Mobile Cyber Physical System concept
for controlled agri-cultural environments

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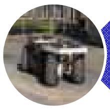
Dr. K. Weidig, Raussendorf GmbH, Obergurig

1 - Global Opportunities of Robotics

2 - Robotics meets nature:
Autonomous systems in agricultural environments



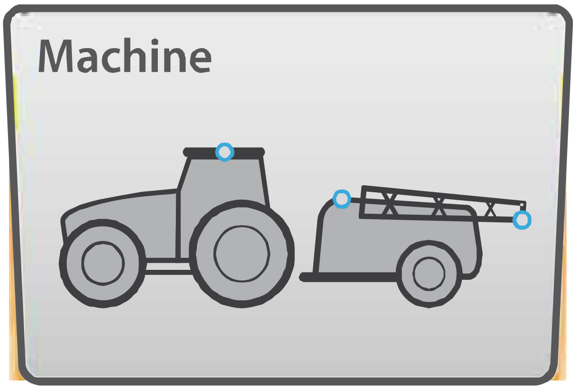
3 - Application examples of robotic platform

4 - Outlook

Main Challenge of Farm Machinery

How do we design agricultural technologies, which

- feed 9 billion people,
- provide renewable energy and
- work environmentally sustainable ??



productivity
peak performance
process quality
cost of ownership

Main Challenge of Farm Machinery

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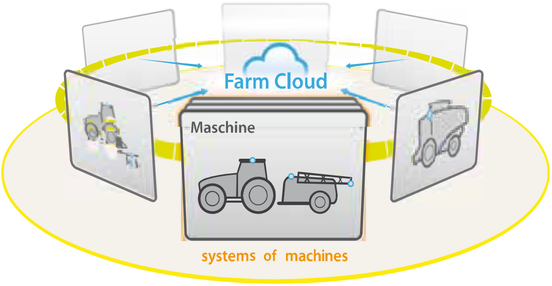
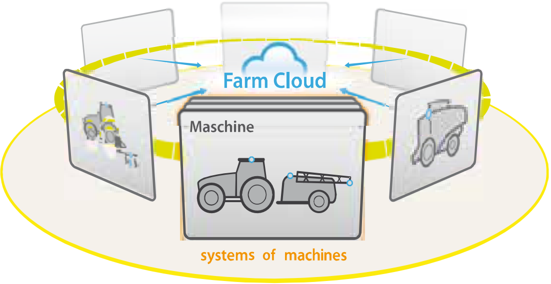


productivity
peak performance
process quality
cost of ownership

⇕

connectivity

Main Challenge of Farm Machinery



productivity
peak performance
process quality
cost of ownership

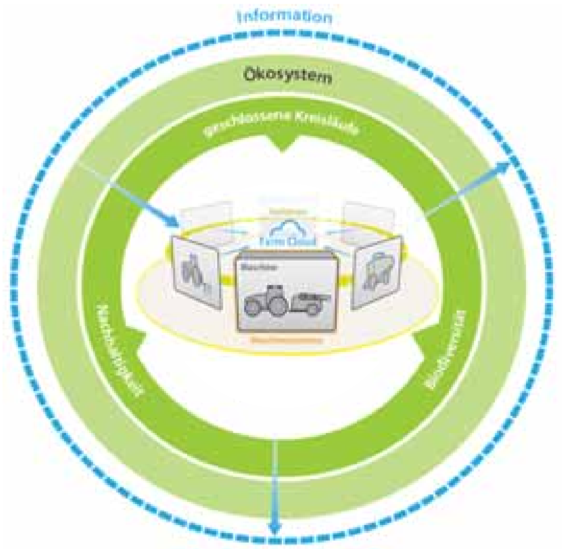
↕

connectivity

↕

sustainability
resource recirculation
biodiversity

Main Challenge of Farm Machinery



productivity
peak performance
process quality
cost of ownership

↕

connectivity

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sustainability
resource recirculation
biodiversity

Definition of cyber physical systems

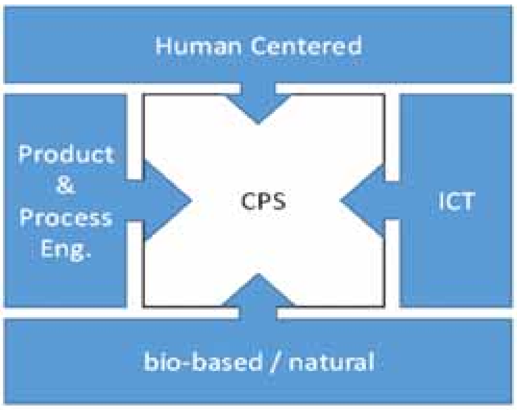
Definition Edward A. Lee, 2008 [1]:

*[Cyber Physical Systems: Design Challenges",
E. A. Lee, Technical Report No. UCB/EECS-2008-8;
http://www.eecs.berkeley.edu/Pubs/TechRpts/2008/EECS-2008-8.html]*

- „Cyber-Physical Systems (CPS) are integrations of computation with physical processes.
- Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa."

Acatech research agenda, 2012 [2]:

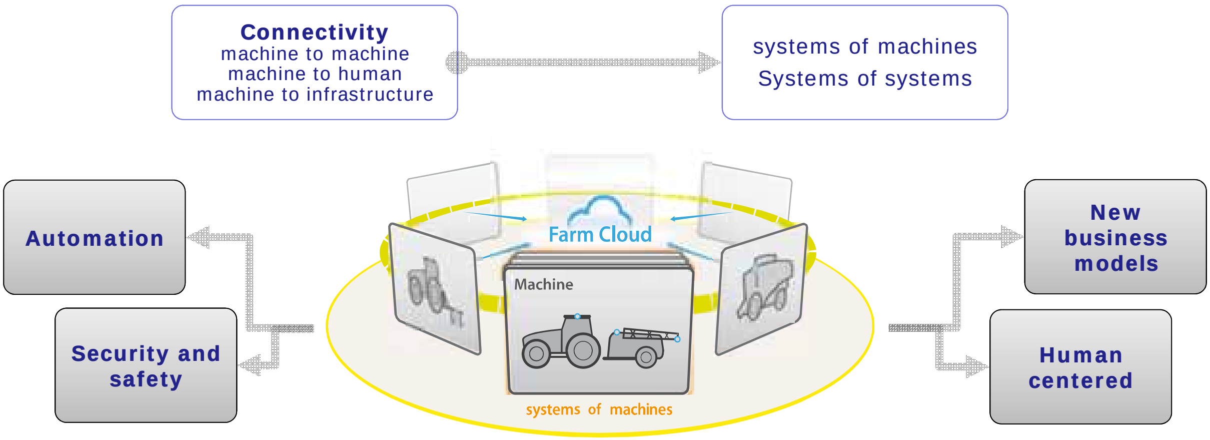
- Connection of physical system with information technology utilizing open global networks (e.g. Internet)
- Typical examples "Smart Grids", „Car-to-X"



[1] Cyber Physical Systems: Design Challenges", E. A. Lee, Technical Report No. UCB/EECS-2008-8; http://www.eecs.berkeley.edu/Pubs/TechRpts/2008/EECS-2008-8.html

[2] Integrierte Forschungsagenda Cyber-Physical Systems, Acatech 2012; http://www.acatech.de/?id=1405

Definition of mobile cyber physical systems



Connectivity
machine to machine
machine to human
machine to infrastructure

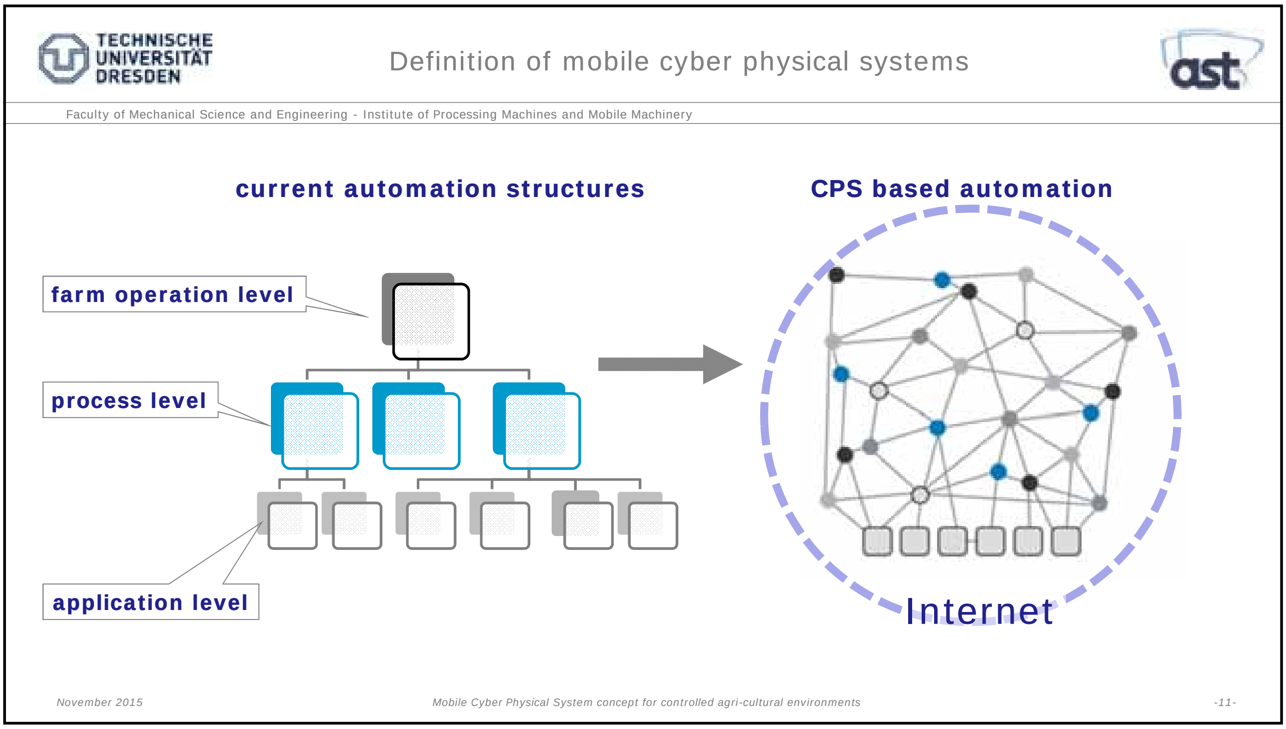
systems of machines
Systems of systems

Automation

Security and safety

New business models

Human centered



Definition of mobile cyber physical systems

current automation structures

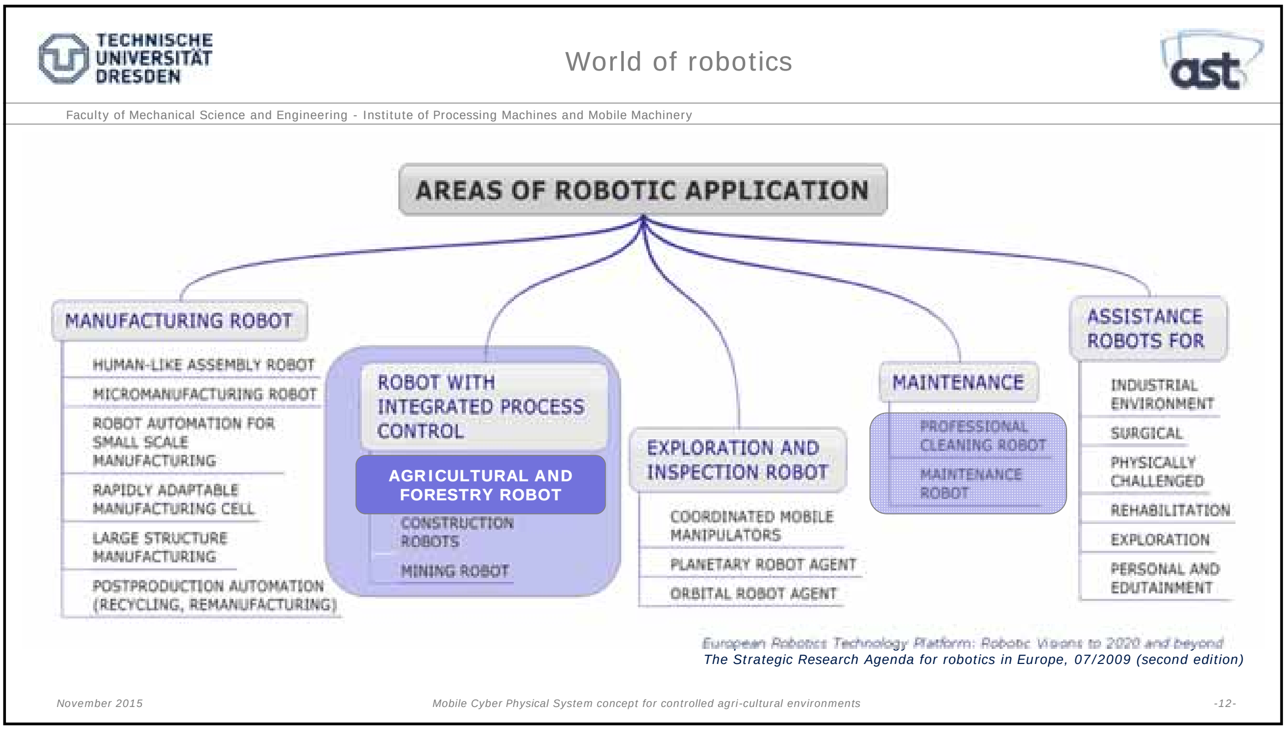
CPS based automation

farm operation level

process level

application level

Internet



World of robotics

AREAS OF ROBOTIC APPLICATION

MANUFACTURING ROBOT
- HUMAN-LIKE ASSEMBLY ROBOT
- MICROMANUFACTURING ROBOT
- ROBOT AUTOMATION FOR SMALL SCALE MANUFACTURING
- RAPIDLY ADAPTABLE MANUFACTURING CELL
- LARGE STRUCTURE MANUFACTURING
- POSTPRODUCTION AUTOMATION (RECYCLING, REMANUFACTURING)

ROBOT WITH INTEGRATED PROCESS CONTROL
- **AGRICULTURAL AND FORESTRY ROBOT**
- CONSTRUCTION ROBOTS
- MINING ROBOT

EXPLORATION AND INSPECTION ROBOT
- COORDINATED MOBILE MANIPULATORS
- PLANETARY ROBOT AGENT
- ORBITAL ROBOT AGENT

MAINTENANCE
- PROFESSIONAL CLEANING ROBOT
- MAINTENANCE ROBOT

ASSISTANCE ROBOTS FOR
- INDUSTRIAL ENVIRONMENT
- SURGICAL
- PHYSICALLY CHALLENGED
- REHABILITATION
- EXPLORATION
- PERSONAL AND EDUTAINMENT

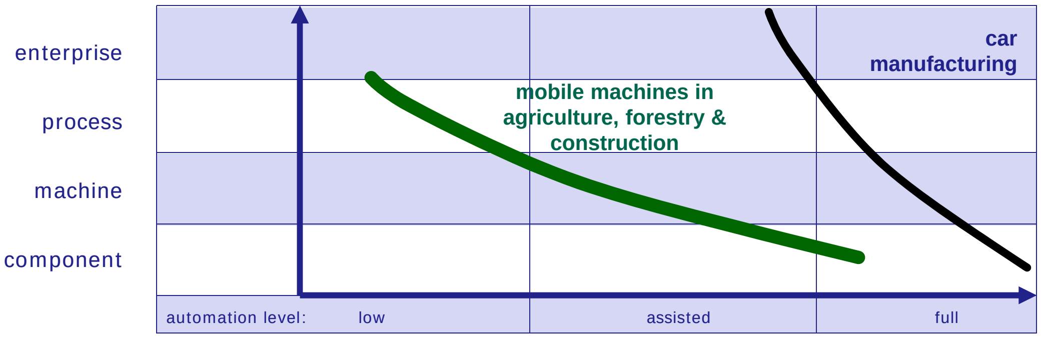
European Robotics Technology Platform: Robotic Visions to 2020 and beyond
The Strategic Research Agenda for robotics in Europe, 07/2009 (second edition)

Autonomous systems in agricultural environments

Robust and economical viable automation is pre-condition for autonomous systems

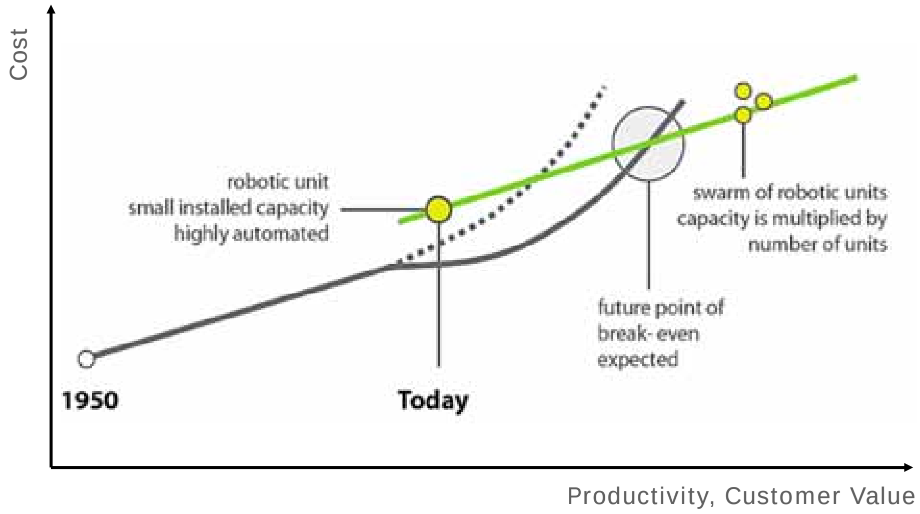
Problem of automation in biobased value chains:

- many disturbances and strong variation of inputs
- lack of sensors and process knowledge
- huge diversity of machines and execution of processes



Griepentrog (2015), modified

Vision of systems of machines towards robotic swarms



TECHNISCHE UNIVERSITÄT DRESDEN

DRESDEN concept

Swarm vision for tillage and seeding
autonomous implement modules
virtually connected to leader

Swarm vision for grain harvest
autonomous combine modules
supervised from local operator

TECHNISCHE UNIVERSITÄT DRESDEN

elWObot project for vineyards and fruit plantages

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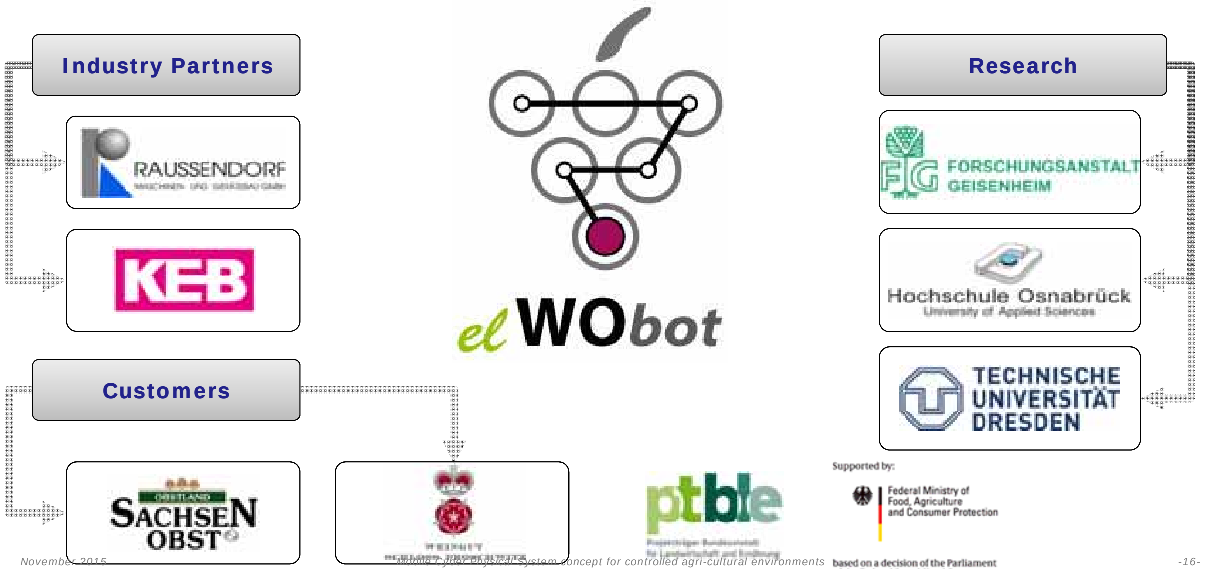
Faculty of Mechanical Science and Engineering - Institute of Processing Machines and Mobile Machinery



Industry Partners

RAUSSENDORF Maschinen- und Gerätebau GmbH

KEB

Research

FORSCHUNGSANSTALT GEISENHEIM

Hochschule Osnabrück University of Applied Sciences

TECHNISCHE UNIVERSITÄT DRESDEN

elWObot

Customers

OBSTLAND SACHSEN OBST

WEINGUT SCHLOSS PROSCHWITZ

ptble Projektträger Bundesanstalt für Landwirtschaft und Ernährung

Supported by:

Federal Ministry of Food, Agriculture and Consumer Protection

based on a decision of the Parliament of the Federal Republic of Germany

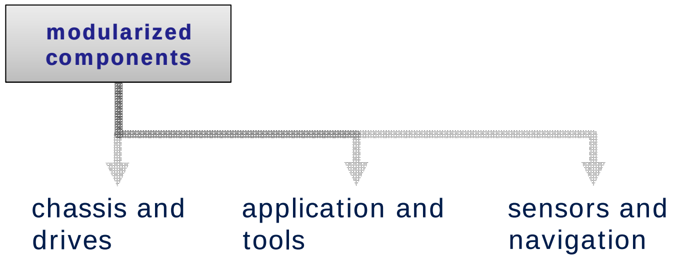
Fruit & Vine
high productivity and quality focused biomass production

• 130 000 ha plantation area (vine to fruit ratio 10:3)	
• Degree of mechanization:	10 %
• Area per robot:	10 ha
• Total market:	1,300 robots
• Life time:	10 years
• Annual market:	130 robots
• Market volume:	€ 9.1 M p.a.

manageable market
controllable environment

Main objectives elWObot

Model range of a robotic platform for vine and fruit with standardized tool interfaces



modularized components

chassis and drives

application and tools

1. spraying
2. mulching
3. cutting / pruning
4. transporting

sensors and navigation

elWObot features

Price

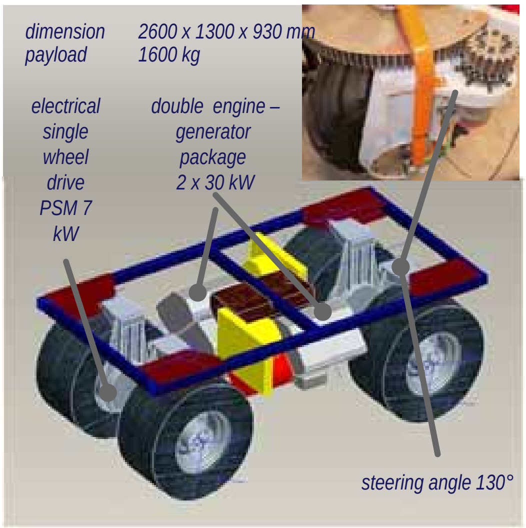
- commercial application - target price: € 60,000 – 80,000

Function

- autonomous navigation on predefined routes in known, defined terrains
- soil conserving undercarriage
- small turning circle for high maneuverability
- operating speed up to 8 km/h and hill capability up to 15%
- exclusion of hydraulics

Operation

- no specific requirement on farm infrastructure
- full documentation in the process chain



dimension *2600 x 1300 x 930 mm*
payload *1600 kg*

electrical single wheel drive PSM 7 kW

double engine – generator package 2 x 30 kW

steering angle 130°

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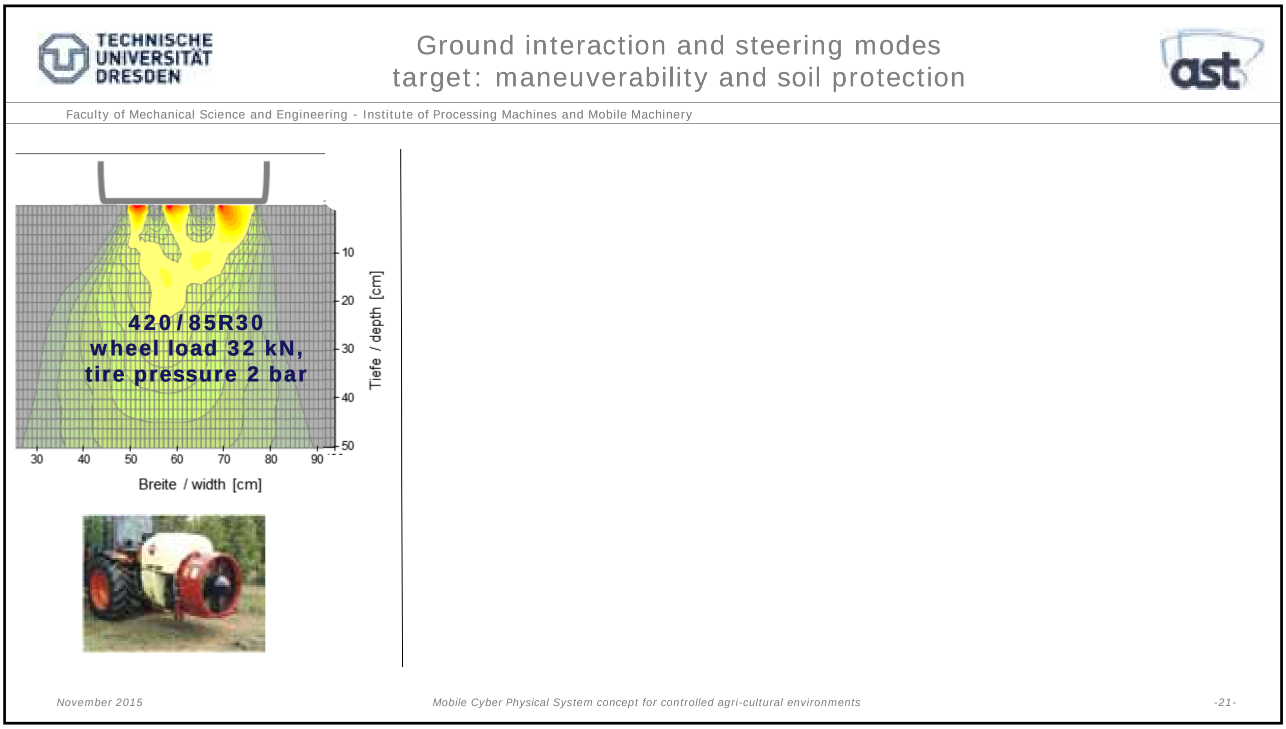
elWObot development blocks

- Geisenheim:
  development and built of spraying application
- Osnabrück:
  development, simulation and test of sensor system and navigation data
- Dresden:
  concept, design and built of chassis, diesel-electric power module and drives
- All:
  vehicle integration and test



TECHNISCHE UNIVERSITÄT DRESDEN

Ground interaction and steering modes
target: maneuverability and soil protection

Faculty of Mechanical Science and Engineering - Institute of Processing Machines and Mobile Machinery

420/85R30
wheel load 32 kN,
tire pressure 2 bar

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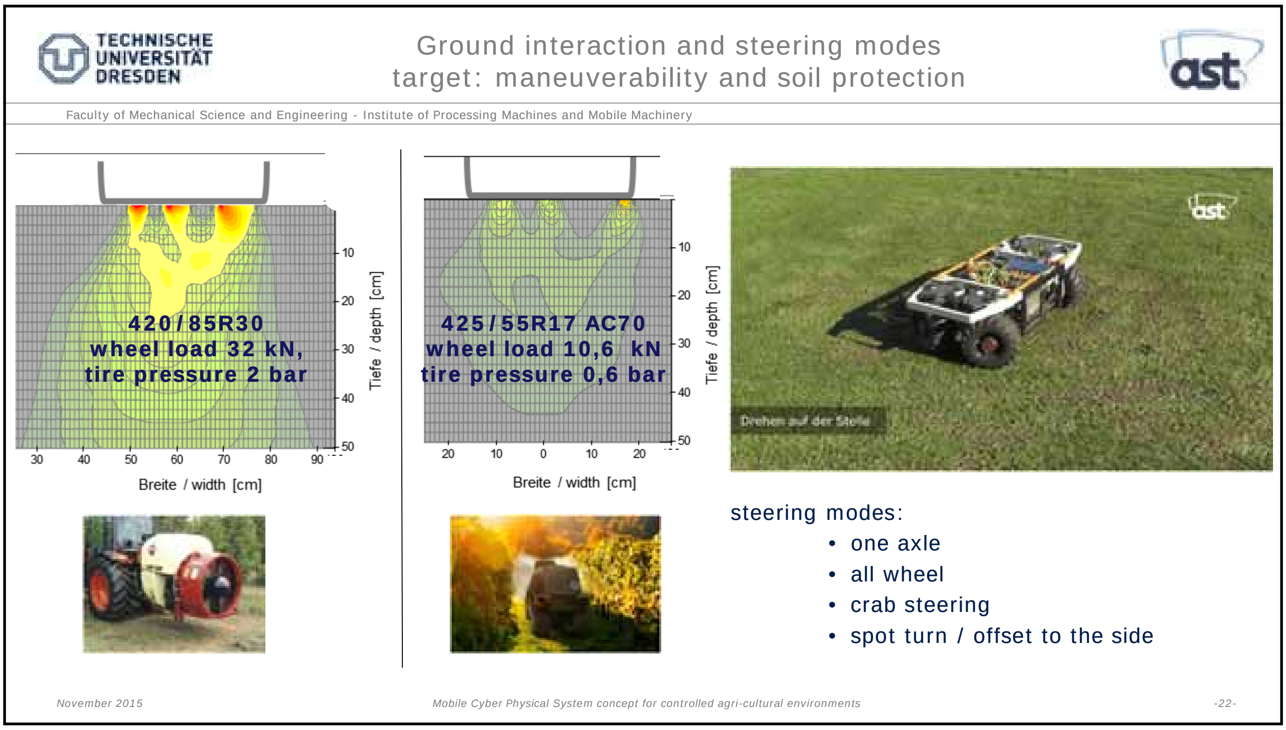

TECHNISCHE UNIVERSITÄT DRESDEN

Ground interaction and steering modes
target: maneuverability and soil protection

Faculty of Mechanical Science and Engineering - Institute of Processing Machines and Mobile Machinery

420/85R30
wheel load 32 kN,
tire pressure 2 bar

425/55R17 AC70
wheel load 10,6 kN
tire pressure 0,6 bar

steering modes:
- one axle
- all wheel
- crab steering
- spot turn / offset to the side

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Outlook

- Focus on connecting agricultural processes into systems of systems
- Autonomous and modular machine platforms enable configuration of customer specific solutions
- Productivity becomes scalable by number of modules

Vision on the way to reality: Agricultural robotic swarming

Thank you for following through the future world of cyber physical systems

Project was supported by

Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz

Innovations-förderung. PT

Bundesanstalt für Landwirtschaft und Ernährung

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Abstract

Recently the development and application of agricultural robotics has come into focus. This does not only include developments at research institutes but also new prototypes and products from companies. In this work agricultural robots are discussed in terms of mobile cyber physical systems, thereby showing the linkage to main focus topics in industry, such as Industrie 4.0, Big Data or Human Machine Interface technologies. The focus is particularly on smaller machines, having the potential for combining ecological, economical and social aspects. As examples specific aspects of the research platforms elWObot (for wine and orchards) and BoniRob (multipurpose platform for agriculture and horticulture) are shown.

1-Global Opportunities of Robotics

Robots are desired and developed to save costs, to improve quality and work conditions, and to minimise waste of resources. The rapidly growing communication technology capabilities enable the transformation of autonomously working machines into Cyber Physical Systems. The digital transformation offers tremendous opportunities of more efficient production using Cyber Physical Systems (CPS / Industrie 4.0) and furthermore enables new business models. The world economies are con-fronted with a radical structural change consequently questioning existing value chains. The overall challenge as well as in biomass production is to move the centre of gravity from the economic aspects towards a better balance with ecological and societal aspects (see Fig. 1 and Fig. 2) by creating economic value without compromising the impact on ecology and society aspects as much as it is done today.

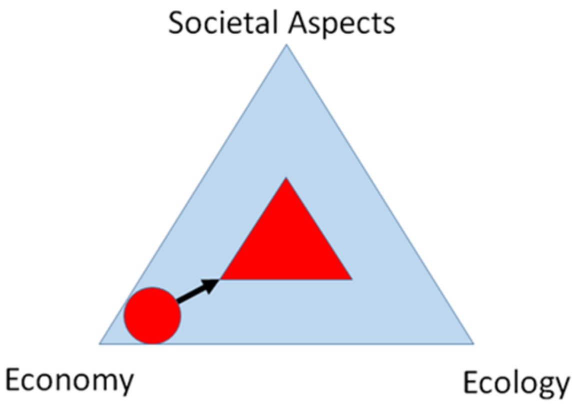

Fig. 1. Sustainability Goal

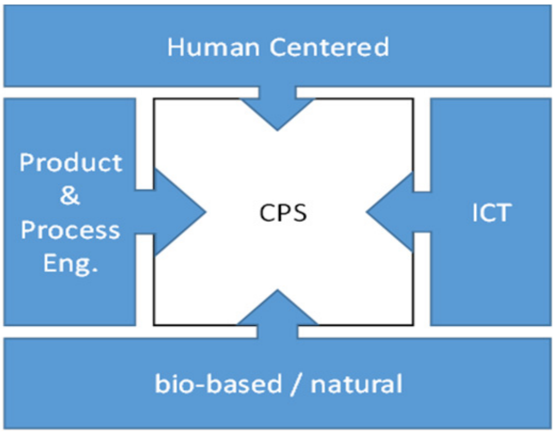

Fig. 2. CPS Drivers

Robots and robotic devices will have a broad impact across many existing and emerging markets, which can be grouped in the following main sectors: industrial, professional service, domestic service, security and space robotics. Fig. 3 provides an overview about the vast area of robotic applications to be expected in the future. While each of the product visions has specific requirements, it is important to find similarities and common challenges.

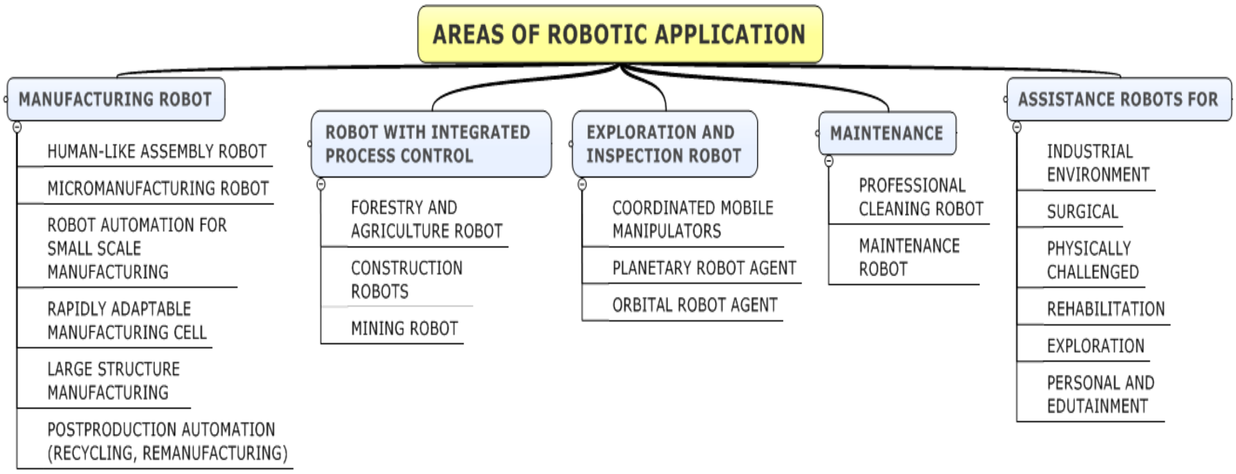

Fig. 3. Range of robotic applications [1]

2-Robotics meets nature: Autonomous systems in agricultural environments

Current robotics-based manufacturing is relatively inflexible. Typically, machines are set up and left to work for long periods of time on one specific operation. Agricultural production employing mobile processing machines provides a much higher complexity of execution, which makes these processes less controllable today. For this reason automation is the main trend with a growing vision towards robotics, where the operator is becoming an administrator of machine(s) with the need of complex decision support. Today automation just unloads operators partially. In the future the process output is considered an aggregation of process objectives while managing input disturbances (a specific of biomass production is that process inputs are only qualitatively known and hardly measurable).

Fig. 4 visualizes the level of automation in production processes utilizing mobile machines compared to car manufacturing. Integration of modern information technology into the value chain of production and processing of natural materials will result in an increase in the degree of automation at all levels leading to improved economy and higher resource efficiency.

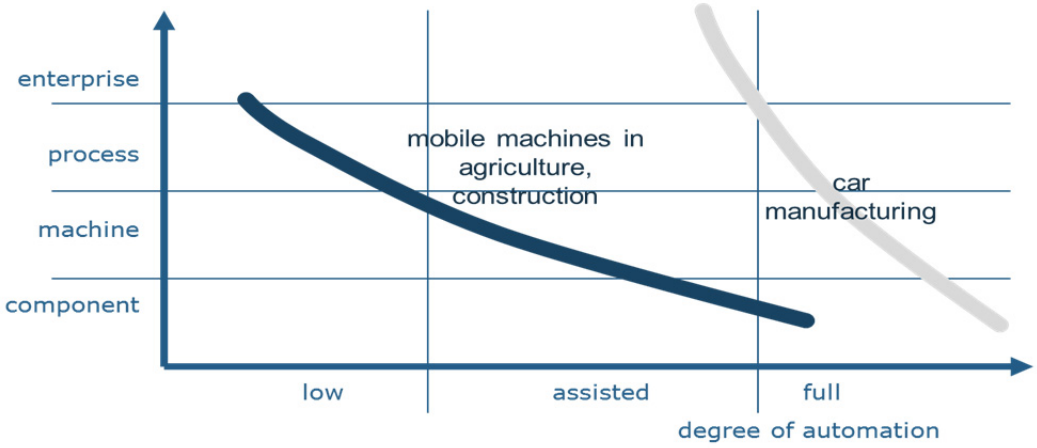

Fig. 4. Potential for automation for mobile machines [2]

For this reason, new mechanization systems are required which reduce the workload through extensive automation, minimize the expenditure of resources, gather the relevant data and thereby enable process optimization. The use of smaller machines, equipped with suitable sensors and intelligence that can cope autonomously with complex operations such as plant protection with pesticide application, would be a big step forward. The resulting potential of using multiple units operated by one operator would significantly increase the single farm productivity. The use of canopy sampling for pesticides saving and new fans with a significantly reduced driving power will further reduce resource requirements. Autonomous vehicle guidance allows continuous monitoring of all relevant machinery and equipment data automatically, a complete documentation of the work performed can be provided and the documentation serves as the guarantee required by commercial law and traceability in the food production.

3-Application examples of robotic platforms

The requirement on autonomous systems in controlled farm environment are discussed in terms of two examples: An autonomous vehicle platform for orchards and vineyards and robotic weeding in agricultural and horticulture production.

Fig. 5 shows a vehicle concept of an agricultural robot for wine and orchards. TU Dresden, in co-operation with Raussendorf Maschinen- und Geraetebau GmbH, Osnabruck University of Applied Sciences and Geisenheim University of Applied Science have developed an autonomous vehicle called elWObot. It will initially be able to autonomously navigate in the plantation and between the rows of trees, while spraying the trunks and tree tops and mulching within the lane.

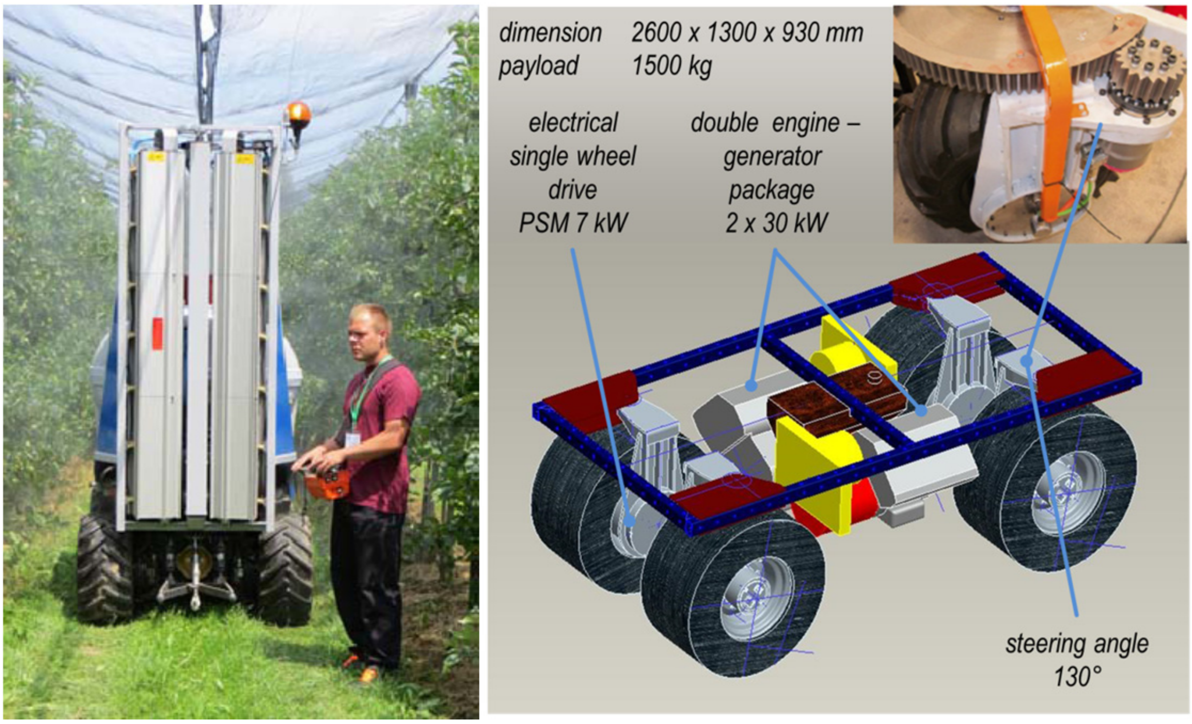

Fig. 5. Remotely controlled prototype and the second generation elWObot

Optional subsequent tasks involve collecting and transporting harvest crates from the tree rows to the depot, tree inventory and yield control and the detection and logging of windfall. Typically, an autonomous mode as well as a remote controlled application (as shown) are options for agricultural robotics. The modular and scalable concept makes it possible to adapt the vehicle to different requirements in orchards and vineyards. Electric drives have been chosen for better controllability and reduced energy requirements. The requirements to be met by the machine concept include:

- commercial application of the vehicle with target price: € 60,000 – 80,000
- autonomous navigation in known, defined terrains on predefined routes
- soil conserving undercarriage with small turning circle for high manoeuvrability
- operating speed up to 8 km/h and hill capability up to 15%
- no requirement on farm infrastructure and exclusion of hydraulics

- full documentation in the process chain

The on-board electronics is divided into a “low-level” control module, which is responsible for vehicle control and monitoring functions, and a “high-level” navigation module, which is responsible for the evaluation of the additional sensors and autonomous operation (Fig. 6).

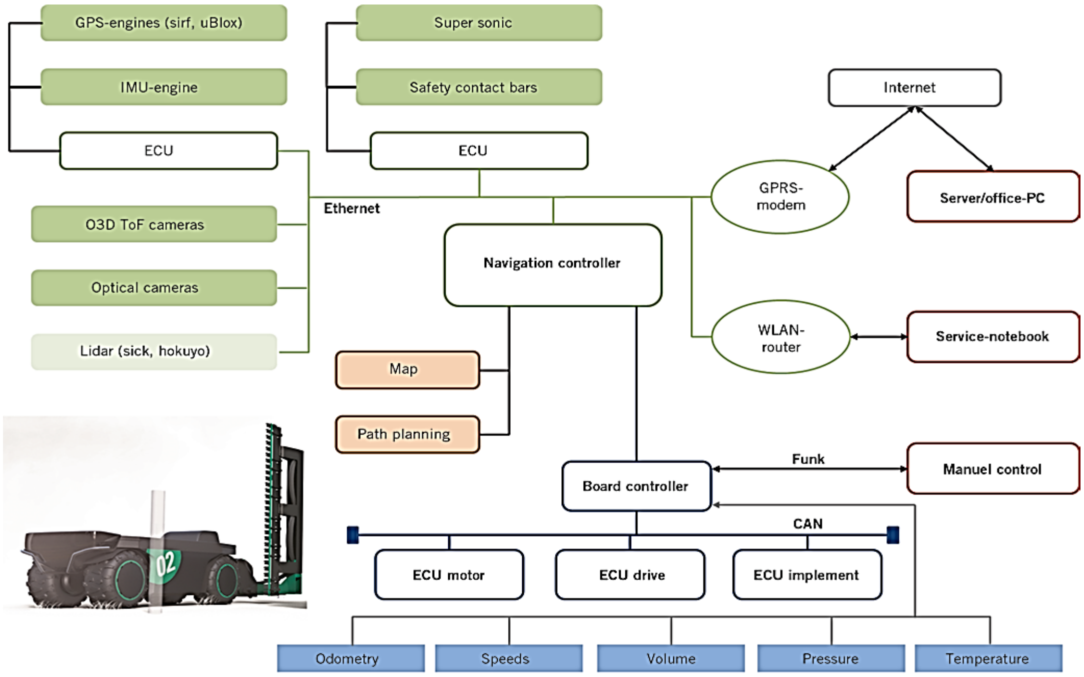

Fig. 6. Full control concept

Next to potential economical and ecological benefits of autonomous robots, the human-machine interface is of high relevance, however, it is not focused – as nowadays on driver assistance. Fig. 7 shows the integration of a remote worked in an automated process of robotic weeding.

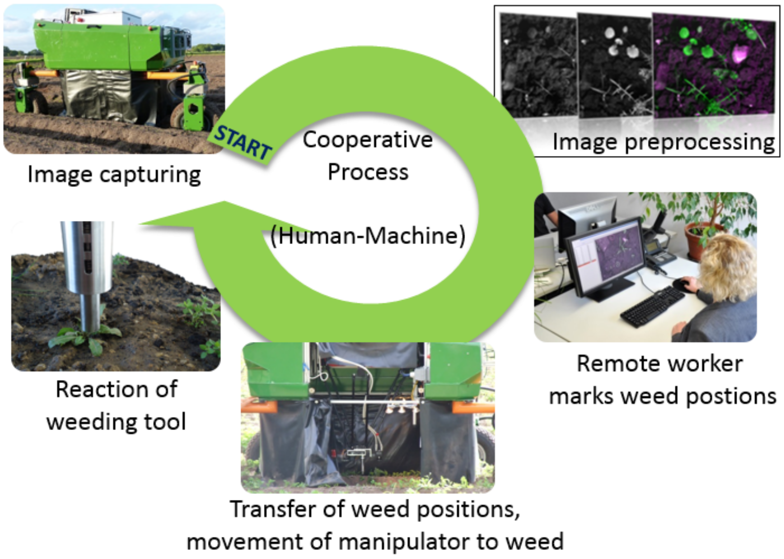

Fig. 7. Human machine integration in the context of a cyber physical weeding application [3]

In the multi-purpose robotic platform BoniRob an actuator is integrated for ultra-precise robotic weeding based on sensor fusion image processing. Due to the complex situation a remote worker provides the weed positions in the first step (RemoteFarming.1), while in the next step the human worker is shifted to a control work, thereby handling complex situations triggered by the image processing quality management. The concept leads to further options in future agriculture with working places on and off the field.

Next to the technological realization with reasonable (optimized) processing, ecological benefits and human integration, the economical feasibility is still of highest relevance today (see Fig. 1). If an internalisation of external costs (like soil damage, chemical pollution) will take place in agriculture, the economical calculations will dramatically change. So far the feasibility study shown in Fig. 5 is based on a business expectation as shown in Fig. 8.

Germany plantation area total	*130 000 ha*
vine	*100 000 ha*
fruit	*30 000 ha*
degree of expected mechanization with robots	*10 %*
plantation area processed with robots	*13 000 ha*
area coverage per robot	*10 ha*
total market	*1 300 units*
lifetime	*10 years*
market demand per year	*130 units*
expected market share Raussedorf	*25 %*

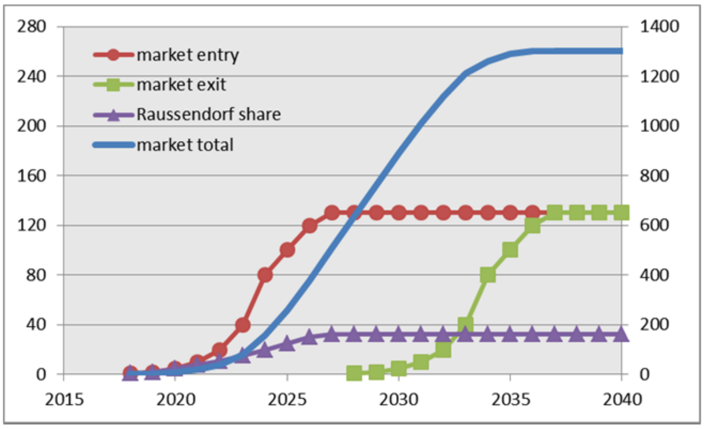

Fig. 8. Market potential for Raussendorf assuming 10 % market penetration for robots

The numbers illustrate the market potential for robot vehicles for orchard and vineyard applications. Calculations are still uncertain and recent works strongly focused on economical aspects, thereby implying a paradigm change in agriculture. An example is the usage of the BoniRob platform for autonomous soil characterization measurements [4].

4-Outlook

The examples shown before can be extended to other platforms as (for example) presented at the Agritechnica 2013/2015, SIMA 2015 or Agritechniek Holland (2014), ranging from weed control to autonomous small tractors. The participation of agricultural companies and non-agricultural companies in the development of agricultural robotics and their system integration has a strong impact on the transfer from research to practice. Interdisciplinary approaches are not only helpful in this context, but are a condition for the success. The technologies in outdoor agricultural applications combine cyber physical systems, big data, Industrie 4.0 as well as specific key technologies (such as imaging technologies, sensor fusion and simulation technologies for development and uncertainty management). Moreover, the system integration as shown in [3] has to be developed and extended. The concept leads to further options in future agriculture with working places on and off the field. Swarm applications [5, 6, 7] are no further a topic for theoretical considerations but are presently turned to first field tests, as for example Fig. 9 shows two BoniRobs on a field [8]. Beside close-to-technology aspects other influences are considered, examples are the acceptance of technologies in the society, legal aspects or validation processes. These aspects are already in focus of research and development projects (see for example [9]).

Fig. 9. Vision on the way to reality: Agricultural robotic swarming [8]

Acknowledgement

The projects elWObot, BoniRob and RemoteFarming.1 are supported by funds of the Federal Ministry of Food, Agriculture (BMEL) based on a decision of the Parliament of the Federal Republic of Germany via the Federal Office for Agriculture and Food (BLE) under the innovation support program.

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