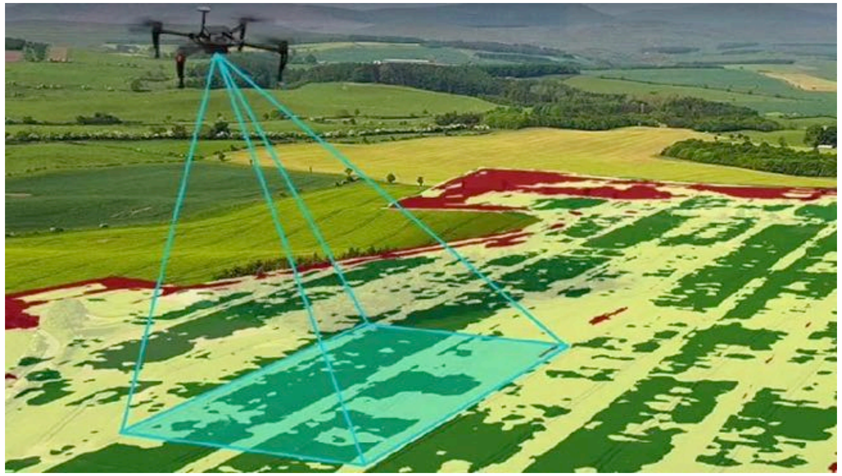


Nach Ortiz et al. (2011), fieldtraks.ca

Challenges

- **More complete coverage**
- **More precise devices that are less susceptible to errors**
- **Data processing speed**
- **Response time of application devices**
- **Standardisation of data formats**

  ➔ Cross manufacturers
- **Broadband connectivity**



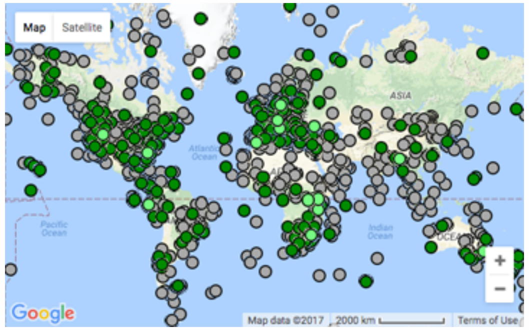
Dronebelow.com, rauch.de

Precision Livestock Farming

How much digitisation is useful?

„goats perceive volcanic eruptions in advance“

- **In relevant areas equipped with micro-emitters**
- **connected to ISS (2018)**
- **Movement data online**



example:

Goats informed precisely and with longer lead time than technical systems about the eruption of the Ätna

Zitat: Martin Wikelski, Direktor des Max-Planck-Instituts für Ornithologie Radolfzell
Quellen: https://www.srf.ch/kultur/wissen/tiere-warnen-vor-katastrophen-ziegen-spueren-wann-ein-vulkan-ausbricht; https://www.orn.mpg.de/ICARUS_de

Precision Livestock Farming (PLF)

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➔Animal as sensor

➔ Disturbance variables

Adaptiert nach 1 (Wathes et al., 2008)

Classification PLF according to Büscher (2019)

- Data exchange between different process computers in the stable
- Data transmission to and from Internet
- Monitoring of livestock and building
- Set-up of networks (wired and wireless) in the stable
- Temporal and spatial survey of animal position

Present situation

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- **Cattle- and poultry-farming**
  - Advanced interconnectedness of technologies
  - Milking parlour with individual cell count
  - Application of multiple sensors (Locomotion etc.)
  - Herd management systems established
- **Pig rearing**
  - fragmented
  - Technology producers rarely cooperate
  - Difficult to establish management systems
- **Challenges**
  - Internet access and speed
  - Data property and -access

Reliable and objective indicators
Prerequisite for PLF and Smart Animal Farming

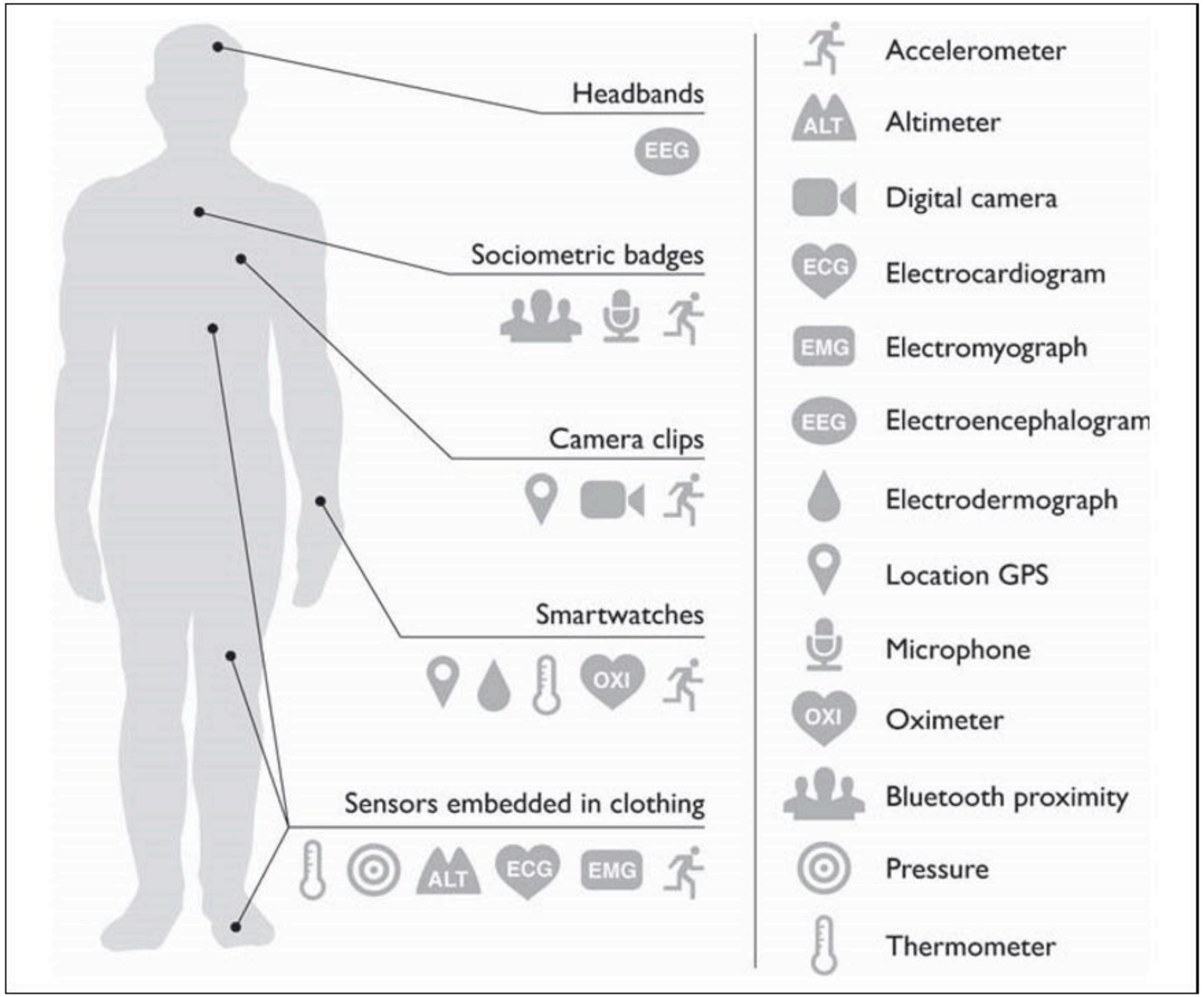
- **Standardisation required**

  ➔ Ascertainable by instruments
- **Appropriateness of measuring procedure**
- **Adaption of methods and sensor technology from other sectors**
- **Multivariate observations**
  - Multiple influencing factors
  - Multiple conflicts of command variables

Sensor systems – Indirect measuring

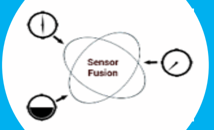
- Feeding
- Water
- Temperature
- Air humidity
- Air velocity
- Noxious gases
- Light
- …
- …
- …

Sensor systems – direct measuring[3]



How to handle the data overflow?

Contactless Sensor systems



direct and environmental measurements

Automatic perception and learning

http://www.cybortra.com

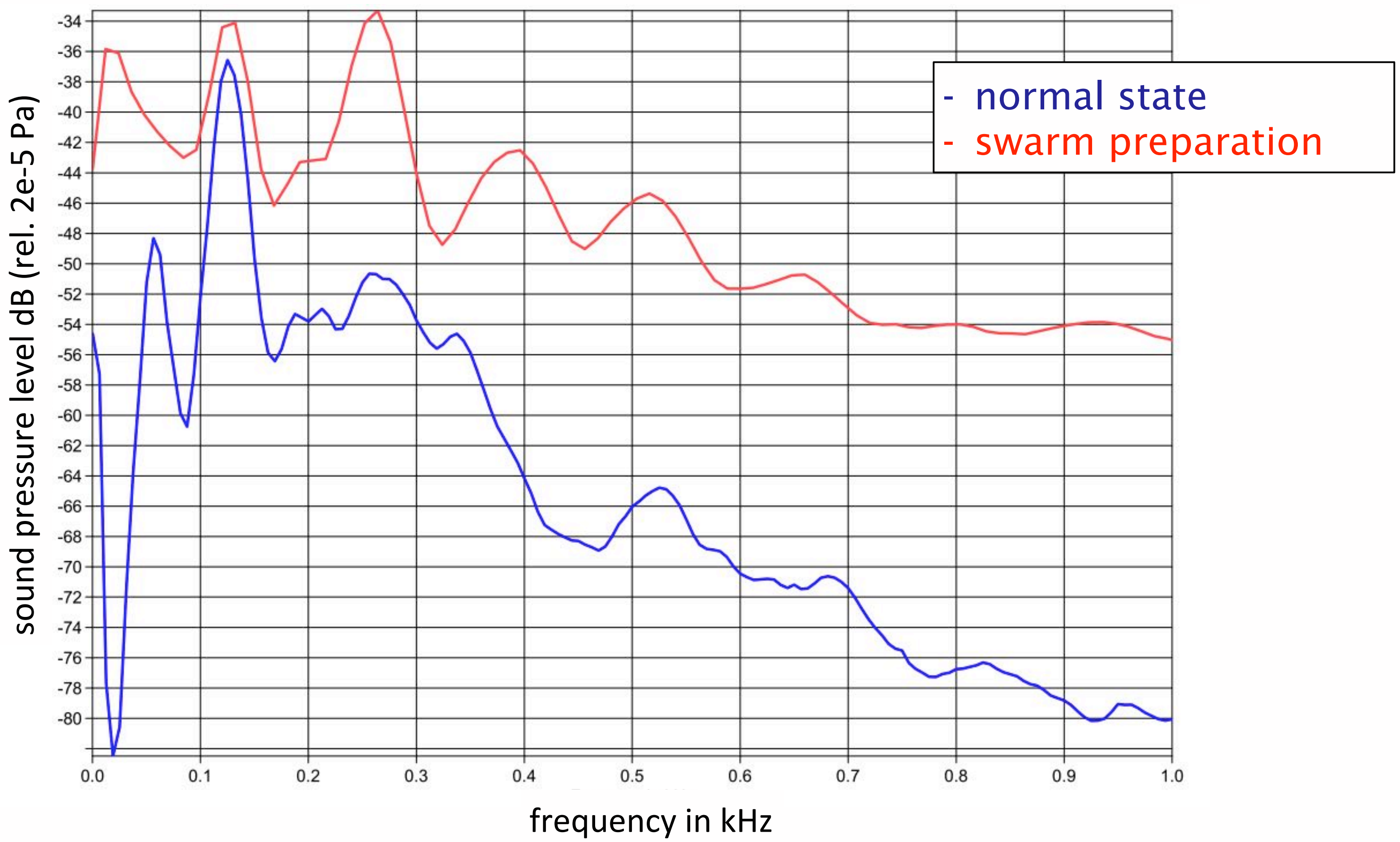
Acoustic bee health monitoring

microphones

SMS-
message

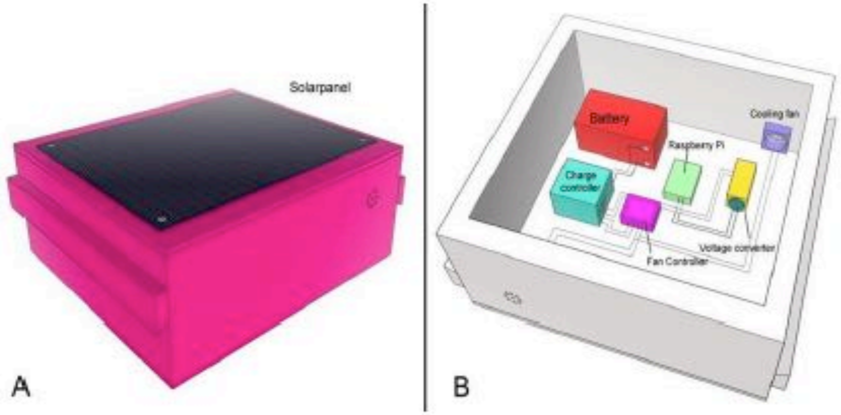
Check by beekeeper

Acoustic bee health monitoring



SAMS
Smart
Apiculture
Management
Services

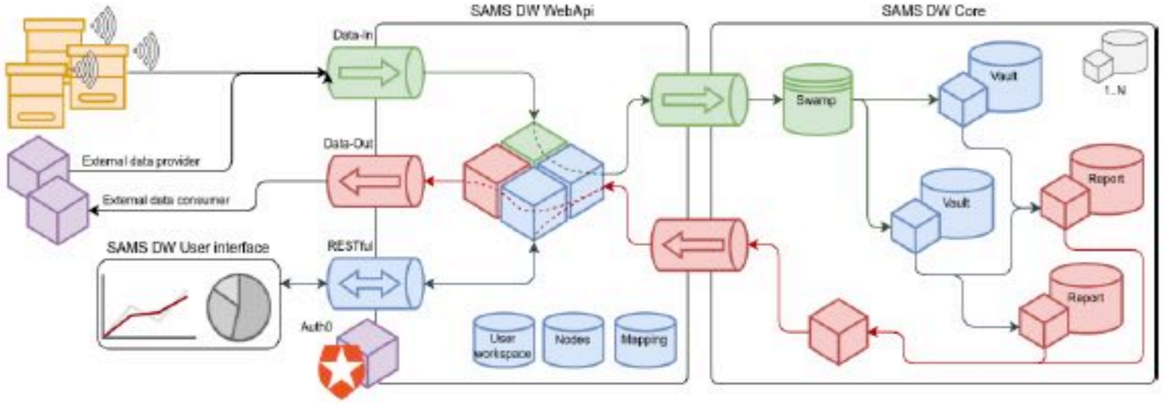
SAMS in a nutshell



SAMS as an ICT solution …

- allows active monitoring and managing of bee colonies
- ensures bee health and bee productivity
- gives answers to the requirements of beekeeping in developing countries
- is available as an open source technology

SAMS supports International Partnership Building in low and middle income countries in ASEAN and sub-Saharan Africa	
Objective	Strengthen the international cooperation of the EU with developing countries in ICT concentrating the field of sustainable agriculture as a vehicle for rural areas.
Duration	01/2018 – 12/2020
Budget	EUR 1.99 million
Funded by	European Union‘s Horizon 2020 Research and Innovation Programme



SAMS
Smart Apiculture Management Services

Objectives of SAMS

- ✓ Strengthen international cooperation of the EU with developing countries in ICT
- ✓ Address requirements of communities and stakeholders to promote and advance forms of existing beekeeping
- ✓ Monitor bee colonies in Germany, Ethiopia and Indonesia through an open source technology
- ✓ Evaluate gained information and convert them into recommendations for beekeepers
- ✓ Overcome country-specific challenges of beekeeping and simplify the management of bee colonies
- ✓ Strengthen interregional and international bee related partnership and cooperation
- ✓ Gain information on bee mortality

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH | UNIKASSEL VERSITÄT | Latvia University of Life Sciences and Technologies | KARL-FRANZENS-UNIVERSITÄT GRAZ UNIVERSITY OF GRAZ | unpad | IQQO | PRIMARY | iceaddis

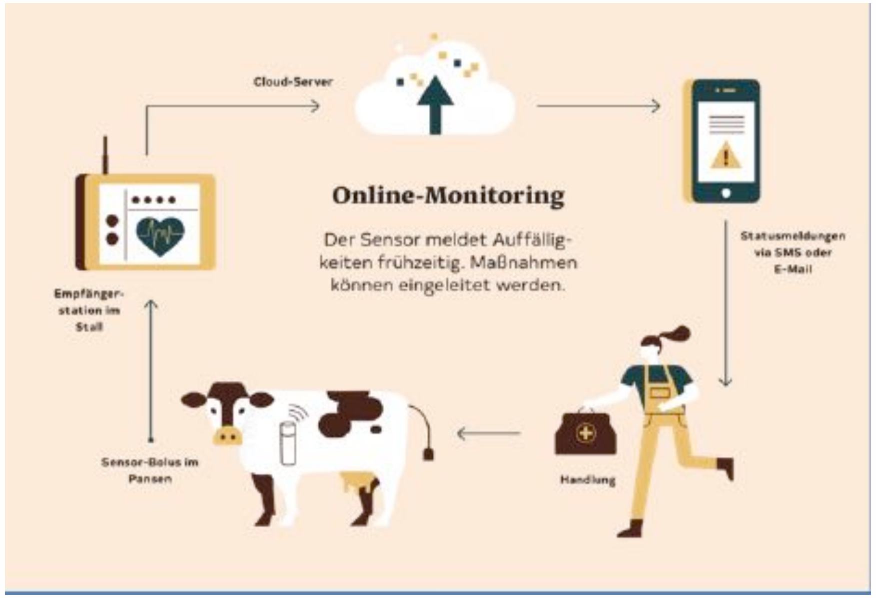
Benefits of bee colony remote monitoring

- Decrease of management costs
- Decrease the number of on-site inspections
- Less disturbance to bees
- Decrease the burden of death rate
- Increase of bee colony production

- Remote monitoring main goal is to identify **different states** of the bee colony and **prevent colony losses!**

Sensors in dairy farming

- **Identity:** animal No., locating (space and time)
- **Activity:** number of steps, resting time, lameness
- **Milk:** Quantity, colour, conductivity, cell count, fat, protein, residues
- **Physiological parameters:** pH-value rumen, temperature
- **Status:** weight, condition, calving prediction
- **Feeding:** concentrate, basic feed, water
- **Health:** disease prediction



„SoundHooves“

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Gefördert durch:

Bundesministerium für Ernährung und Landwirtschaft

Bundesanstalt für Landwirtschaft und Ernährung

aufgrund eines Beschlusses des Deutschen Bundestages

Measuring system for automated early diagnosis of lameness by acoustic analysis of impact sound generated from the course of cow movements

ptble FKZ: 2817902015

SoundHooves – relevance of lameness

- **Lameness correlates with:**
  - Udder health
  - Body condition
  - Scoring effect
  - Fertility
- **Lameness causes up to 850 Euro costs per cow and year**
- **Lameness is the third most frequent loss cause for cows in Europe**

SoundHooves – Implementation

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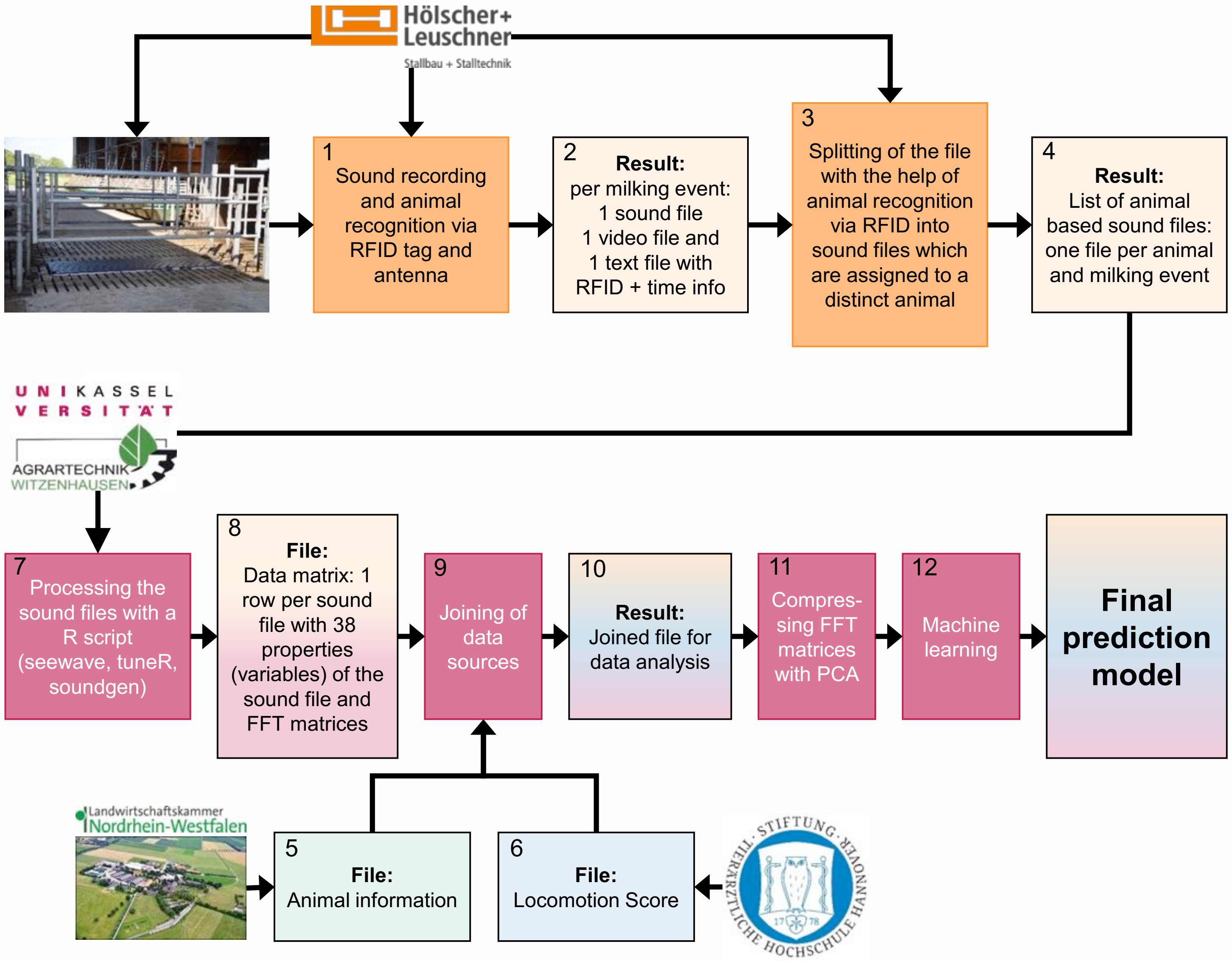

Conclusion and outlook

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- **Rapid development of digitisation in animal husbandry**
- **Huge increasing potential**
  - Animal welfare and health
  - Efficiency of management
- **Risks/ obstacles**
  - Data ownwership and sovereignty
  - Ethical questions
- **Challenges**
  - Reliable and objective indicators
  - Multi-attribute data evaluation
  - Multiple conflict of command variables

Impact of Energy Supply and Advanced Climate Control on Plant Quality

Why greenhouses?

- **Plant protection**
  - Unfavourable climate
  - Out of season production
- **Valuable products**
  - Ornamental plants
  - Vegetables (and fruits)
  - herbs
- **Manipulation of the environment**
  - Increase of quality and/or yields
  - Raise of profit
  - Requires acurate control of setting

Production considerations

Quality – yield - profit

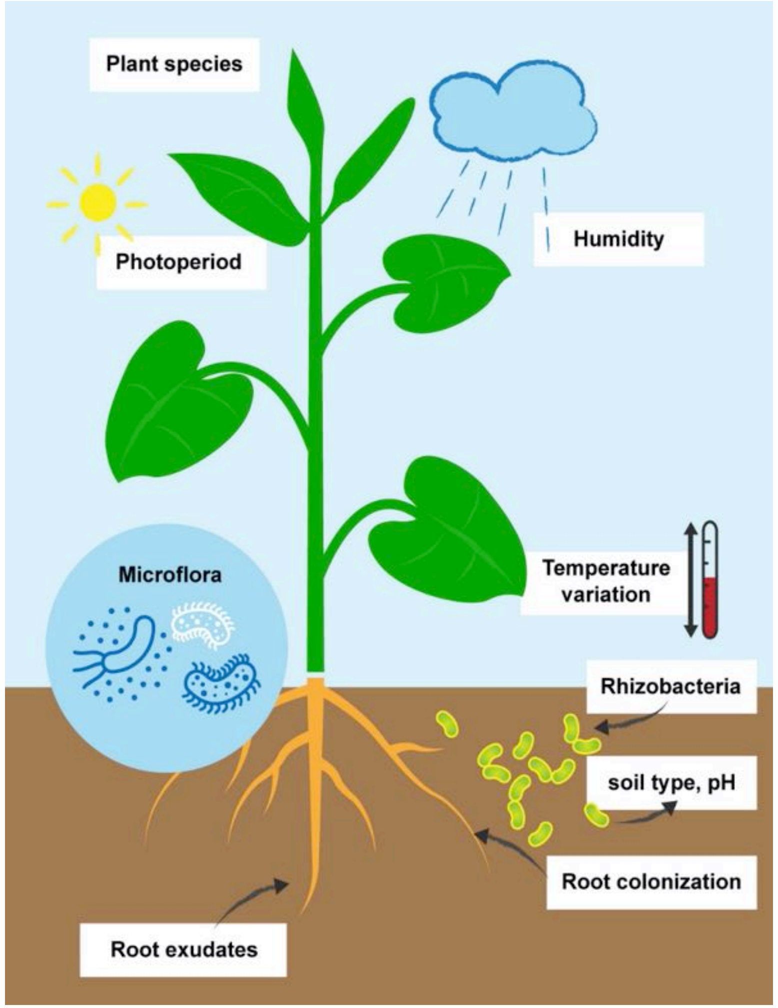
- Efficient production management
- experience and training of producers
- suitable greenhouse structure
- proper fitting, installation and maintenance of systems
- Efficient climate control
- Procedures for integrated production and protection (IPP)

➔ **Often conflicting requirements**

https://financialtribune.com/sites/default/files/field/image/17january/04-as-flower_1032-ab.jpg
https://static1.squarespace.com/static/570c1ecdb654f97eee80ed41/t/584467e7414fb5f82e8fefdd/1480878062140/

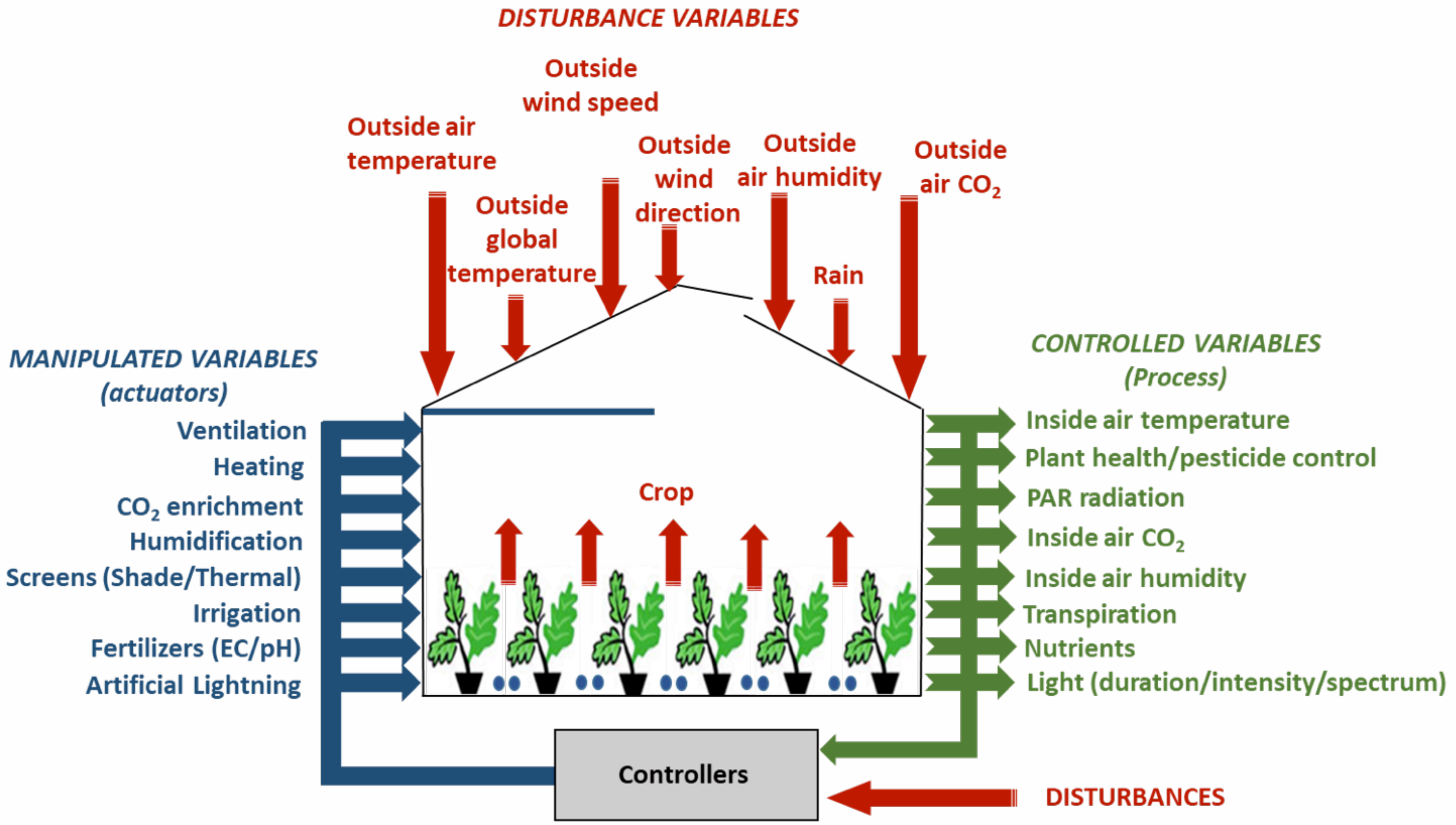
Environmental conditions

- Water
- Nutrients
- Soil and substrates
- Biotic factors
- Air supply and distribution
- Light intensity and quality
- climate
  - Temperature
  - Air humidity



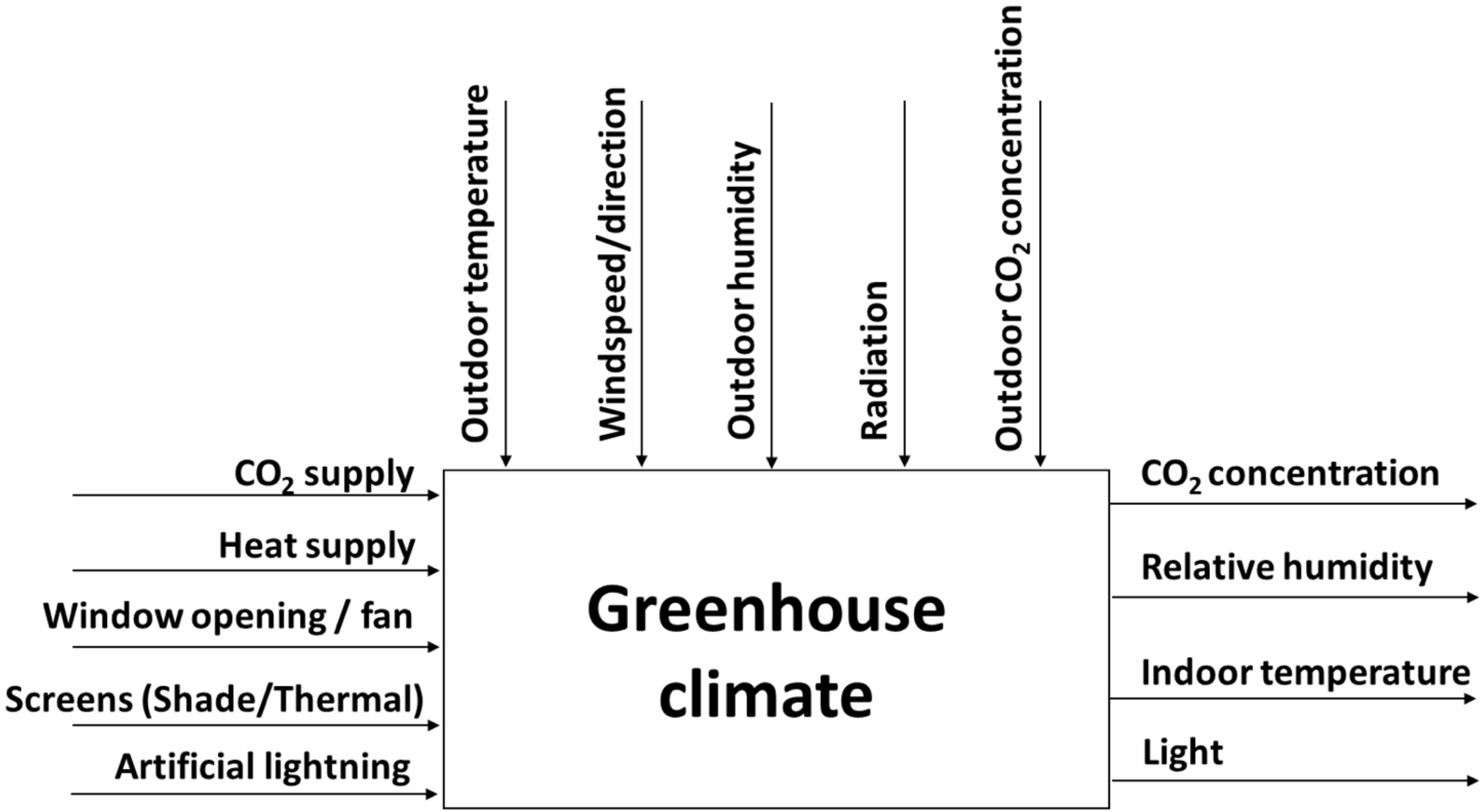
http://popups.ulg.ac.be/1780-4507/docannexe/image/7578/img-1.jpg

Resulting production demands



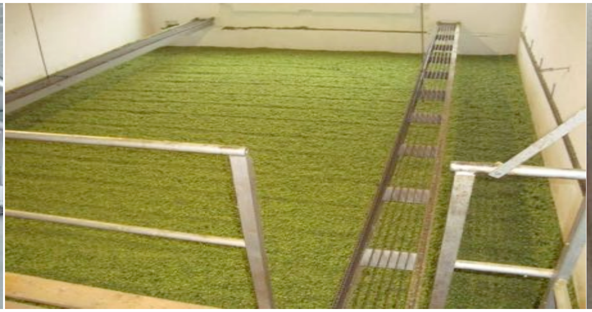
Rodriguez et al. (Ed.) (2015). Modeling and control of greenhouse crop growth, Springer, Cham Heidelberg New York Dordrecht London

Basic principles of climate control



Bakker et al. (1995). Greenhouse Climate Control – An integrated approach, Wageningen Academic Publishers, Wageningen

Smart drying



Use of sensors and E-learning

Context

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Energy | Food | Water | Climate

Shortage of food, water or energy can destabilize the world

Context

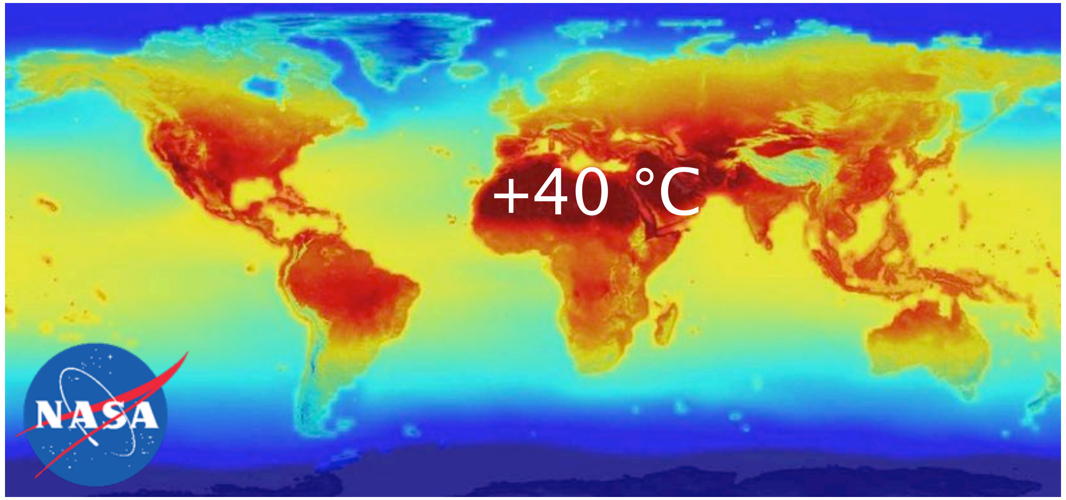
TOT. POPULATION
7.45 billions

1/9 HUNGRY PEOPLE
830 millions

ONE OF THE BIGGEST CHALLENGES
Zero hunger

Source: 2016 World Hunger and Poverty Facts and Statistics

Context

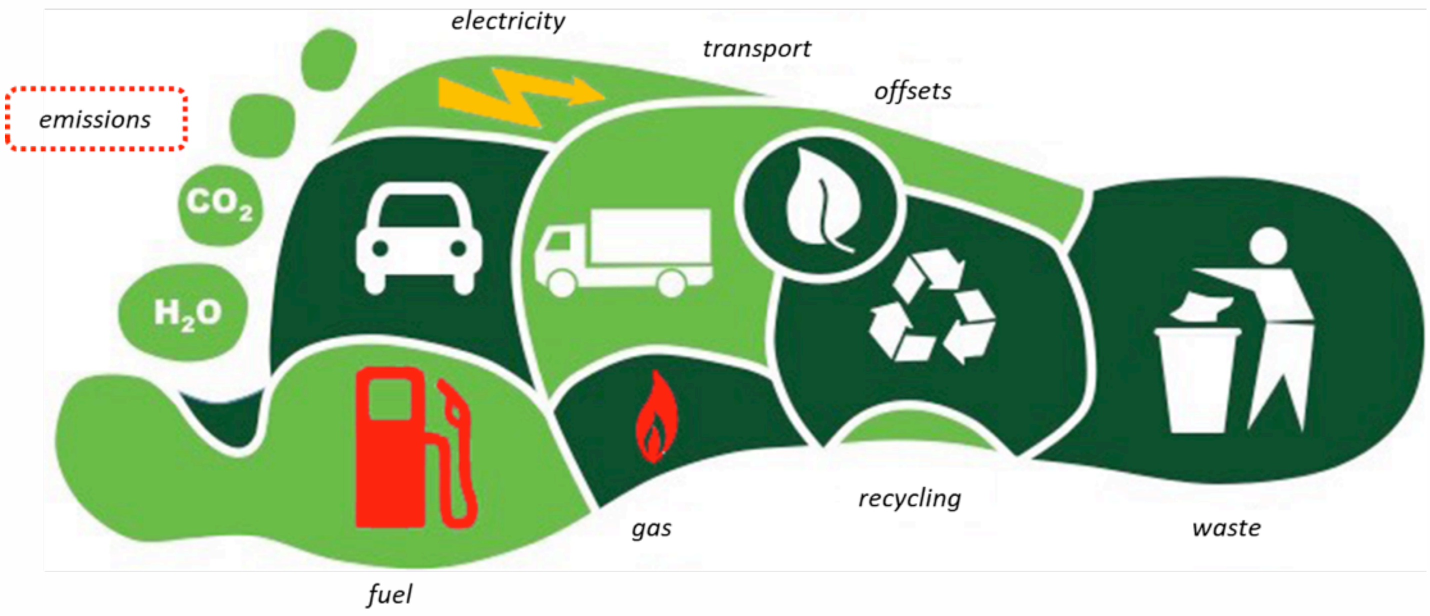


YEAR 2050
World population projected to reach 9.7 billions

YEAR 2100
Our habitus risks to change dramatically

State of the art

- **Low automation level**
- **Food drying is energy-intensive**
  - *Compromises product quality*
  - *Compromises environment (green house gases)*



Energy and technology

- **Drying and energy**
  - 15-25% of all industrial energy demand in industrialised countries
  - Energy efficiency of convection drying av. ~35-45% sometimes as low as 10%
- **Drying and technology**
  - Processing conditions decades-old
  - Control systems inflexible
  - Product changes dynamically, process is static
  - No assessment of cumulative impact of unit operations

➔ **Product quality inferior**

➔ **Energy demand too high**

http://www.innotech-ing.de

Raw material handling and preparation

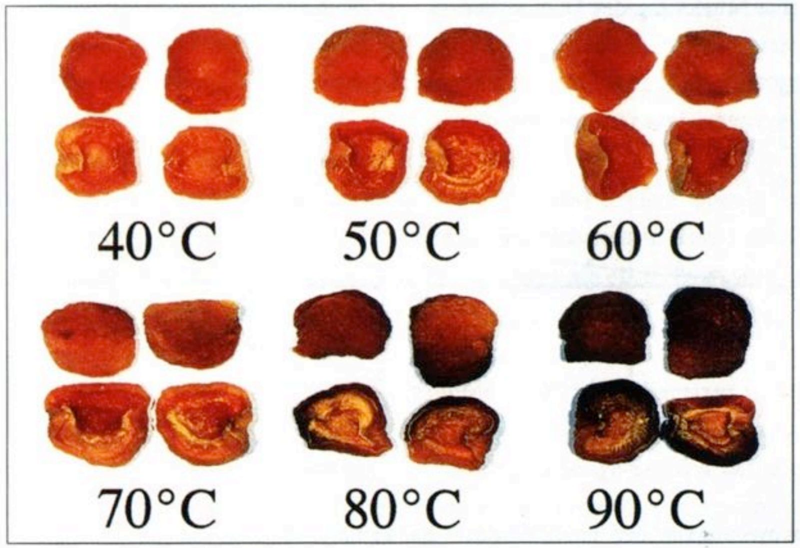
- **Herbs and hops**
  - Short shelf life before processing
    - E.g. hops: 4-6 h, appropriate airing required
  - Sensitivity to processing conditions
    - Aromatic and other components
  - Colour retention
- **Fruits, vegetables, meat**
  - Sensitivity to processes and processing conditions
  - Susceptible to changes (e.g. oxidation) over time

  ➔ **Reduce lag time**

➔ **Damage to product quality cannot be counteracted downstream!**

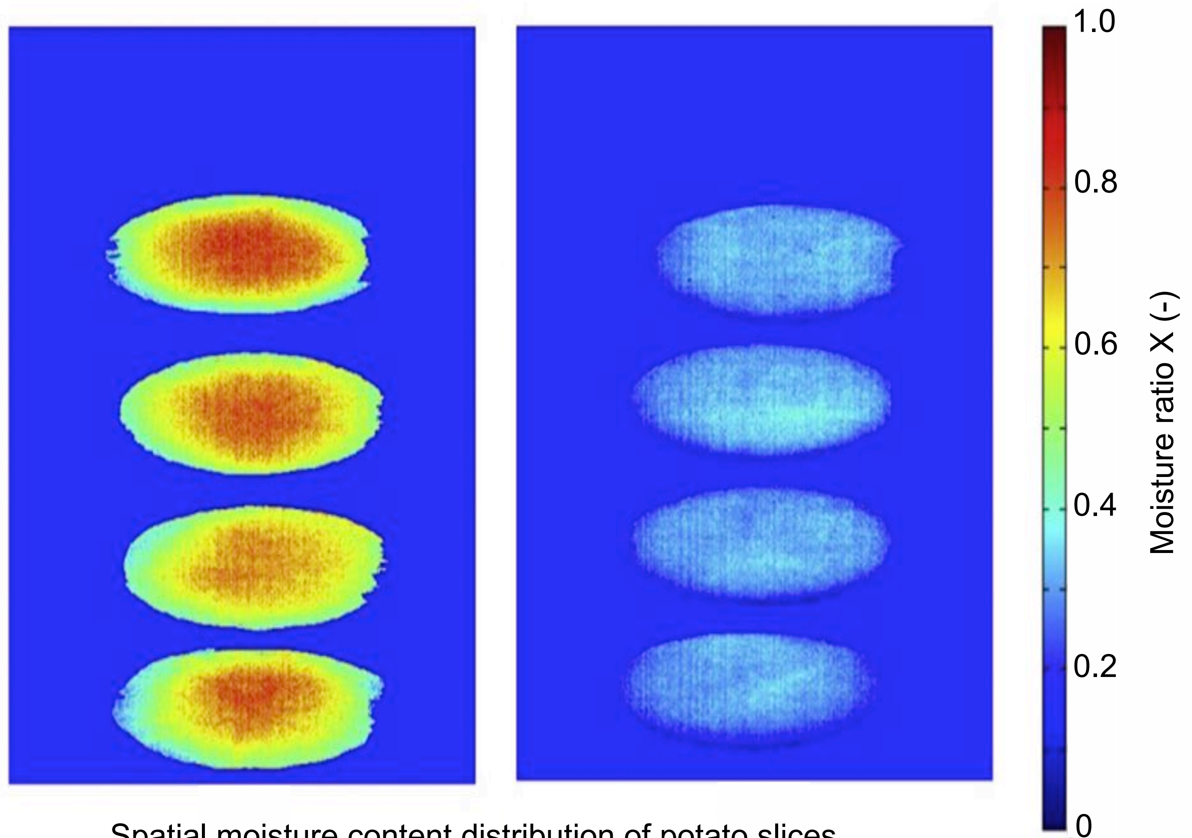
Relevance of the topic – Quality changes and design needs

- Mechanical
- Chemical
- Biological
- Sensorial
- Nutritional
- Optical

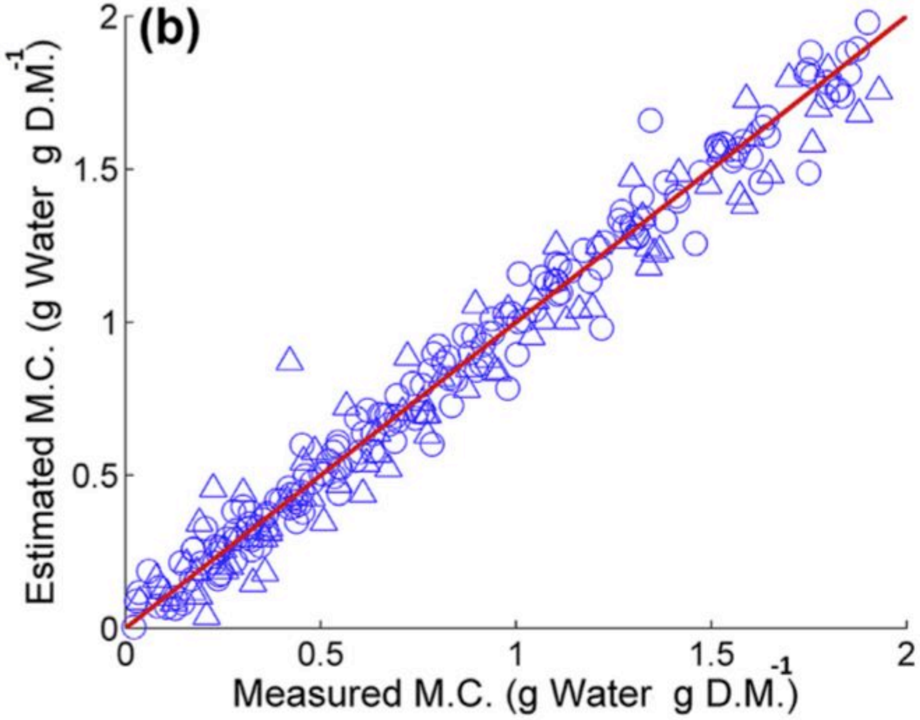


→ Cumulative impacts analysis
→ Product driven design and optimisation
→ Direct (non-invasive) sensor systems
→ Product driven control systems

Moisture content (MC) distribution potato



Spatial moisture content distribution of potato slices



Amjad et al. (2018). Biosystems Engineering 166, 170-183

The future of drying

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- Research needs for “smart drying systems”
- Enhancement of sustainability by using
  - *Computer technology*
  - *Microcontroller and Sensors*
  - *On-line, in-line, at-line Sensor technologies*
  - *Mathematical Modelling*
  - *Machine learning (e.g. deep learning)*
  - *Heuristic statistical evaluation*
  - *Low power wide area network*
  - *Handling of big data volumes and Cloud Computing*
- Increase of product quality

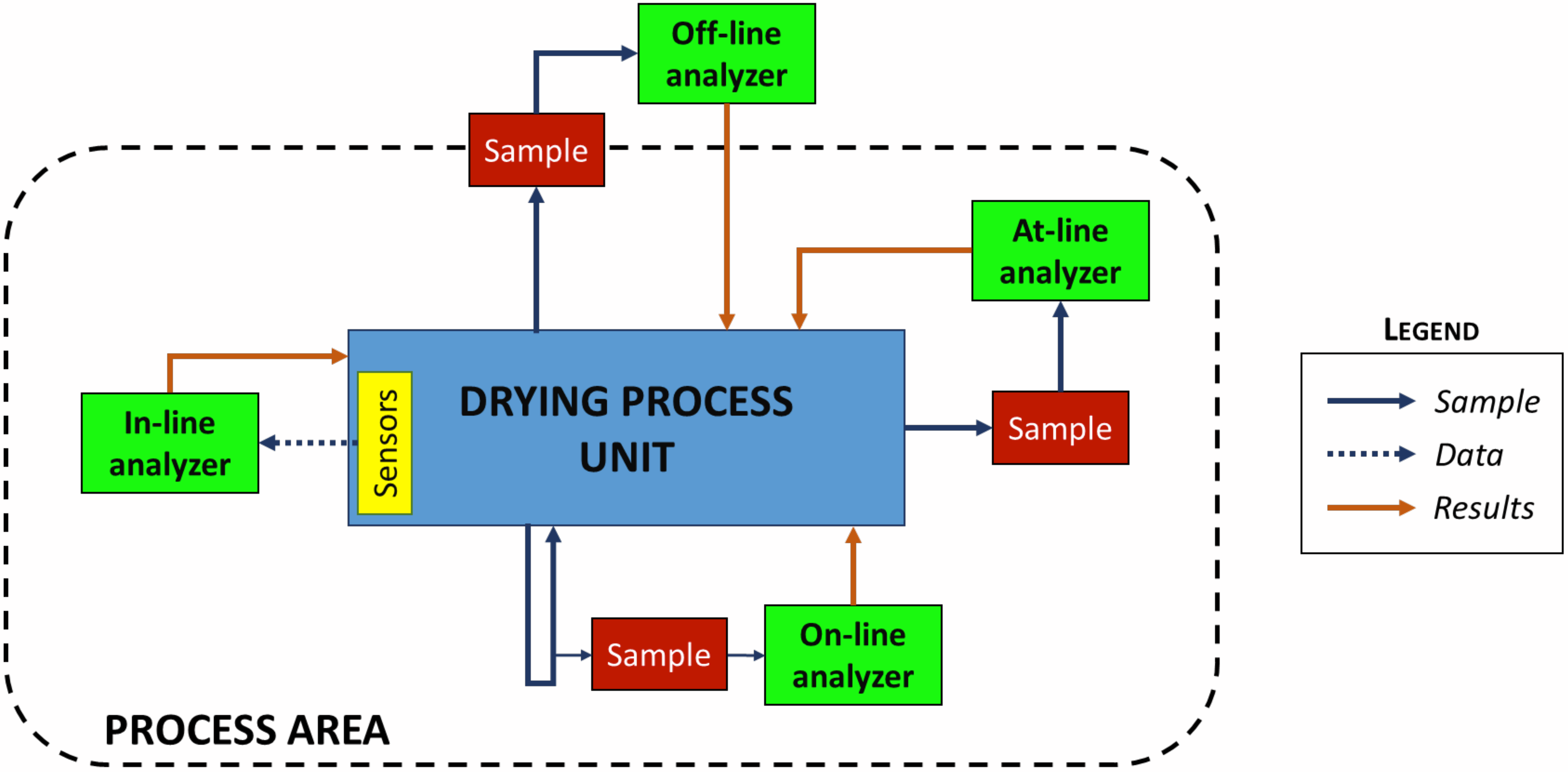
Smart drying: available technologies

1) Control systems for drying environment
   - *pressure*
   - *temperature*
   - *air velocity*
   - *humidity*
2) Biomimetic systems
   - *odor-sensing system (electronic nose)*
   - *taste-sensing system (electronic tongue)*
3) Computer vision technology
4) Microwave/dielectric spectroscopy
5) Visible and/or Near Infrared spectroscopy
   - *single point*
   - *multi/hyperspectral imaging*
6) Magnetic resonance imaging
7) Ultrasound techniques

- Influence on the quality of the product
- Information about the progress of drying

- Smell and taste
- Size, shape and colour
- Chemical, physical and physicochemical characteristics
- Information about the progress of drying

Measuring system

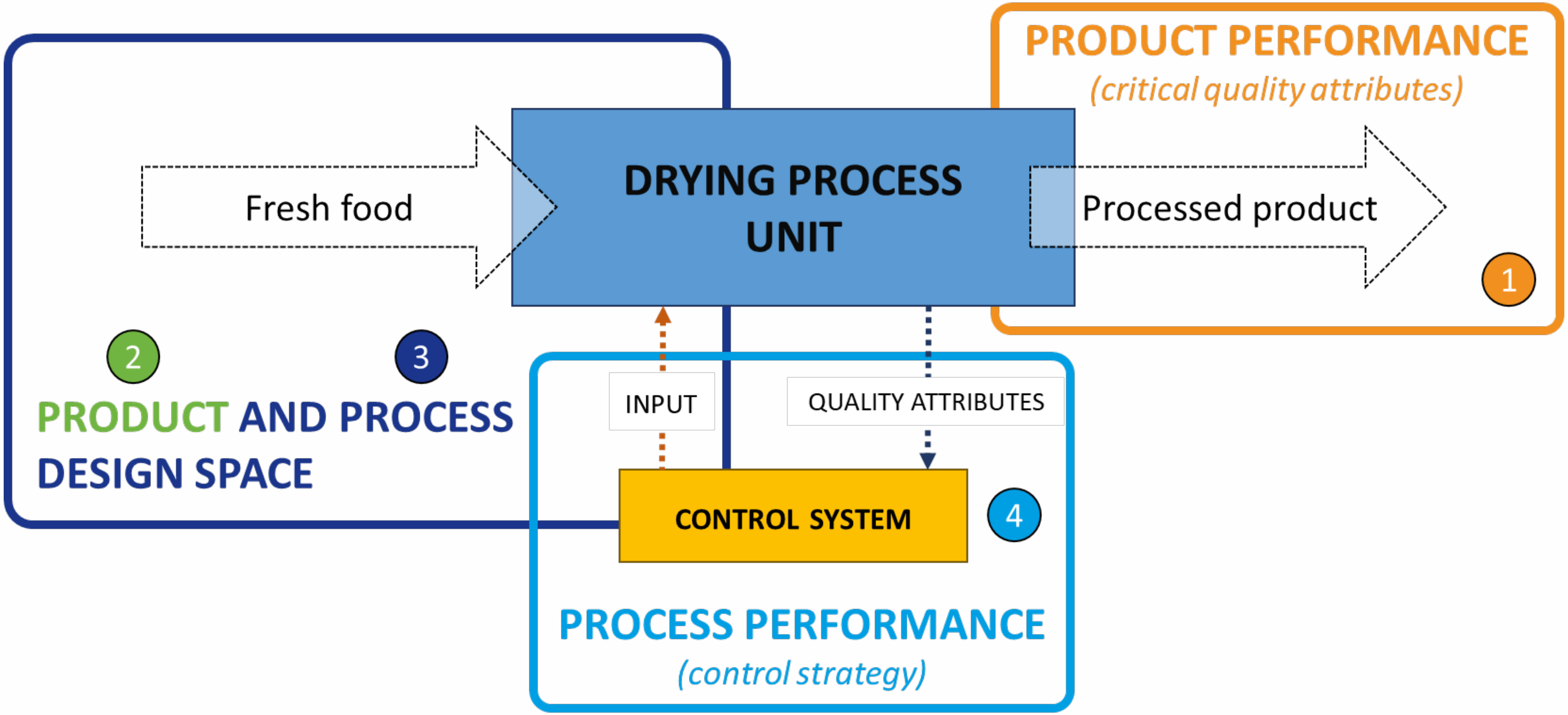


Quality by Design (QbD) Strategy

- **Starting point: knowledge about the product to process**
- **Reliable and objective indicators**
- **Deep understanding of the process**

Properly designed smart drying technology can help significantly increase efficiency and productivity

QbD



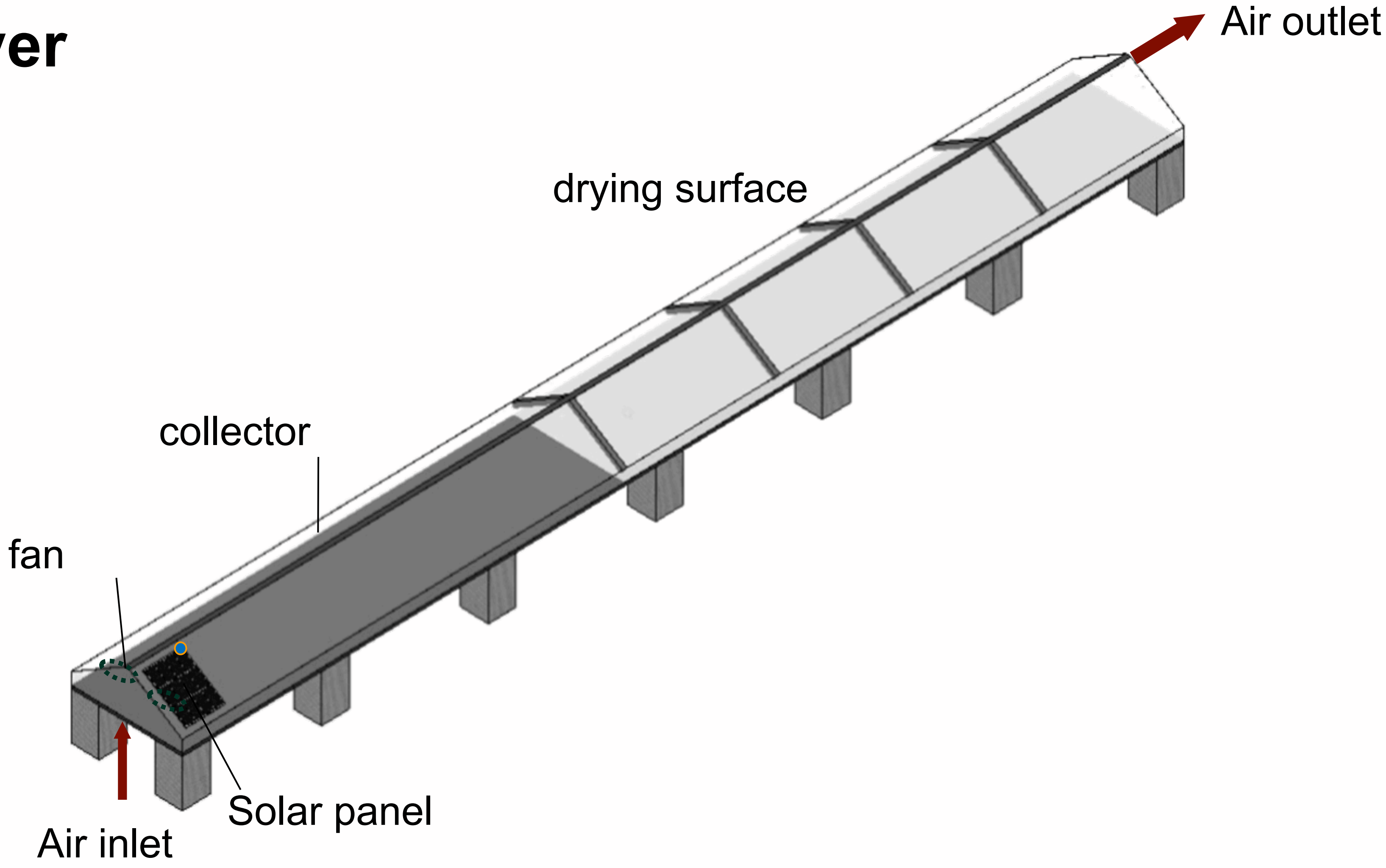
PRODUCT PERFORMANCE
(critical quality attributes)
Fresh food
DRYING PROCESS UNIT
Processed product
1
2
3
PRODUCT AND PROCESS DESIGN SPACE
INPUT
QUALITY ATTRIBUTES
CONTROL SYSTEM
4
PROCESS PERFORMANCE
(control strategy)

Solar Drying – process optimisation

Solar Tunnel dryer

Type Hohenheim

Length: 18 m
(Collector: 8 m)
(Drying: 10 m)
Width: 2 m



Case study – quality drying of medicinal herbs melissa officinalis

Fresh leave

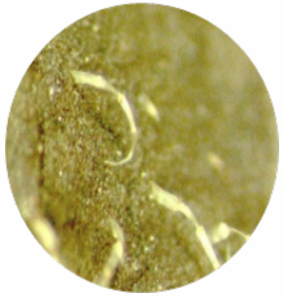
Experimental factors

Light- and shade-drying
Section of dryer
Layer thickness
Air velocity

Leave at

Optimum drying

Bad drying



colour
Oil content
humidity

→ Solar drying →

colour
Oil content
Drying time

Note: optimum drying temperature for melissa = 45°C

Case study – quality drying of medicinal herbs melissa officinalis

Experimental factors

28

Faktor				
	Light and shade drying	Sections of tunnel (m)	Layer thickness (g/m2)	Air velocity (m/s)
Level	C_o	X_p	L_d	V_a
Low	Light	0.8	900	0.4
high	Shade	7	1800	0.8

Response

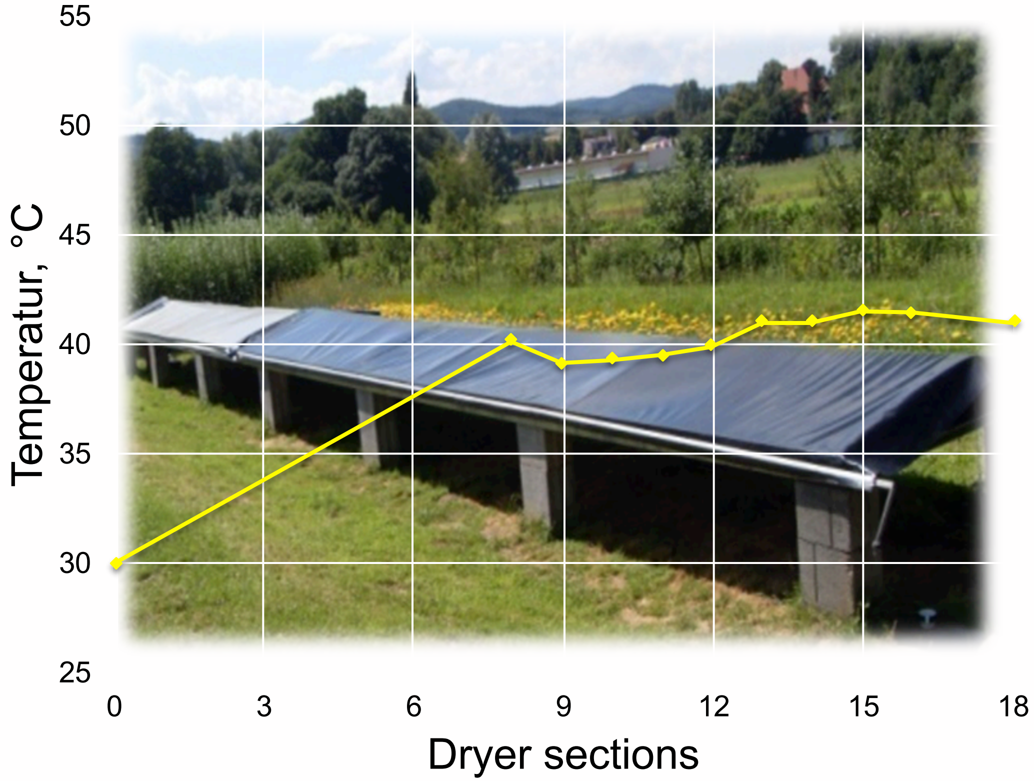
- Drying time t_d
- Colour change ΔE
- Oil content O_c

AGRARTECHNIK WITZENHAUSEN

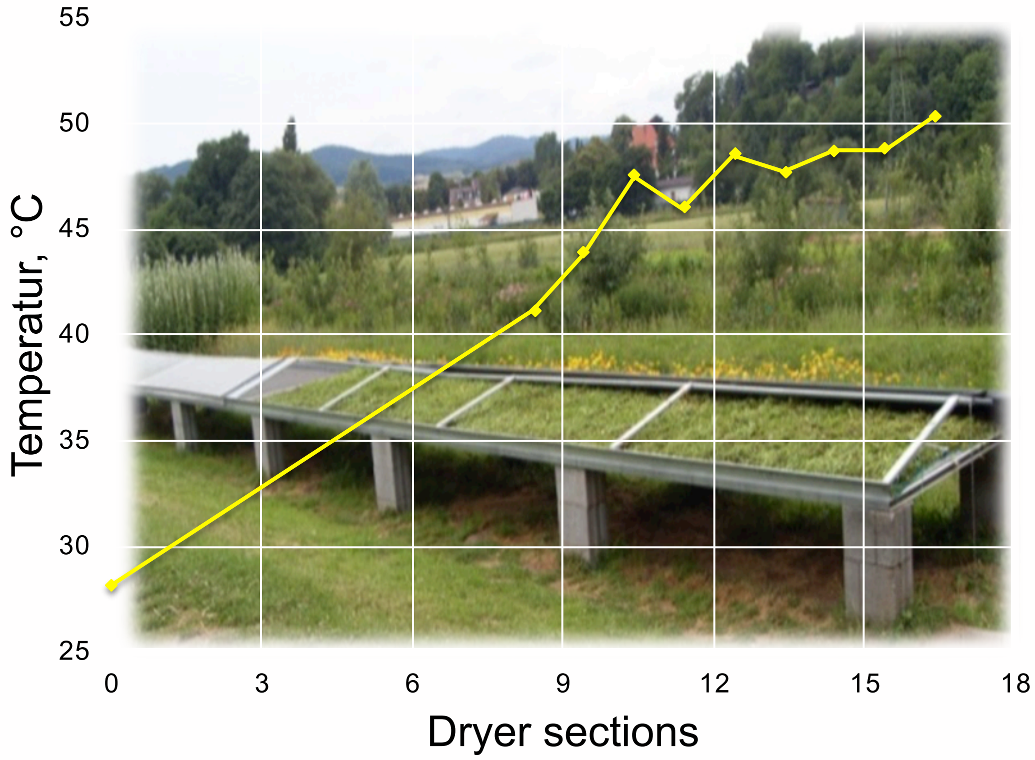
ÖkologischeAgrarwissenschaften UNIKASSEL

Case study – quality drying of medicinal herbs melissa officinalis

shadowed



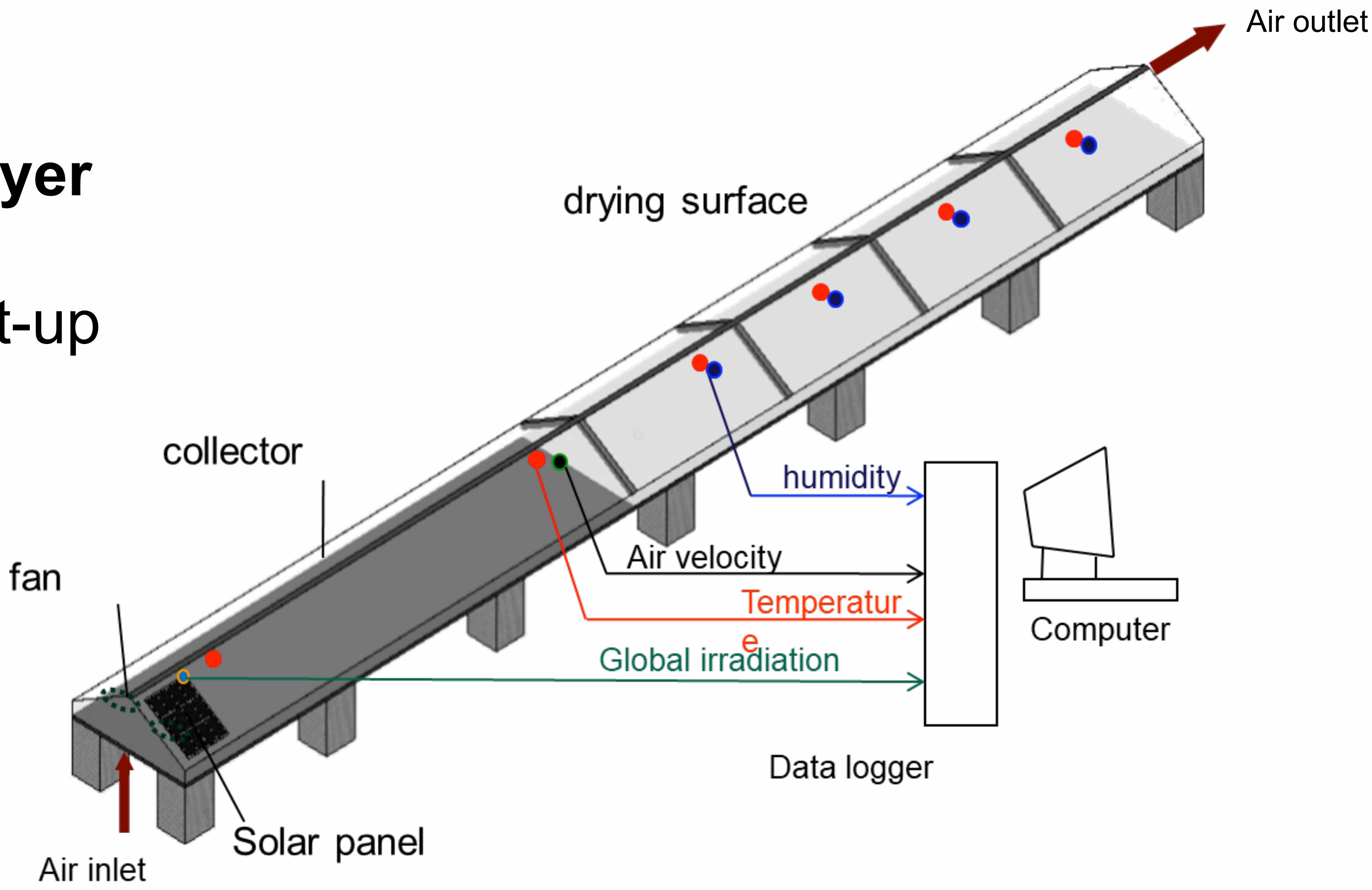
unshaded



Research design

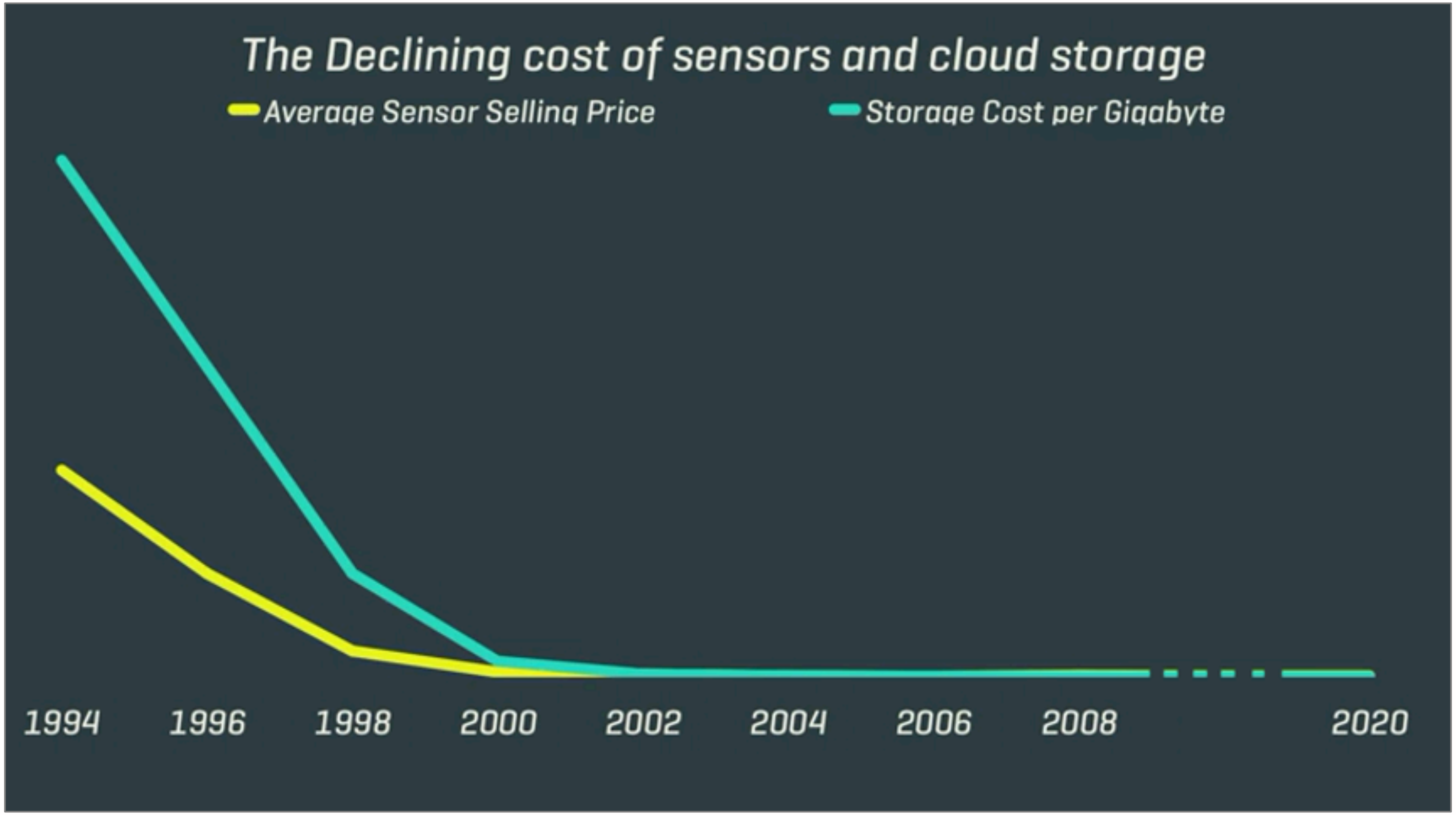
Solar Tunnel dryer

Experimental set-up

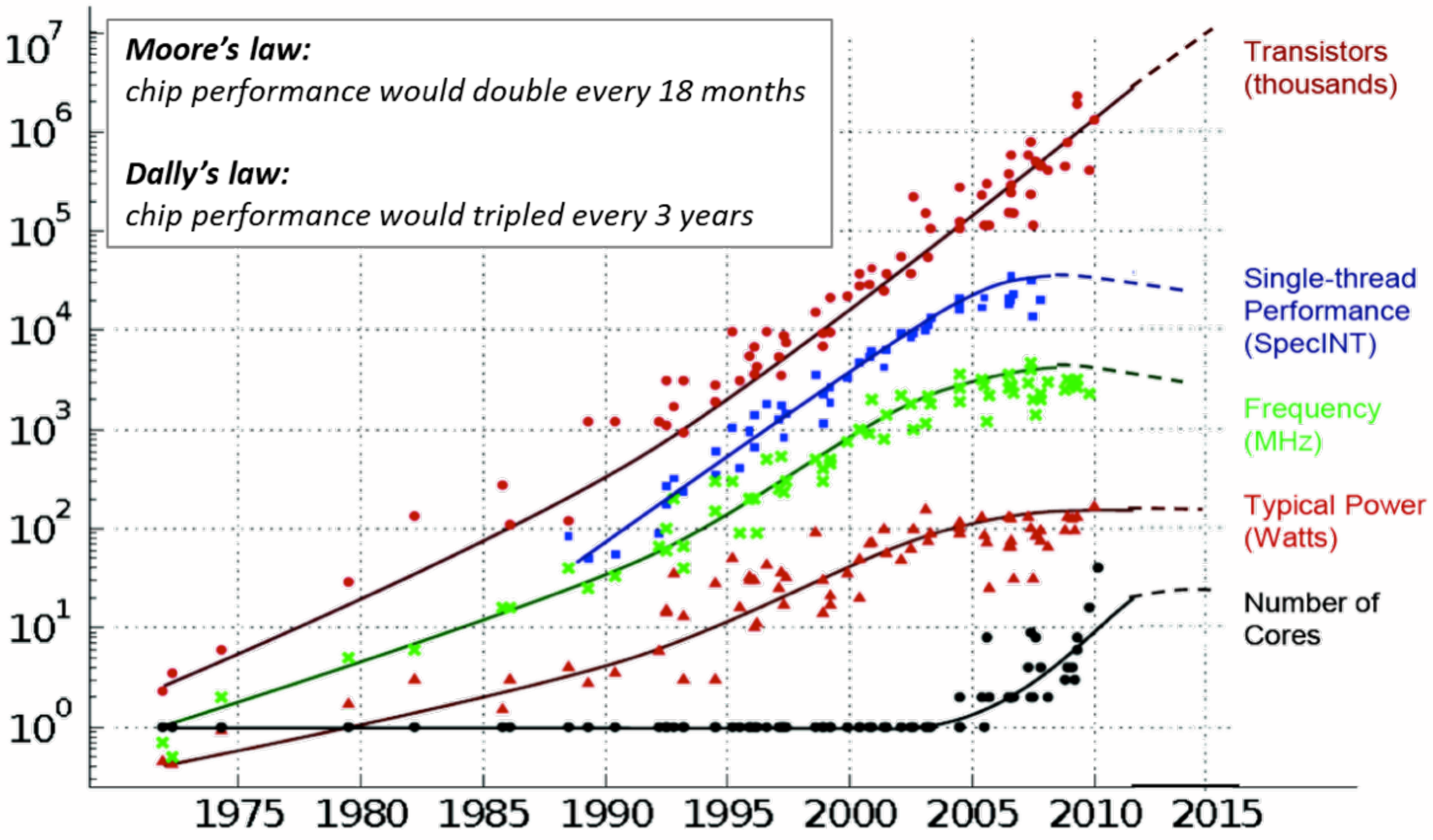


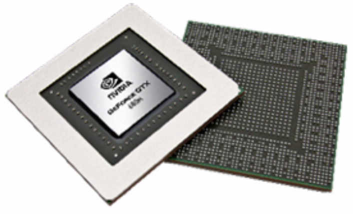
The way forward

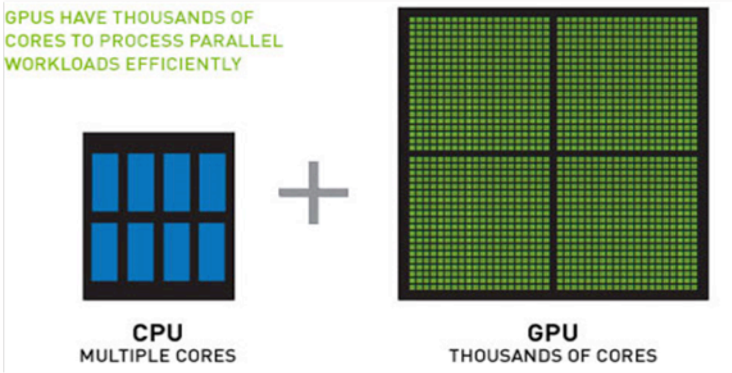
Average sensor- und storage costs



Trends in integrated circuit technology



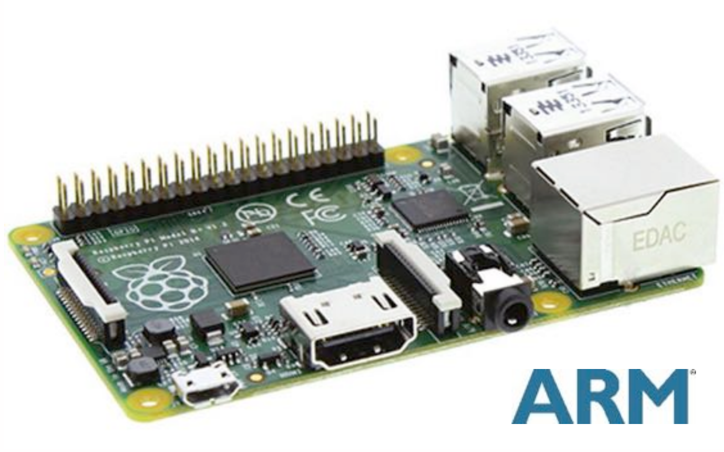


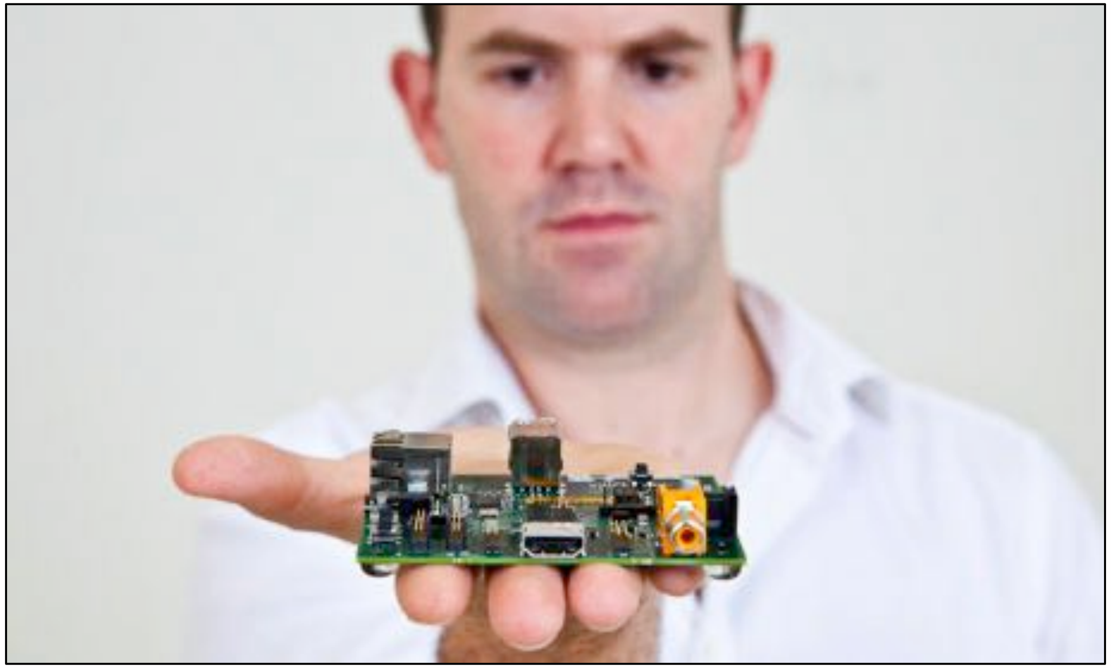


Central Processing Unit | Graphics Processing Unit

Low-cost Computers

Raspberry Pi®



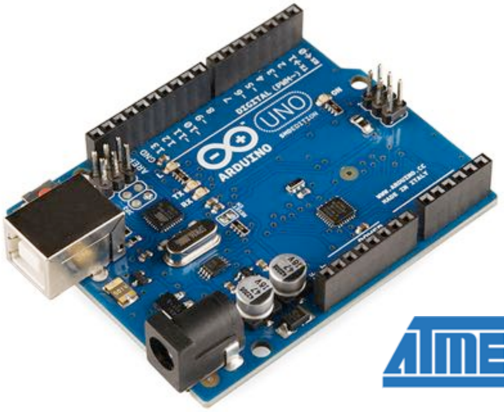


Eben Uptor

UNIVERSITY OF CAMBRIDGE

Low-cost control units

ARDUINO



ATMEL

Massimo Banzi

Low-cost sensors

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intel Developer Zone

TCS3414CS Color Sensor

ID: tcs3414cs

Alternate Name: Grove Color Sensor

Component Type: Color Sensors

Connection Type: I2C

API's: C++ Python Node.JS

MQ303A Alcohol Sensor

ID: mq303a

Alternate Name: Grove Alcohol Sensor

Component Type: Gas Sensors

Connection Type: AIO, GPIO

Available in: Transportation & Security Kit

API's: C++ Python Node.JS

Grove CO2 Sensor

ID: mhz16

Alternate Name: MHZ16 Serial CO2 Sensor

Component Type: Gas Sensors

Connection Type: UART

API's: C++ Python Node.JS

Cloud storage

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Low power wide area network

SIGFOX One network A billion dreams
LoRa
nwave
LTE-M
NB-LTE
INGENU
WEIGHTLESS
IEEE 802.11ah
DASH7 ALLIANCE
EC-GSM
ZigBee 3.0
Bluetooth 4.0

low cost | long range | low power | secure

Bid data management

hadoop

mongoDB

Cloud computing services

amazon web services

Google Cloud Platform

Microsoft Azure

Conclusions

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- Need of novel drying technologies
  - Reduction of CO2 footprint
  - lower life-cycle costs
- Intelligent dryers are already realisable
- ICT in food industry is cost-efficient
- Parallel Computing is the most promising and efficient tool for the development of machine-learning models

Occam's Razor principle

'Among competing hypotheses, the one with the fewest assumptions should be selected'

Machine learning – artificial intelligence

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- artificial neuronal web
- Fuzzy-Logic
- Genetic Algorithm
- Neuronal Fuzzy-Systems
- Algorithms to reduce dimensionality (i.e. t-distributed stochastic adjacency)

BUT ➔ causality vs collinearity

Some challenges and limits of Digitisation

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- **Social-ecological objectives**
  Digitisation should contribute to sustainable energy, transport, agriculture and resource management (climate protection, ending hunger and poverty)
- **Education**
  Critical and emancipatory handling of digital technology and media
- **Development and trade policy aspects**
  Trade agreements must not contain any restrictions for taxation and open source. Benefits and costs of digitisation should be shared equally
- **IT security (software liability)**
  Software developers need to take responsibility for emerging risks
- **Privacy and control**
  Set-up of framework conditions for the control of digital monopolies

Thank you for your attention




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- hessem@uni-kassel.de