AI-Autonomous Robots for Agriculture – Weeding with Laser

WeLASER Summer School

Precision Agriculture and Robotics

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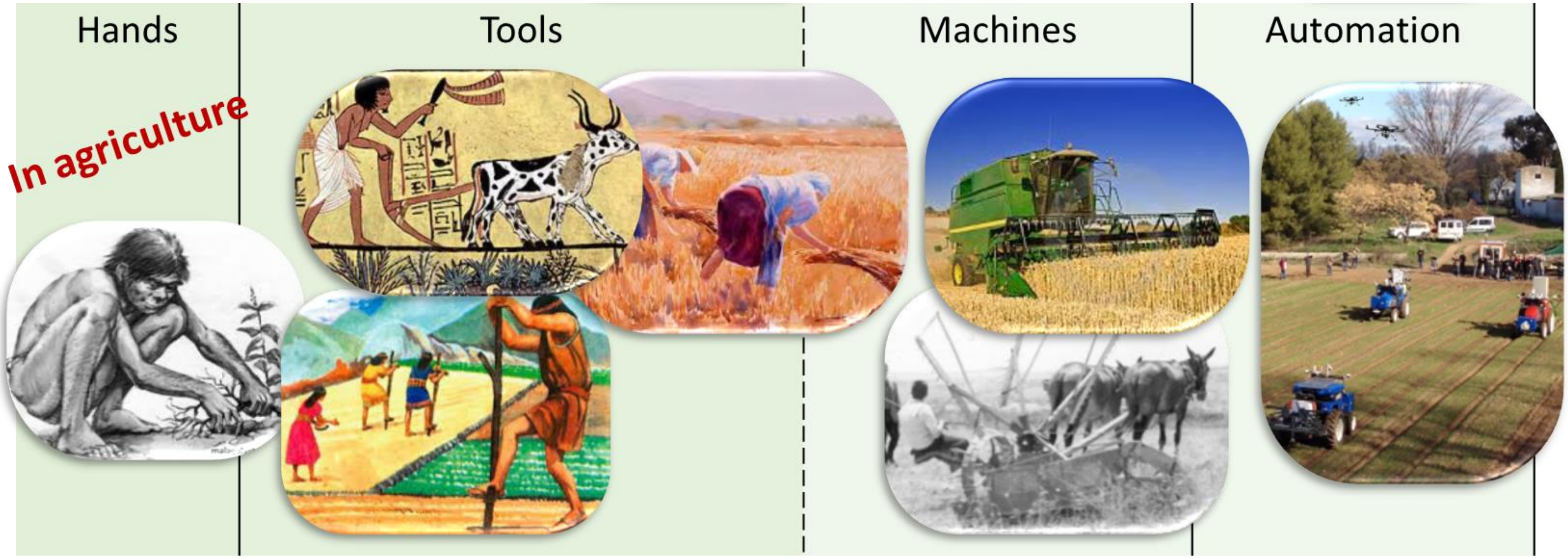
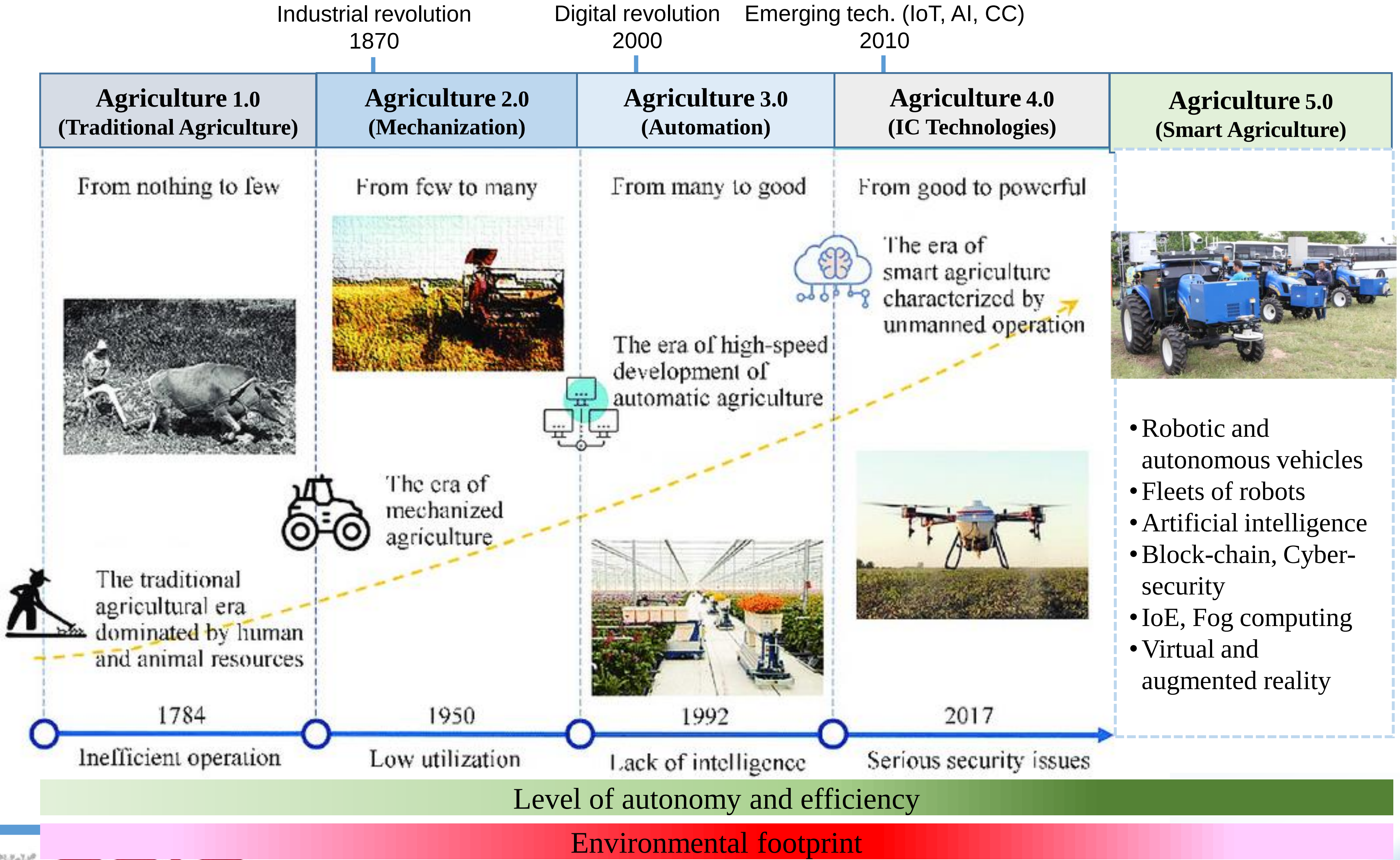
CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS · FUTONICS · LZH LASER ZENTRUM HANNOVER e.V. · UNIVERSITY OF COPENHAGEN · AGREENCULTURE Smart robots for smart farming · COAG · ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA · IETU Instytut Ekologii Terenów Uprzemysłowionych · GHENT UNIVERSITY · van den borne aardappelen

Agriculture: Evolution

- **Agriculture**
  - Agriculture is the art and science of cultivating the soil, growing crops and raising livestock.



Agricultural Revolution Roadmap

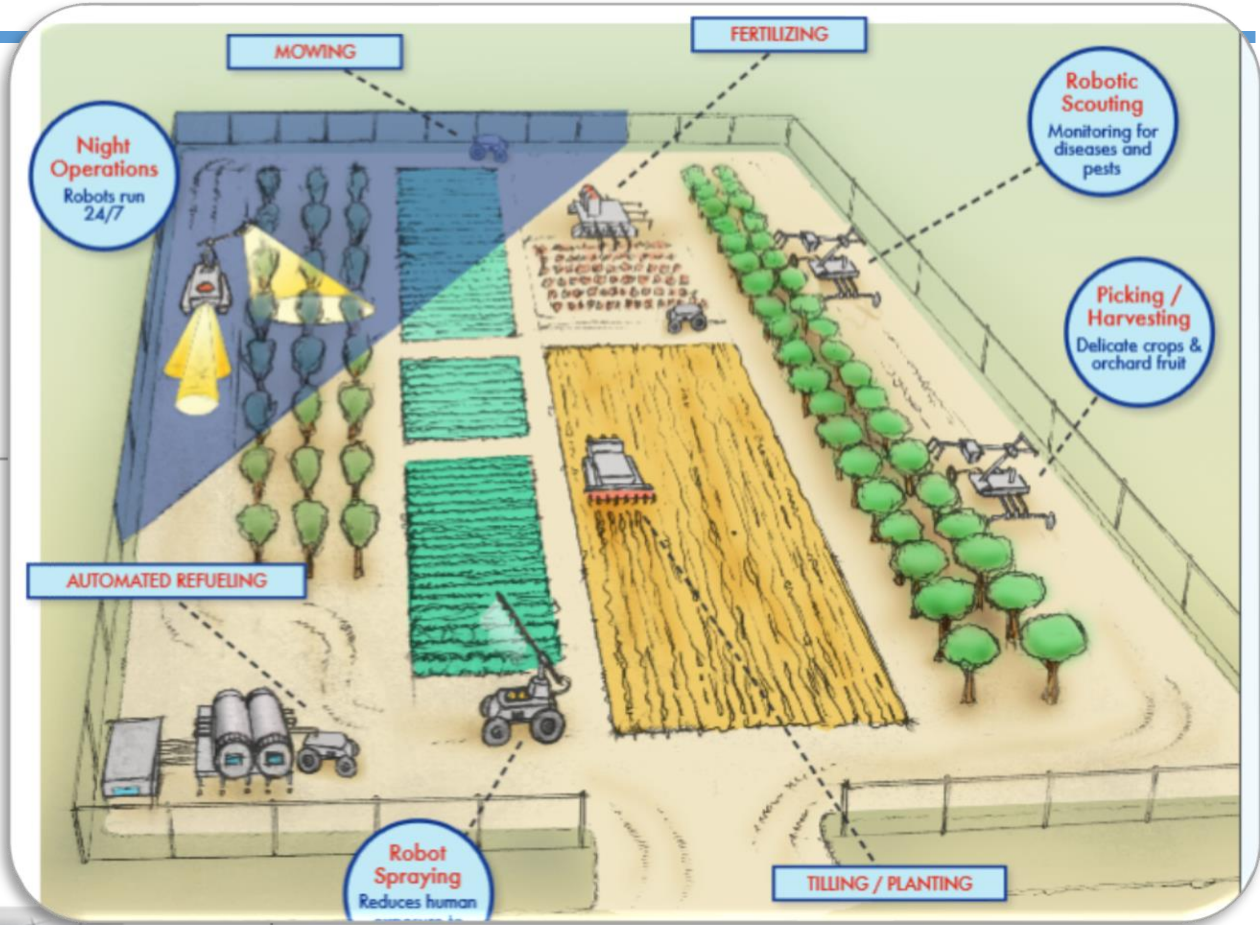


https://www.researchgate.net/figure/Characteristics-and-confronted-issues-of-agriculture-development-from-Agriculture-10-to_fig1_346331996

Agriculture: Evolution

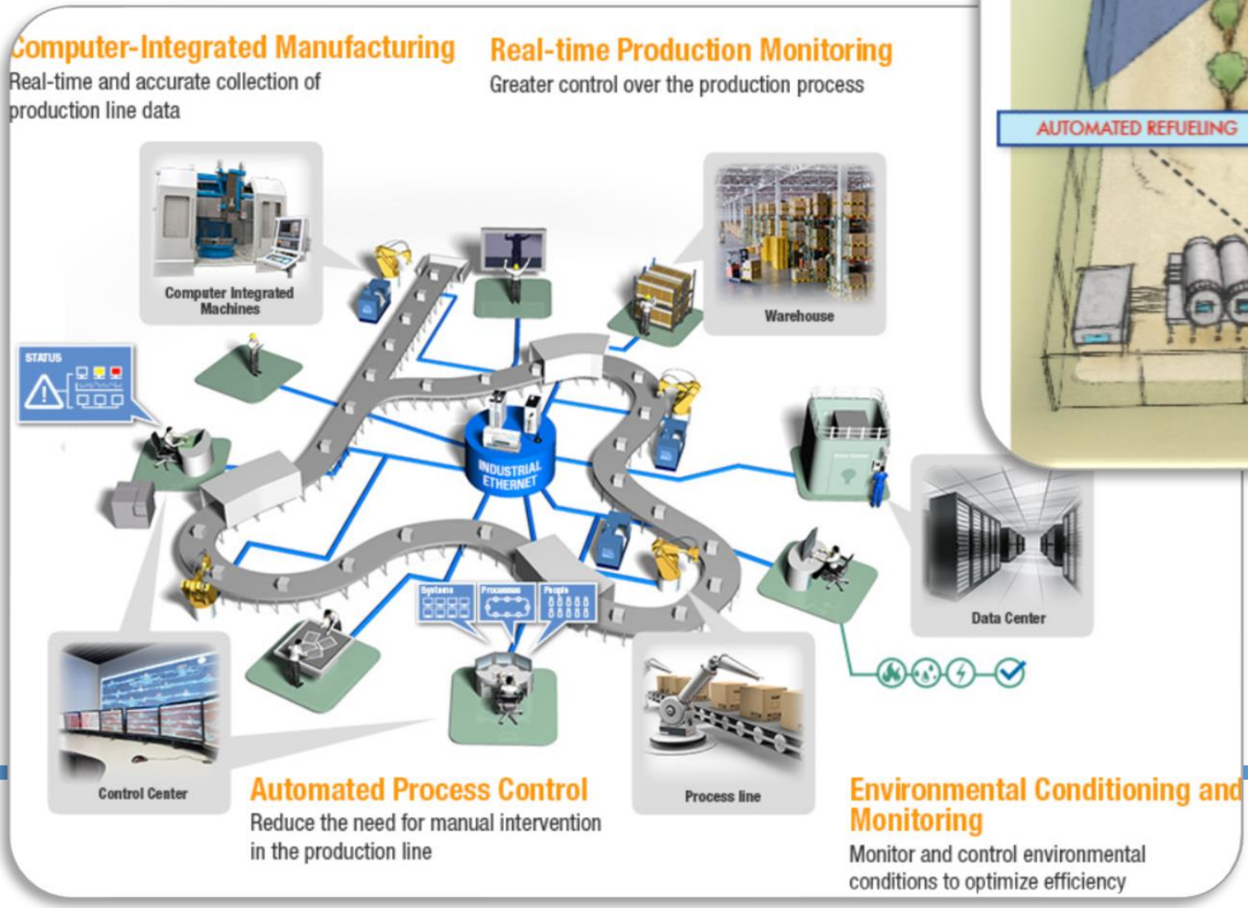
- **Agriculture**
  - **New terms:** Precision Agriculture (PA); Precision Farming; Smart Farming, Site-specific Crop Management, Fully Automated Farms, AI Farms, …….
- **Precision agriculture (PA)**
  - Definition 1: PA is a farming management concept based on observing, measuring and responding to inter and intra-field variability (both spatial and temporal) in crops for optimum profitability, sustainability, and protection of the environment
  - Definition 2: PA is a way to apply the right treatment in the right place at the right time (Gebbers and Adamchuk, 2010)
- **Smart farming**
  - Smart farming focuses on capturing data and interpreting them using computing technologies to make farm operations more predictable and efficient.
- **Fully Automated Farm**
  - No human activity except supervision

Agriculture: Evolution

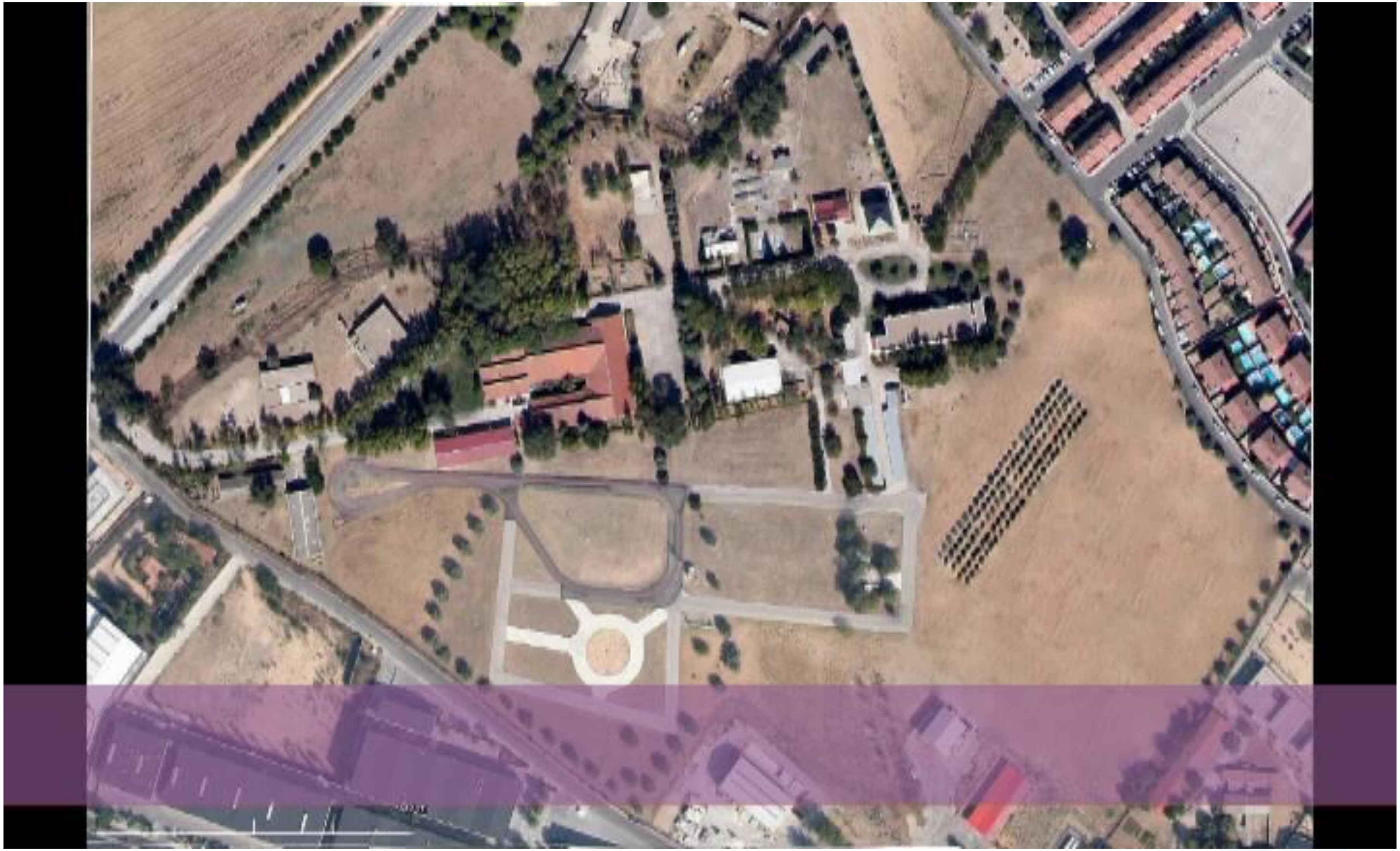


Fully Automated Farm

Fully Automated Factory



Agriculture: Smart Farm



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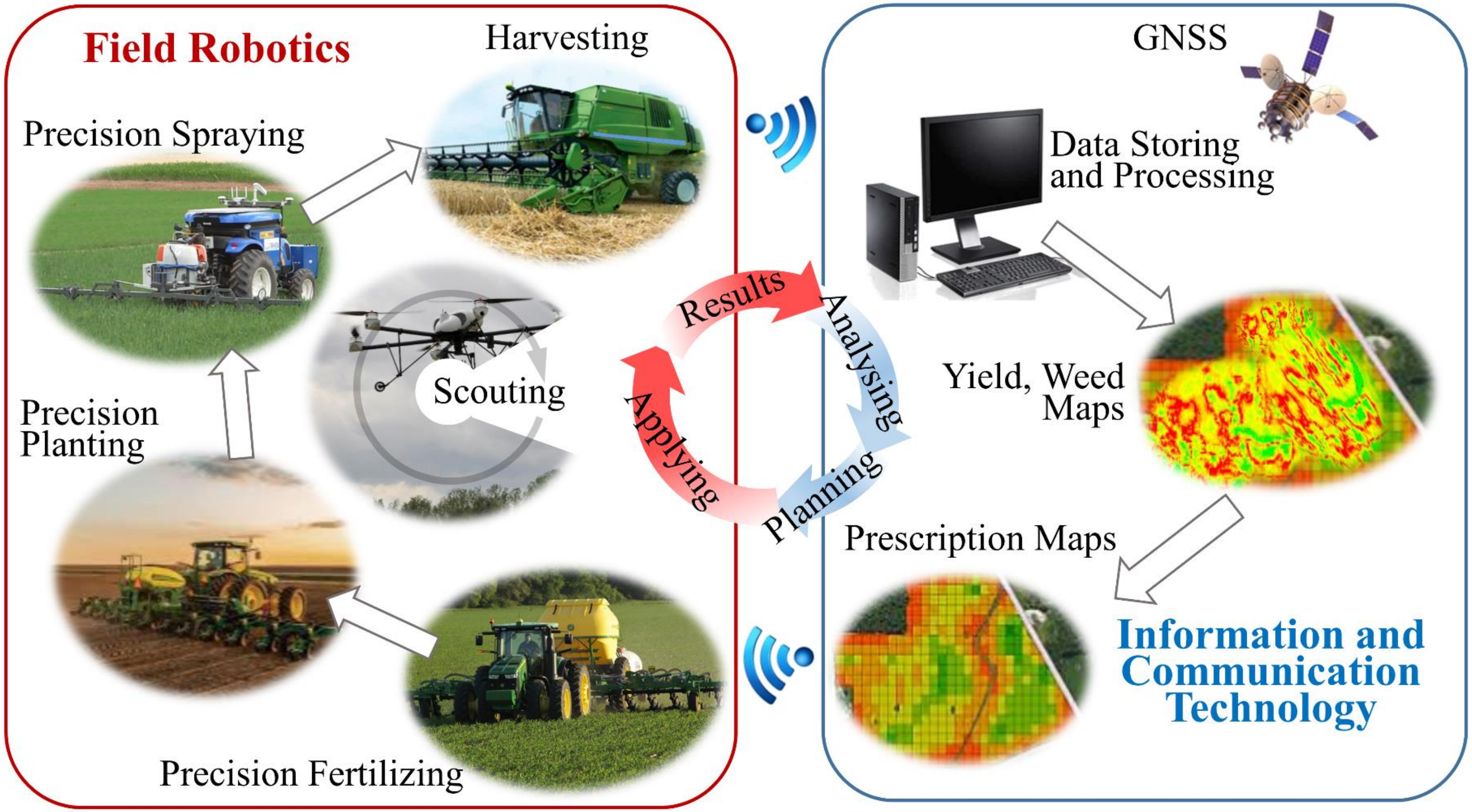
Agricultural equipment

- **Conventional scheme**
  - ❑ Implement/tool + tractor (Interchangeable)

- **New scheme**
  - ❑ Implement/tool + robot (Interchangeable)

  - ❑ Structure for a specific application (Uninterchangeable)

Technologies involved in PA/Smart Farming



Precision Agriculture

Perception Systems
- Observing/measuring

Decision Support System
- Manage with the objective of optimizing the profitability of inputs while preserving the environment

Application
- Actuating

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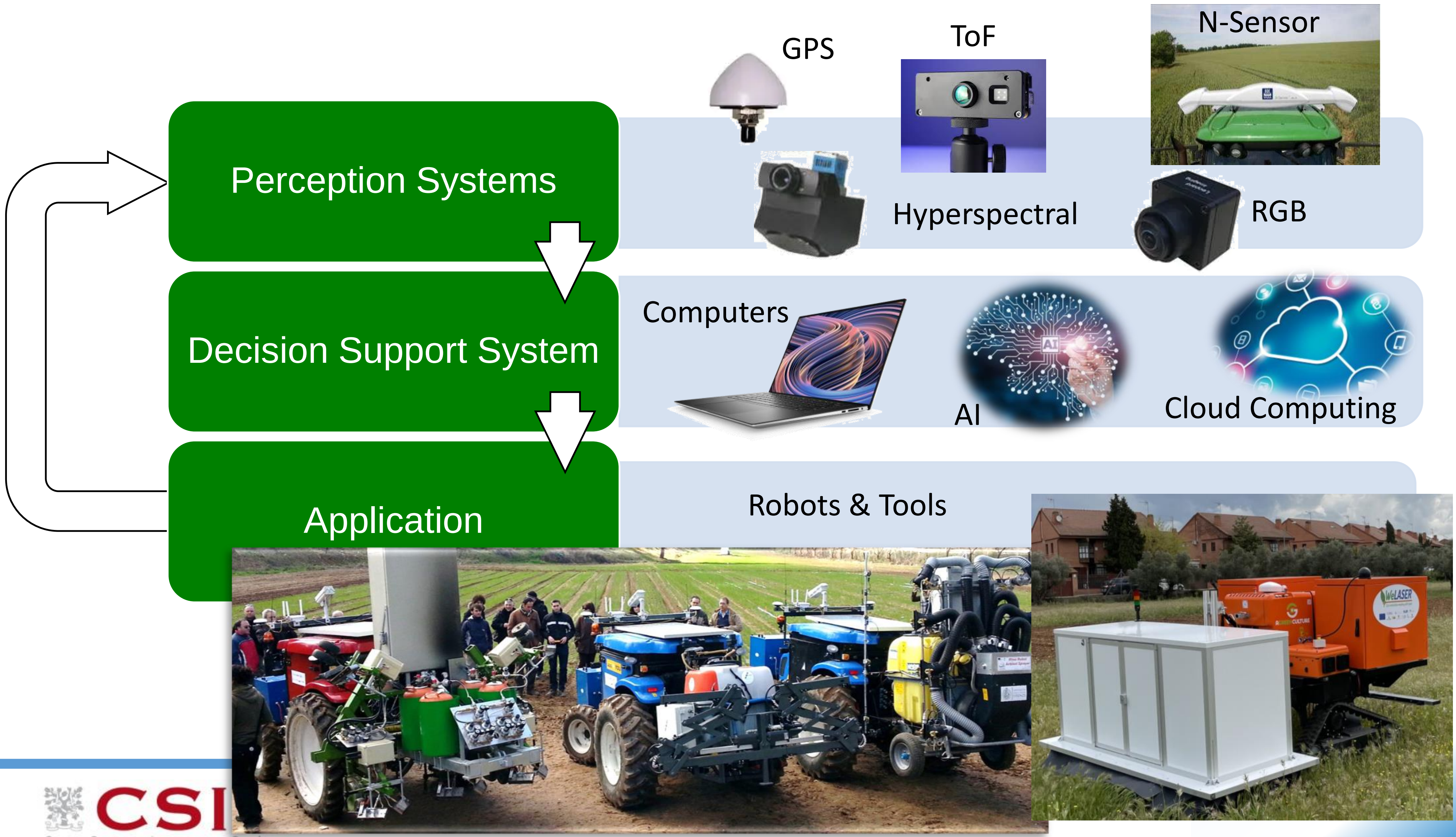
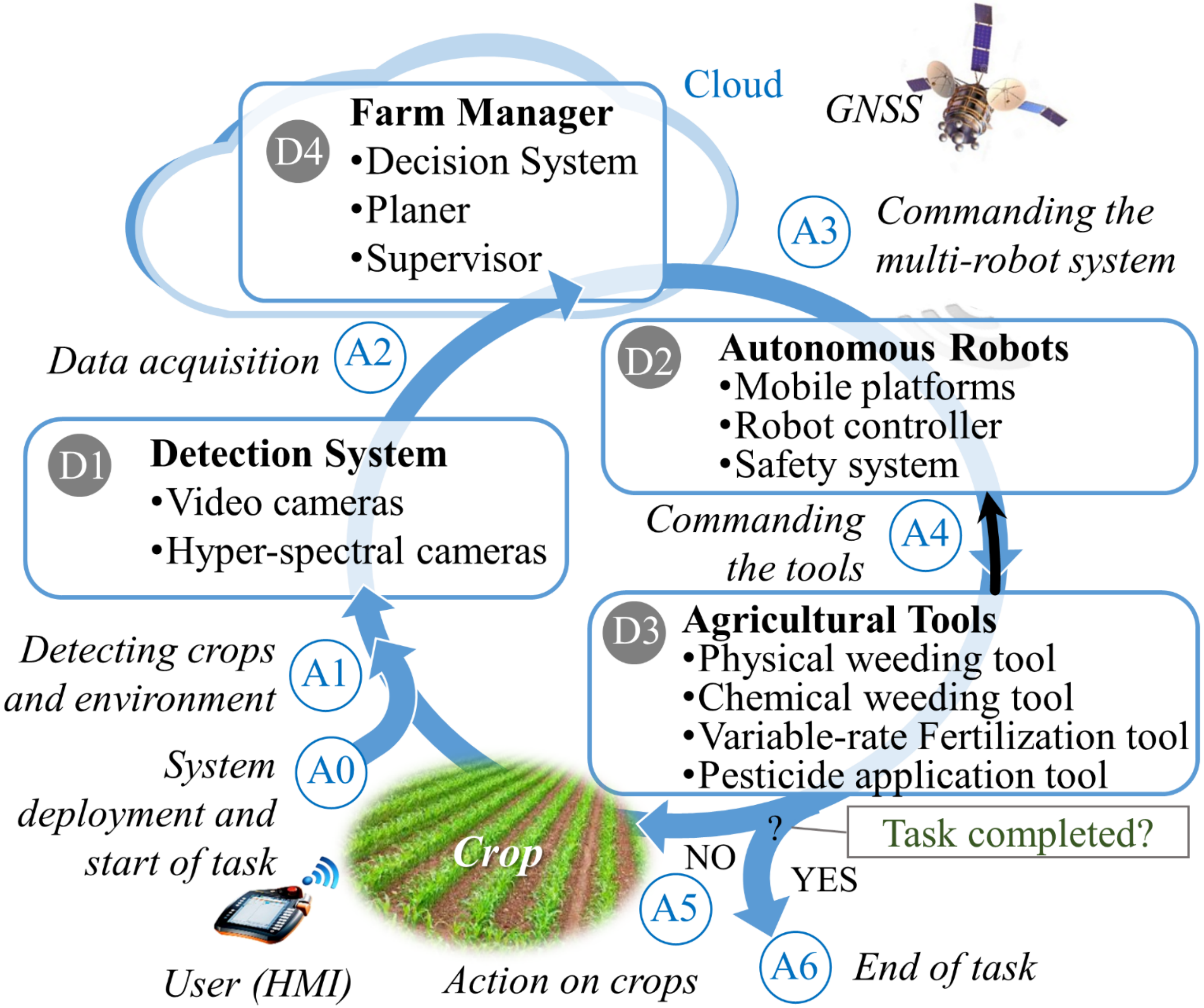
Precision Agriculture



Example of PA task



Robotics for Agriculture

- **Manipulators**

- **Mobile (Autonomous) robots**

Ground

Aerial

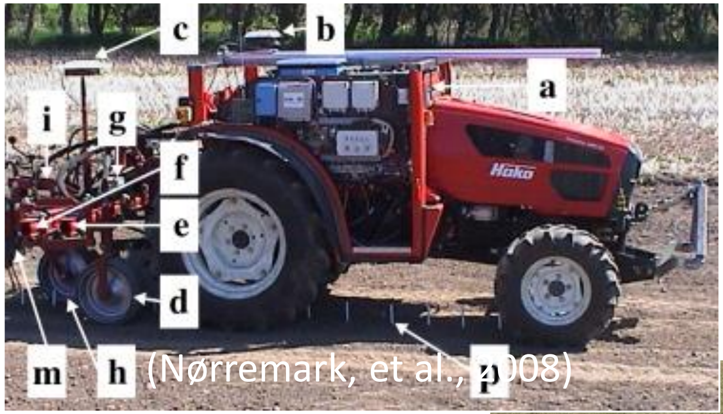
Robotics for Agriculture

- Manipulators

- **Mobile (Autonomous) robots**

Ground Autonomous Robots

- **Trends:**
  - ❑ Adaptation of conventional vehicles (tractors)
  - ❑ Specific structure (New designs)

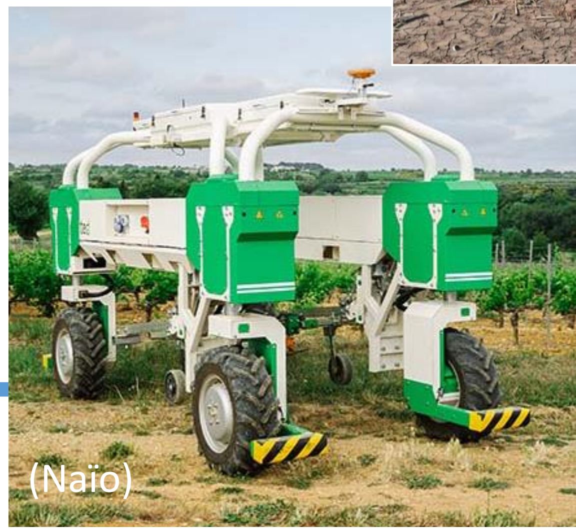


(Nørremark, et al., 2008)


(RHEA, 2014)


(Bergerman et al. , 2015)


(Agreenculture)


(Naïo)

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Ground Autonomous Robots

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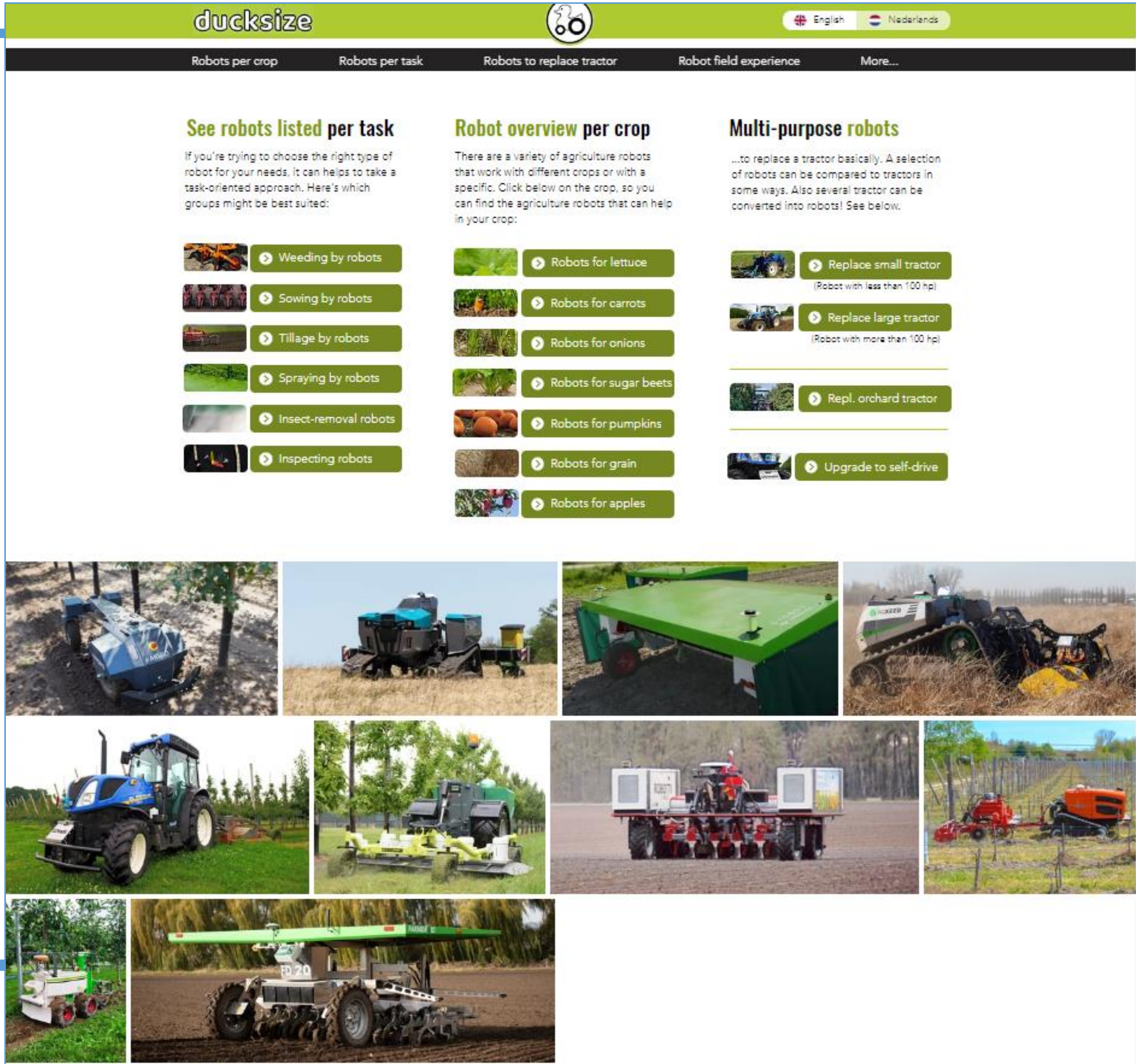
Ground Autonomous Robots

https://www.ducksize.com/



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Agriculture Robots based on commercial vehicles

Institution	Year	Description
Stanford University (US)	1996	Automatic large-farm tractor using 4 GPS antennas.
University of Illinois (US)	1998	A guidance system using a sensor based on machine vision, an RTK-GPS and a GDS.
Carnegie-Mellon University (US) - Demeter project	1999	A self-propelled hay harvester for agricultural operations.
Carnegie-Mellon University (US) - Autonomous Agricultural Spraying project	2002	A ground-based vehicle for pesticide spraying.
LASMEA-CEMAGREF (France)	2001	This study investigated the possibility of achieving vehicle guiding using a DGPS as the only sensor.
University of Florida (US)	2006	An autonomous guidance system for citrus groves based on machine vision and LADAR.
University of Aarhus and the University of Copenhagen (Denmark)	2008	An automatic intra-row weed control system connected to an unmanned tractor.
RHEA consortium (EU)	2014	A fleet (3 units) of tractors that cooperated and collaborated in physical/chemical weed control and pesticide applications for trees.
Carnegie-Mellon University (US)	2015	Self-driving orchard vehicles for orchard tasks.
University of Leuven (Belgium)	2015	Tractor guidance using model predictive control for yaw dynamics

Ground Autonomous Robots

- **Trends:**
  - ❑ Adaptation of conventional vehicles (tractors)

[Fendt]

Fendt 209F Driverless tractor mowing

[John Deere]

John Deere's fully autonomous tractor

[CNH-I]

The CNH Industrial Autonomous Tractor Concept (Full Version)

Agriculture Robots based on specific structures

Vehicle (Year)/ *Manufacturer*	Status	Type	Dimensions (m)	Weight (Kg)	Speed (ms^{-1})	Payload (kg)
BoniRob (2009) ***Bosch***	Prototype	Independent steering	2.8×2.4×2.2	1,100	1.5	150
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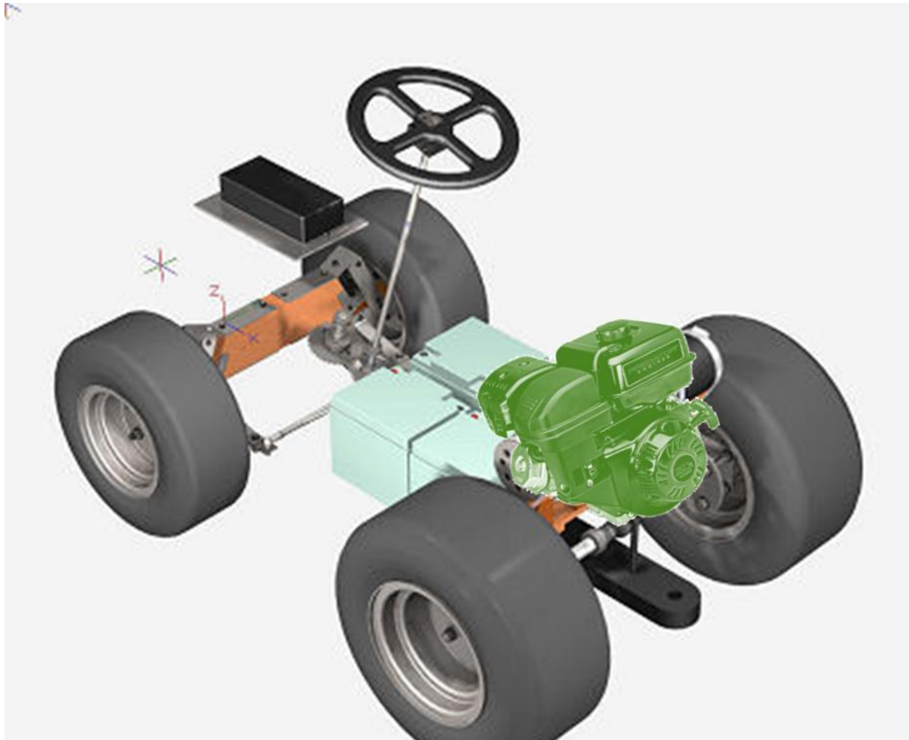
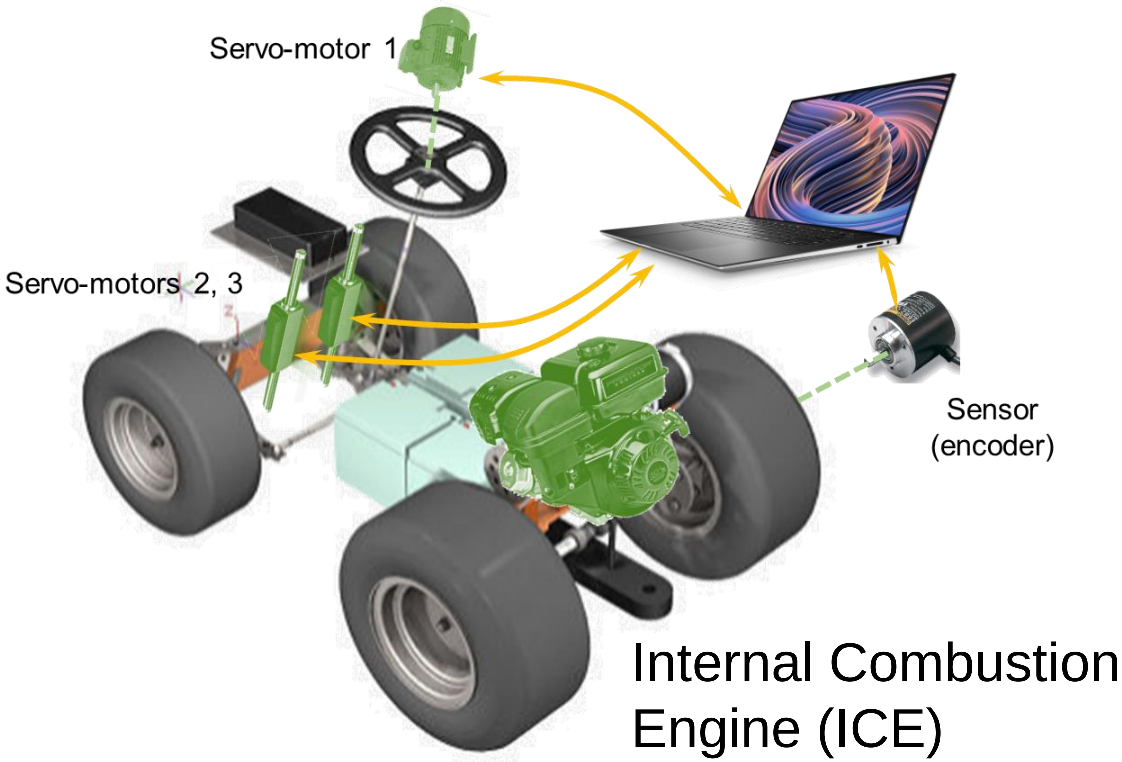
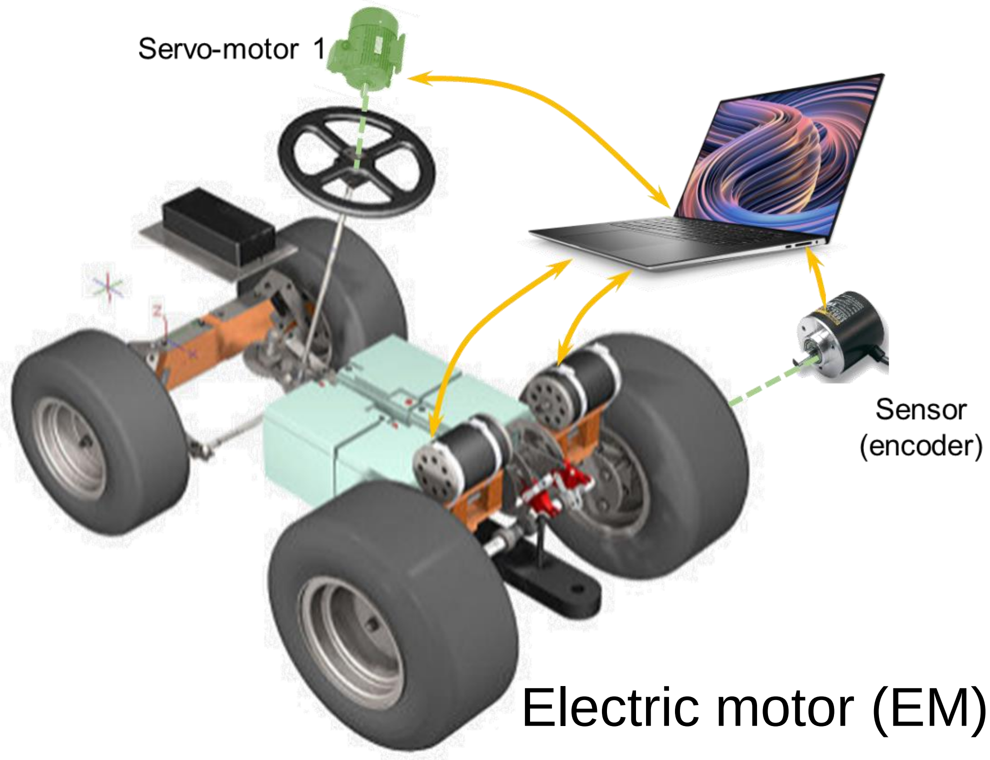
Adaptation of conventional vehicles

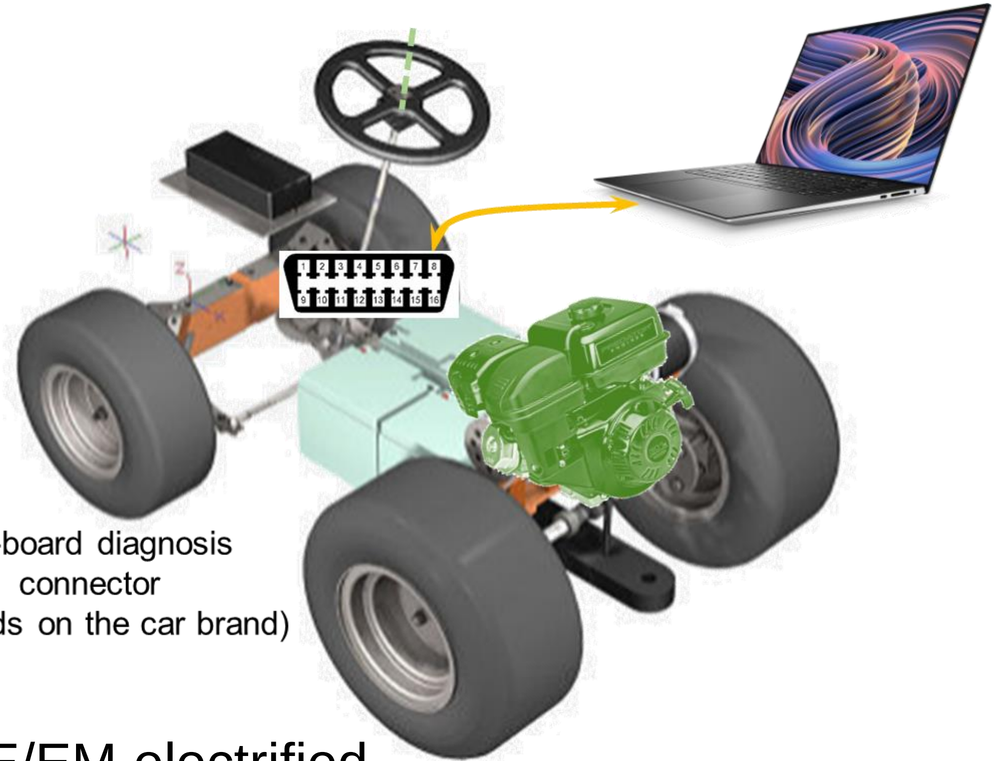


Chassis

Adaptation of conventional vehicles



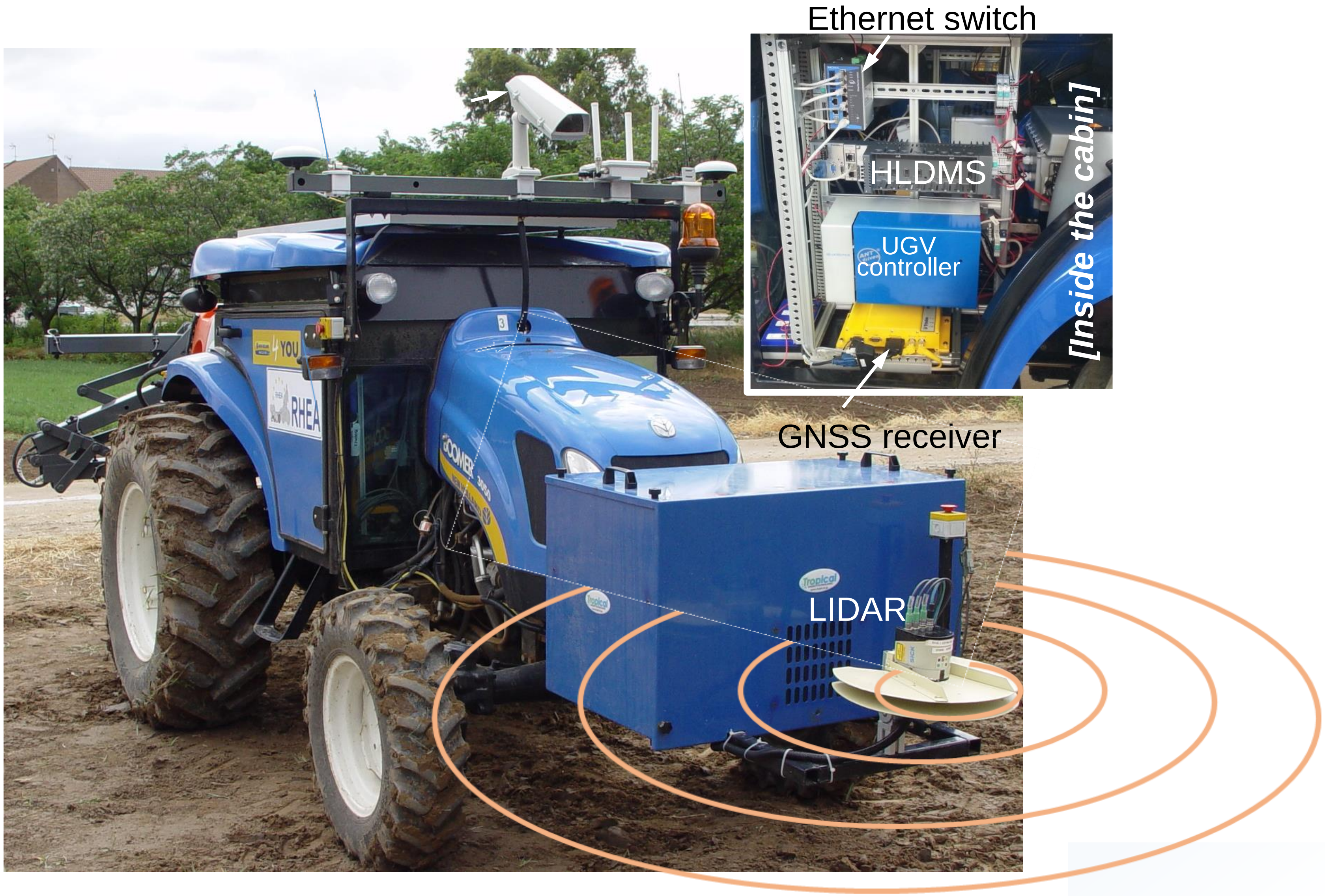




ICE/EM electrified

Commercial EM robot

Adaptation of conventional vehicles



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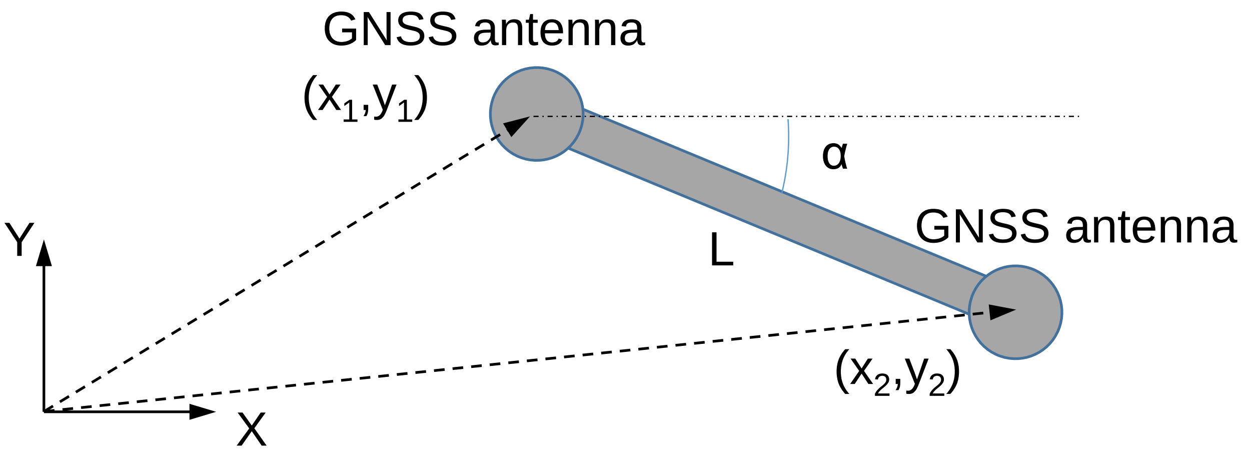
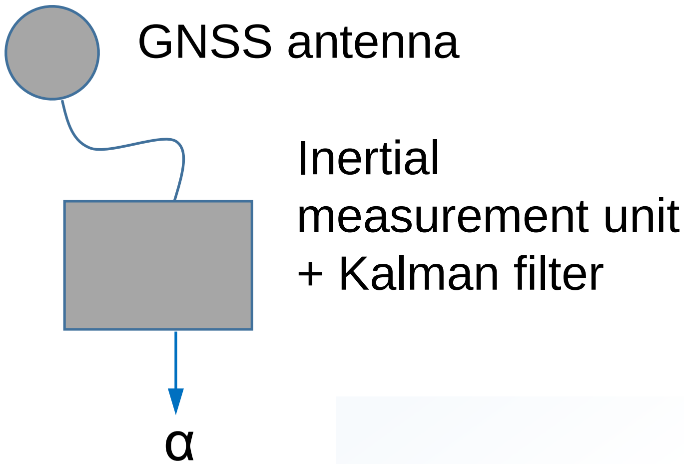




Mobile robot structures

- **Number of wheels:**
  - ❑ Three nonaligned wheels are the minimum to ensure platform static stability.
  - ❑ Most field robots are based on 4 wheels, which increases the static and dynamic stability.

Mobile robot structures

- **Wheel orientation type:**
  - ❑ **Fixed wheel:** This wheel is connected to the platform in such a way that the plane of the wheel is perpendicular to the platform, and its angle (orientation) cannot change.
  - ❑ **Orienting wheel:** The wheel plane can change its orientation angle using an orientation actuator (Active Wheel).
  - ❑ **Castor wheel:** The wheel can rotate freely around an offset steering joint. Thus, its orientation can change freely.

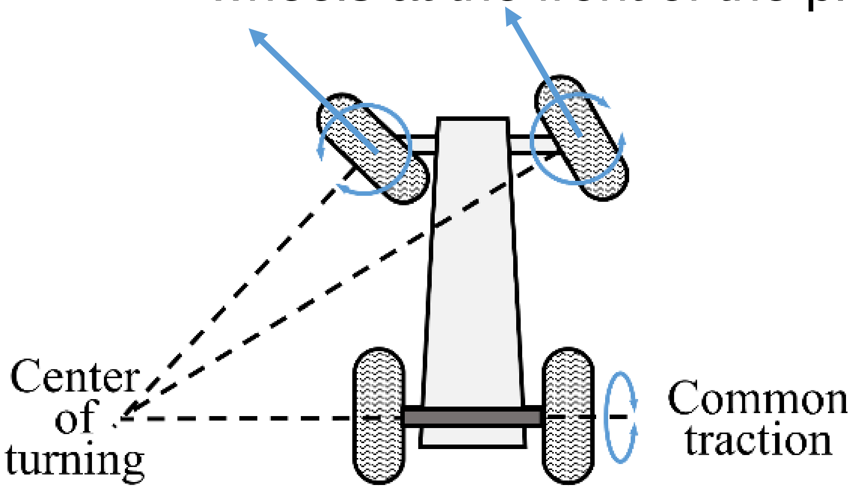
Mobile robot structures

- **Wheel power type:**
  - ❑ Passive wheel:
    - ❖ The wheel rotates freely around its shaft, not providing power (e.g., Caster).
  - ❑ Active wheel:
    - ❖ Traction: An actuator rotates the wheel to provide power.
- **Hybrid wheel**
  - ❑ Independent traction and steering

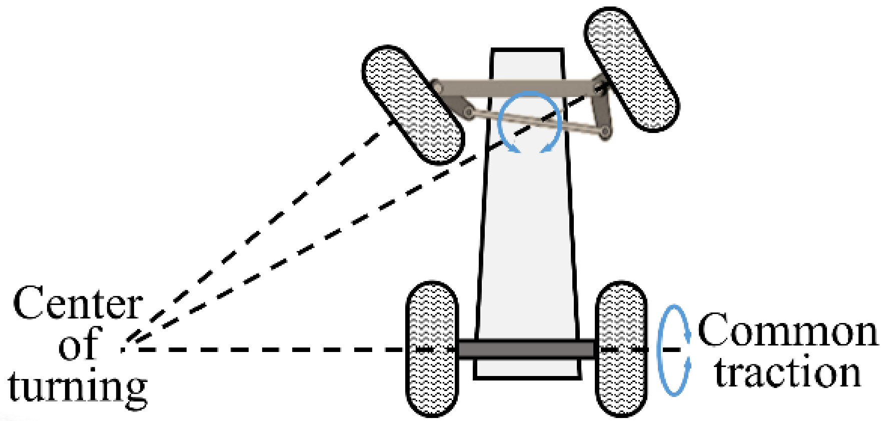
Mobile robot structures

- **Wheel arrangement:**
  - ❑ **Coordinated steering scheme**

    Two fixed active wheels at the platform's rear and two passive orienting wheels at the front of the platform



b) Independent steering driving



a) Ackermann steering driving

Mobile robot structures

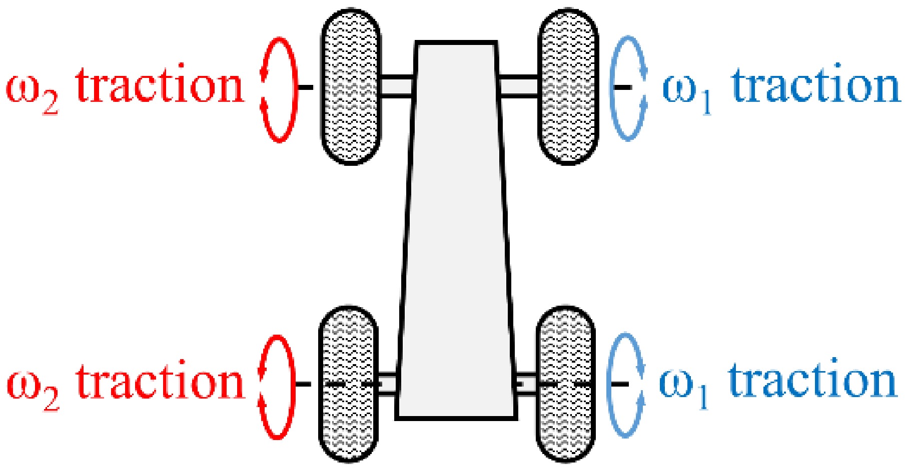
- **Wheel arrangement:**
  - **Coordinated steering scheme**

Coordinated Steering scheme	Characteristics
Advantages	– Simplicity – Few actuators (2) if based on the Ackermann device – Good turning accuracy if the front wheels are steered independently
Disadvantages	– Large turning radii – Ideal rotation in only three steering angles if based on the Ackermann device – Requires 3 actuators and more complex control algorithms if based on front wheels steered independently – Steering control on loose grounds, e.g. after ploughing, is difficult
Use in agriculture	– New mobile robotic designs are abandoning this scheme, which only offers simplicity. Hence, such steering control is not expected to be used in smart farms.

Mobile robot structures

- **Wheel arrangement:**
  - **Skid steering scheme:**

    The simplest structure for a mobile robot consists of four fixed, active wheels, one on each corner of the mobile platform.



c) Skid steering driving

Mobile robot structures

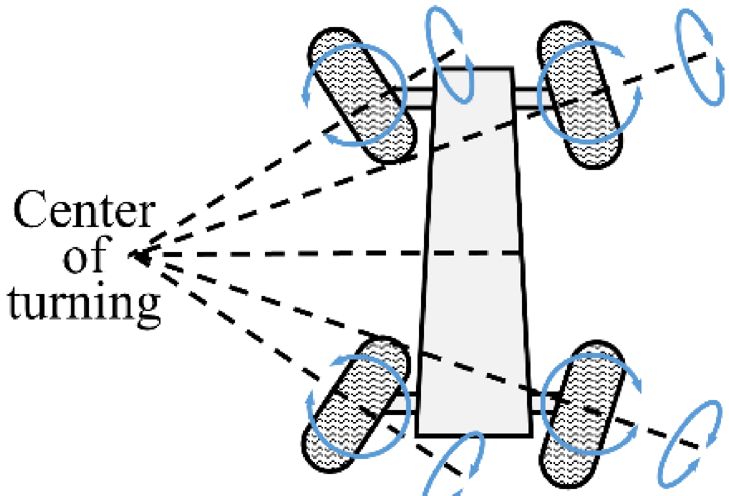
- **Wheel arrangement:**
  - **Skid steering scheme:**

Coordinated Steering scheme	Characteristics
Advantages	– Compact, robust, few parts – Agility (motion with heading control and zero-radius turns). – Few actuators (2)
Disadvantages	– The maximum forward thrust is not maintained during turns – Terrain irregularities and tire-soil effects demand unpredictable power supply – Vehicle rotations erode the ground and wear the tires.
Use in agriculture	– This steering scheme is simple and robust but not very precise in loose terrain; however, it is being used in new robot structures.

Mobile robot structures

- **Wheel arrangement:**
  - **Independent steering scheme:**

    An independent steering scheme controls each wheel, moving it to the desired orientation angle and rotation speed.



d) Independent steering and traction driving

- **Wheel arrangement:**
  - **Independent steering scheme:**

Coordinated Steering scheme	Characteristics
Advantages:	– Full mobility (omnidirectionality including crab motion)
Disadvantages:	– Many actuators and parts (8 for a 4-wheel robot) – Complex control algorithms
Use in agriculture	– This steering scheme is the more versatile of the schemes, but it is also more complex and expensive. However, most engineering systems evolve by increasing their sophistication and robustness while decreasing their cost; hence, this scheme will be intensively used in smart farms.

Current Robots for Agriculture

- **Over 62 projects analysed [1] reveal that** (more than 50 pictures included)
  - ❑ 80.65% are in the research stage.
  - ❑ 37% of robotic systems are 4WD (Four-wheel drive).
  - ❑ 22.06% are used in weeding tasks.
  - ❑ Main sensors for navigation
    - ❖ 50% use cameras,
    - ❖ 20% RTK/GNSS/INS, and
    - ❖ 16% LiDAR.

[1] Oliveira, L.F.P.; Moreira, A.P.; Silva, M.F. Advances in Agriculture Robotics: A State-of-the-Art Review and Challenges Ahead. Robotics 2021, 10, 52. https://doi.org/10.3390/ robotics10020052

Main characteristics of current mobile robots

Vehicle (Year)/ *Manufacturer*	Status	Type	Dimensions (m)	Weight (Kg)	Speed (ms^{-1})	Payload (kg)
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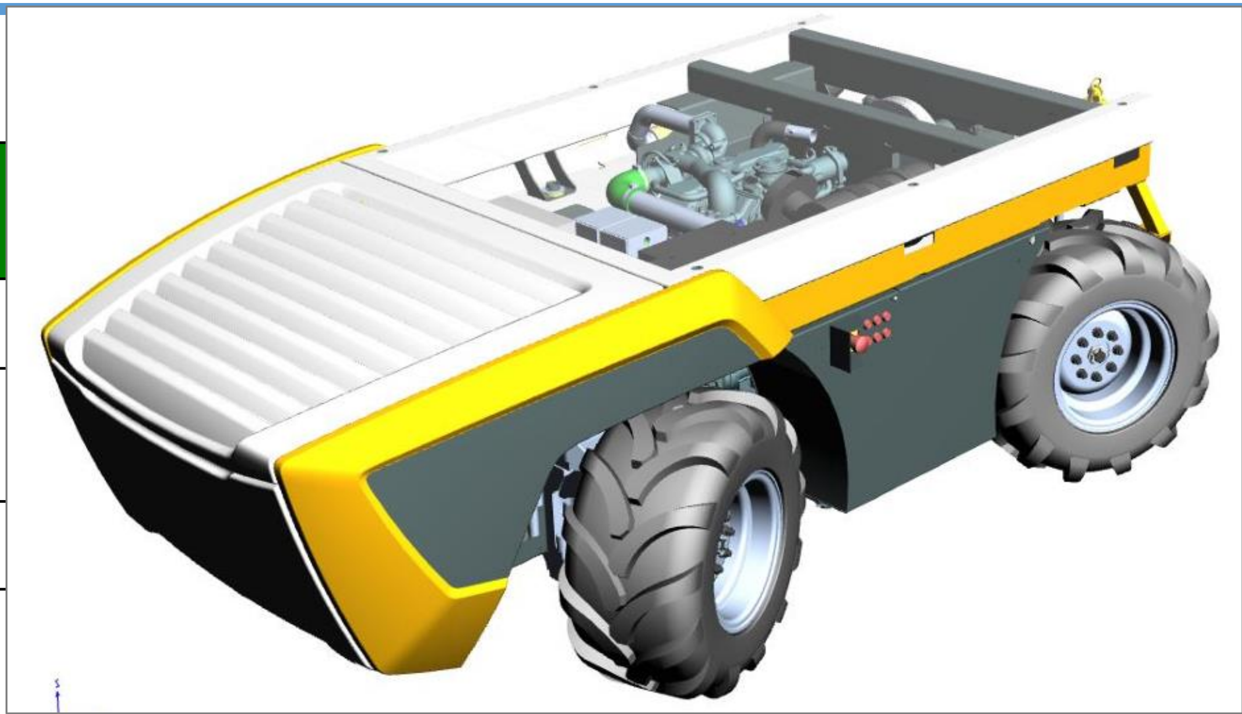

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Prospective characteristics for agri robots

Characteristics	Value	Comments
Dimensions	Length: ~3.0 m; Width: ~1.50 m; Height: ~1.00 m	• Vehicles for carrying sensing systems → small (low payloads), • Vehicles for treatments need to carry medium to heavy loads (pesticides, fertilizes, etc.), e.g., existing sprayers → 600–700 kg, including 200–300 L of active ingredients.
Weight	1,200–1,700 kg	
Payload	500–1,000 kg	
Speed	3–25 km h^{-1}	Treatment speed is limited by the treatment process. However, robots need to move among working fields; therefore, they must feature a reasonably high-top speed.
Position accuracy	±0.02 m	The current DGPS accuracy suffices for real applications. However, specific real-time localization systems, RTLS, can be used in small areas where GNSS is unavailable (radio frequency identification tags (RFID), ultra-wideband tags (UWB), etc.).
Clearance	0.35–1 m	Weed control is performed at an early crop-growth stage; therefore, the minimum ground clearance of the robot must be approximately 0.35 m. A ground clearance of approximately 1 m will facilitate application of treatments at later crop-growth stages.
Track width	1.50–2.25 m	• In narrow-row crops, tramline control is required. • In wide-row crops, the tramlines must be in the inter-row spacing. A robot track width of 1.50 to 2.25 m is required to enable 2 or 3 rows to pass under the robot's body.
Energetic Autonomy	~ 8 to 10 h	Robots based on combustion engines (e.g., tractors) can operate autonomously for approximately 10 hours, at minimum. The duration of autonomous operation for electrically driven systems should be similar.

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