RRLAB
THE ROBOTICS RESEARCH LAB

An Autonomous Lightweight Robot for Steepslope Viticulture

Eike Gassen
Robotics Research Lab
Department of Computer Science
University of Kaiserslautern, Germany

Syllabus

- Motivation
- Design
- Simulation
- Control Architecture
- Concept Optimization

What is a Steep slope vineyard

Steep slope vineyard in Zell-Merl

[Kal]

Flat terrain vineyard in Napa Valley

[Nap]

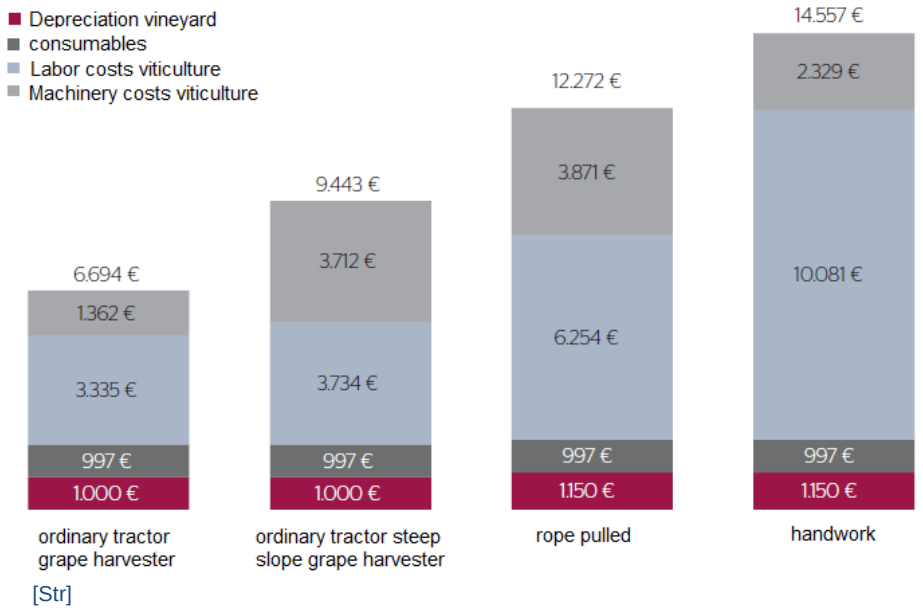
Steep Slope Cultivation

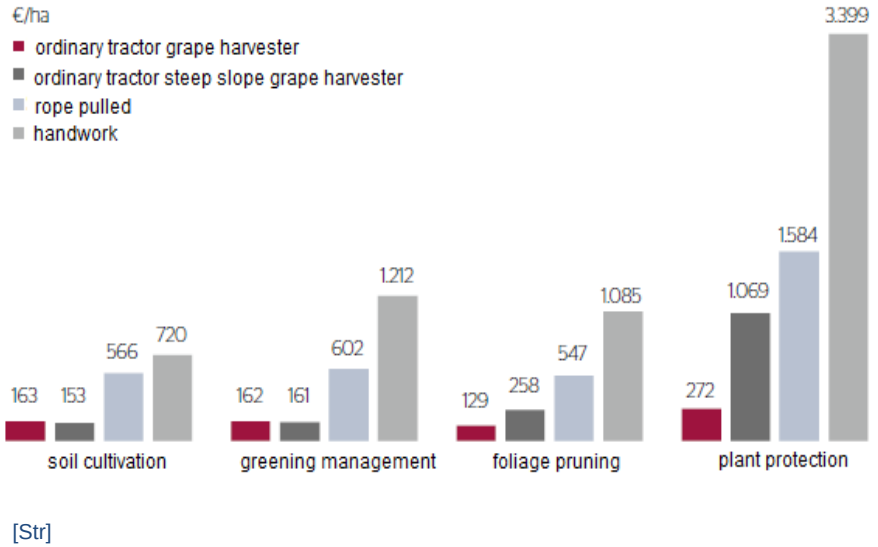
- Fall line cultivation
  → high amount of manual labor

- Shortage of workers
  → autonomous robots

Target Setting

- Preservation of steel slope viticulture





→ Automation of plant protection:
- Cost reduction
- Health protection of the user

Requirments

Environment

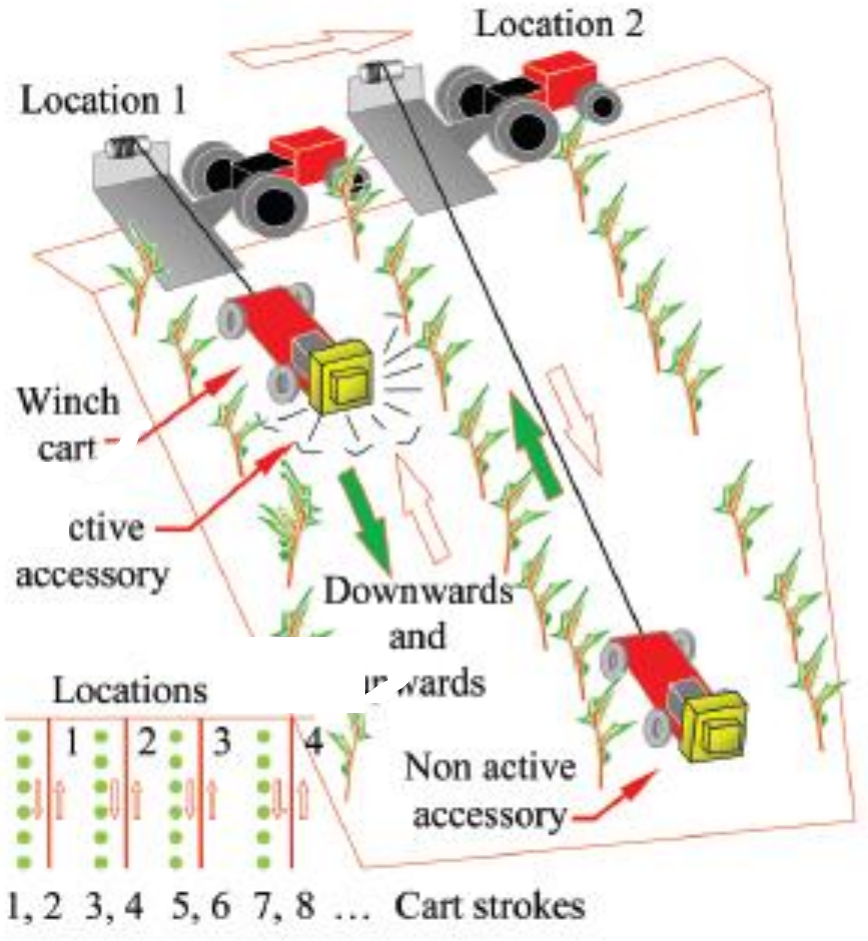
- 100 m long rows
- 70% inclination

Vehicle

- Lenght < 1.6 m
- Width < 0.8 m
- Height < 1.8 m
- Minimum speed = 1.5 $\frac{m}{s}$
- Mass < 250 kg

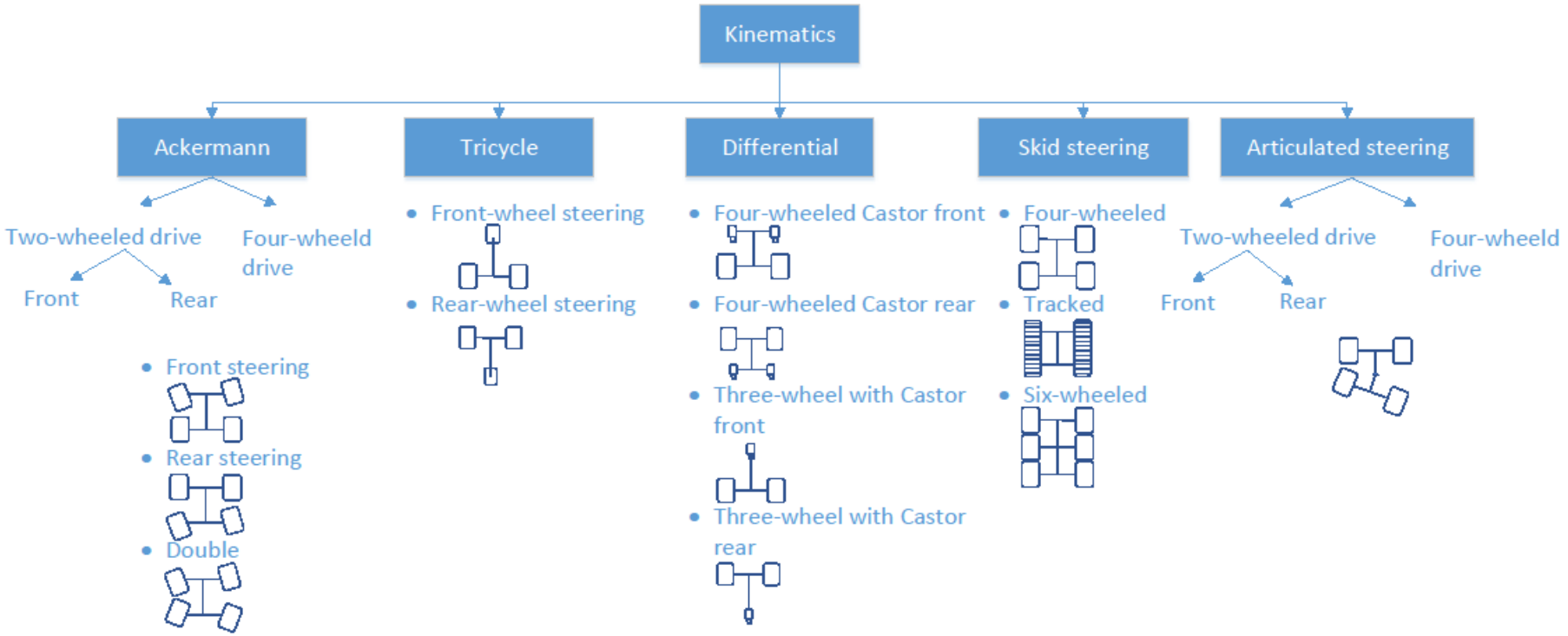
→ Winch needed for inclination!

Tractor-Trailer Combination

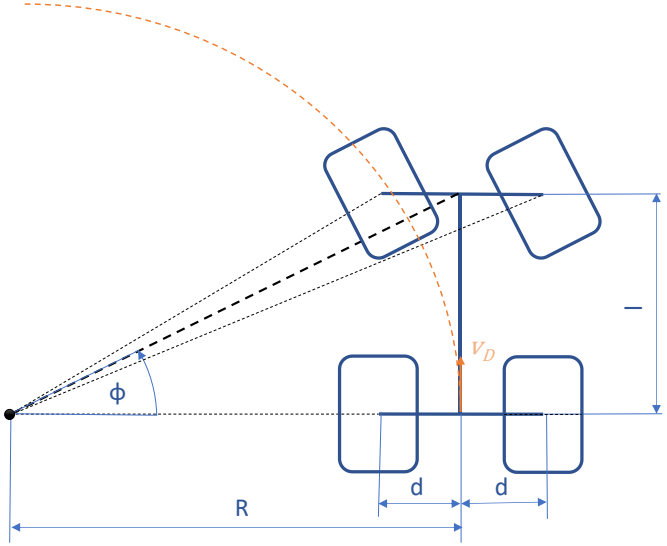


[Kod]

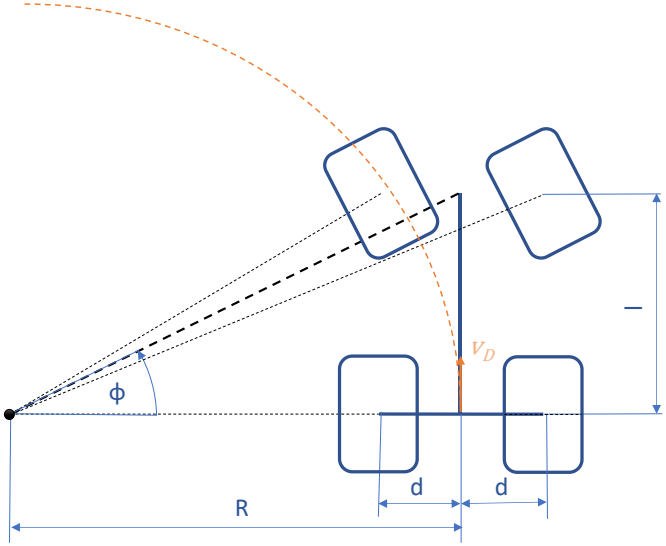
Kinematic Concept



Kinematic Concept



Ackermann



Enhanced Ackermann

Evaluation of Concepts - Criteria

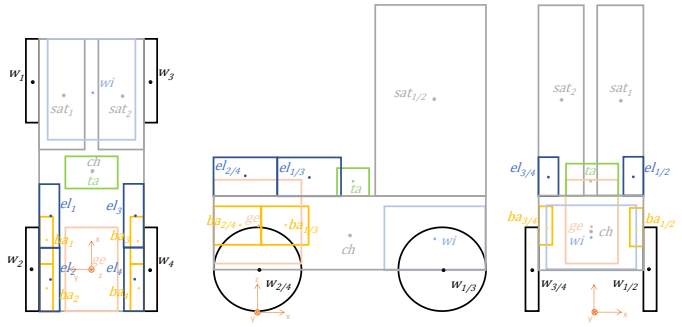
- **Weight**
- Spatial arrangment
- Mobility
- Ground contact

→ Cost Utility Analysis

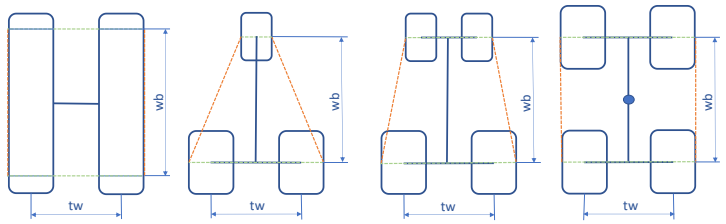
- Stability against **backward tilting**
- Stability against **lateral tilting**
- **Controllability**

Modeling

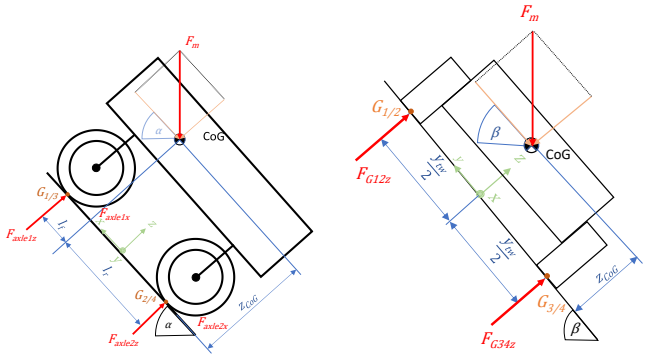
- Point Mass Model → CoG and mass



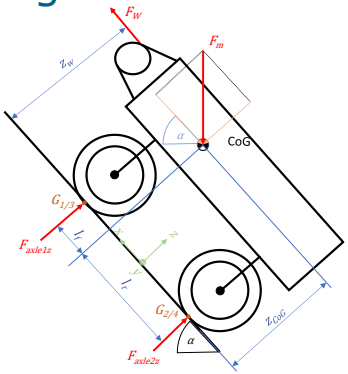
- Tilting Edges



- Tilting Angles



- Tilting Angles with Winch



Extract from Cost Utility Analysis

		Tricycle				Differential							
Criteria	Weighting	concept 10		concept 11		concept 12		concept 13		concept 14		concept 15	
-	-	p	w v	p	w v	p	w v	p	w v	p	w v	p	w v
Weight	0.2	8	1.6	8	1.6	8	1.6	8	1.6	9	1.8	9	1.8
Spatial arrangement	0.05	6	0.3	6	0.3	8	0.4	8	0.4	8	0.4	8	0,4
Mobility	0.05	7	0.35	7	0.35	9	0.45	9	0.45	9	0.45	9	0.45
Stability against backward tilting	0.15	7	1.05	7	1.05	7	1.05	7	1.05	7	1.05	5	0.75
Stability against lateral tilting	0.2	2	0.4	2	0.2	8	1.6	8	1.6	2	0.4	1	0.2
Controllability	0.25	2	0.5	2	0.5	4	1	4	1	3	0.75	3	0.75
Ground contact	0.1	3	0.3	3	0.3	4	0.4	4	0.4	2	0.2	2	0.2
$\sum$	1	-	4.5	-	4.5	-	6.5	-	6.5	-	5.05	-	4.55

Simulation

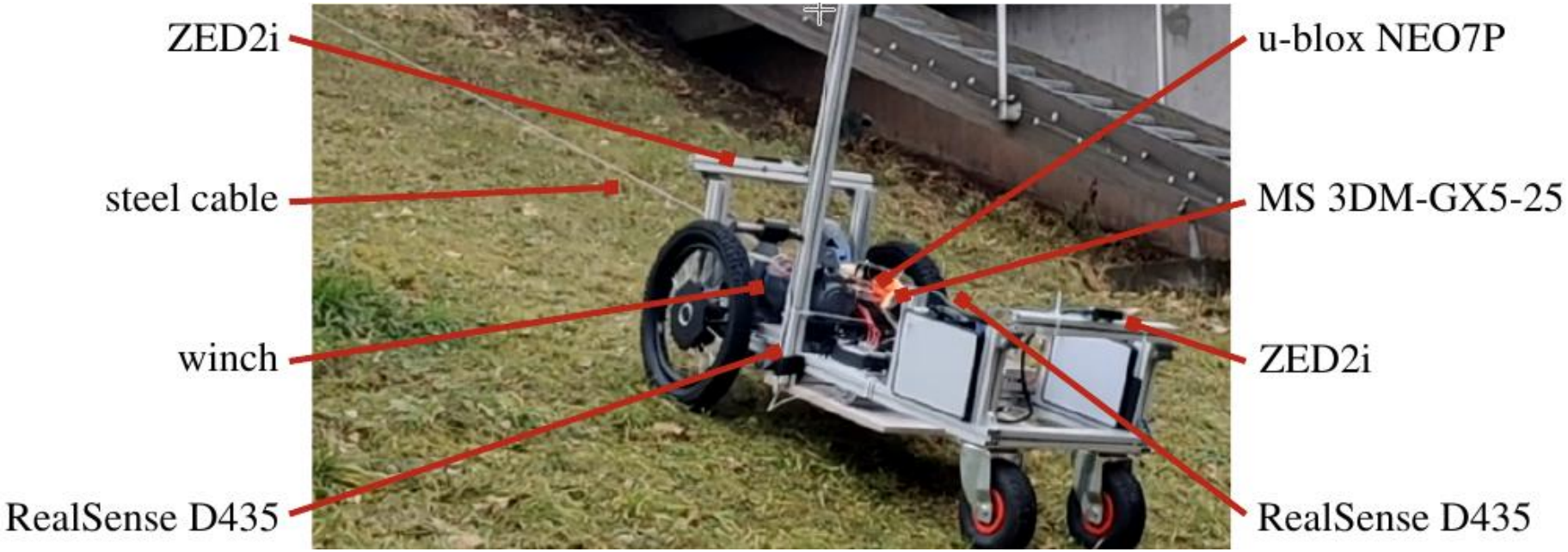
- Generation of training data
- Test of perception & navigation algorithms
- System development without a physical vehicle

- Consideration of
  - Light conditions
  - Snow, wind, rain, fog
  - Dust

- Simulation of sensors and vehicle dynamics
- Generation of different fields and plants
- Simulation of growing process

Simulation in Unreal Engine

Robot Prototype



Robot's Specifications

Table 1: Hardware and kinematic specification of the demonstration robot.

Property	Value	Property	Value
Wheel Base	1.18 m	Max. Velocity	1.50 $m\,s^{-1}$
Track Base	0.69 m	Max. Curvature	0.84 m^{-1}
Vehicle Length	1.71 m	Min. Turning Radius	1.18 m
Vehicle Width	0.76 m	Min. Turning Cycle	2.36 m
Vehicle Height	0.75 m	Max. Ground Clearance	0.26 m
Tire Radius	0.28 m	Tilt Angle*	32.80°
Length KC To Front	0.31 m	Max. Fwd Incl. Angle*	00.00°
Length KC To Back	1.40 m	Max. Bwd Incl. Angle*	46.00°

* under the assumption of a mounted sprayer attachement and higher center of gravity

Sensor	x [m]	y [m]	z [m]	Φ [°]	ψ [°]	φ [°]
ZED2i (f)	1.26	0.00	0.60	0.00°	0.00°	0.00°
ZED2i (b)	-0.32	0.00	0.60	0.00°	0.00°	180.00°
Realsense D435 (l)	0.50	0.34	0.60	0.00°	0.00°	90.00°
Realsense D435 (r)	0.50	-0.34	0.60	0.00°	0.00°	-90.00°
MS 3DM-GX5-25	0.00	0.00	0.60	0.00°	0.00°	0.00°
u-blox NEO7P	0.00	0.00	0.80	0.00°	0.00°	0.00°

Sensor Recording in Vineyard

Architecture Properties

- Modularity, exensibility and maintainability

- Robustness
  Environmental disturbances like changes in:
  - weather
  - illumination
  - season-related appearance

- Real-time performance
  - safety navigation in steep slope environment → short-term safety

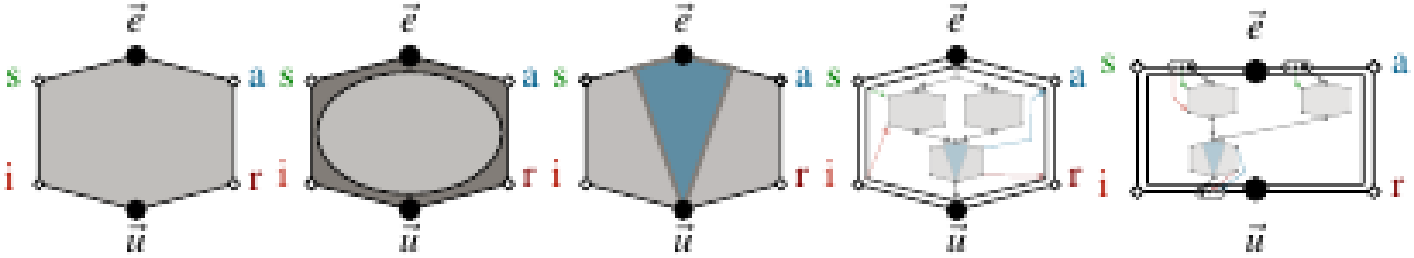
- Light weight implementation
  Fewer computational resources available → careful management of resources and algorithms

  → Problem: current state-of-the-art robotic systems and control architectures not designed to work in such harsh environment

Control Architecture

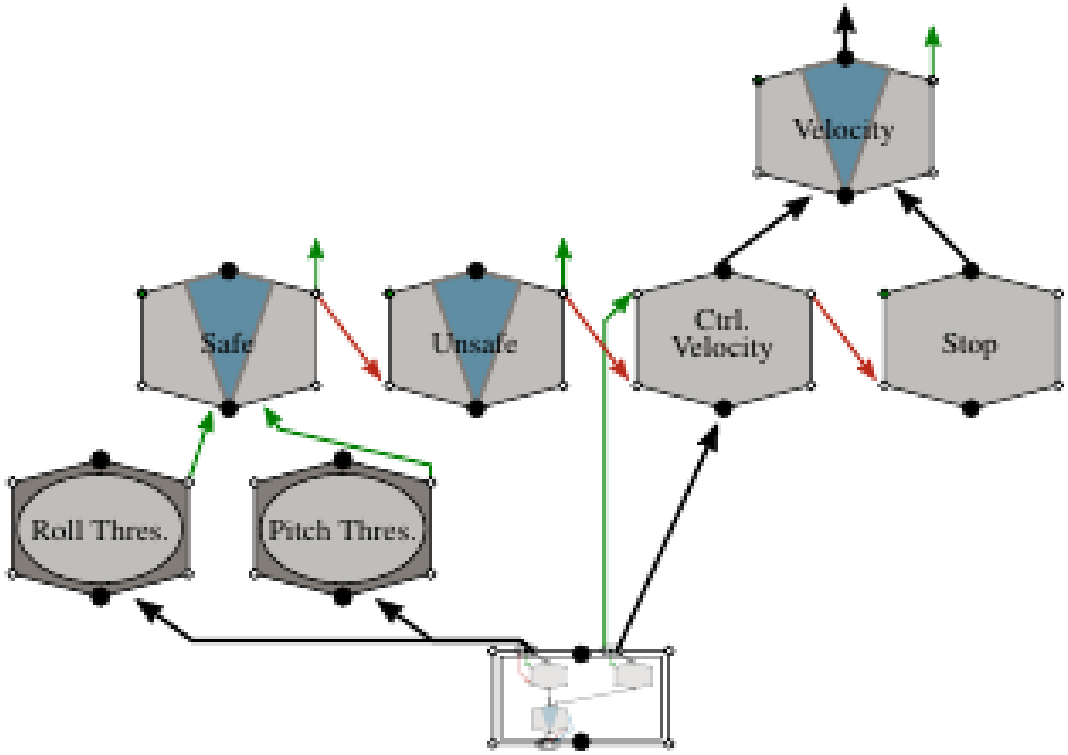
Behavior-based control (iB2C) architecture:

- decouples control and data flows
- modularization, abstraction, interaction of different components



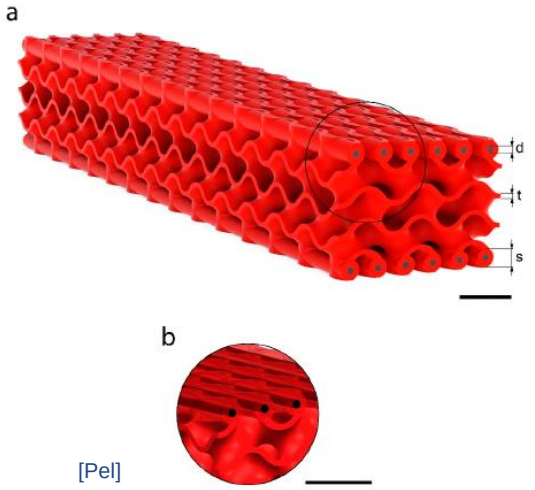
Control Architecture

Example behavior network: rollover prevention safety system



Concept Optimization

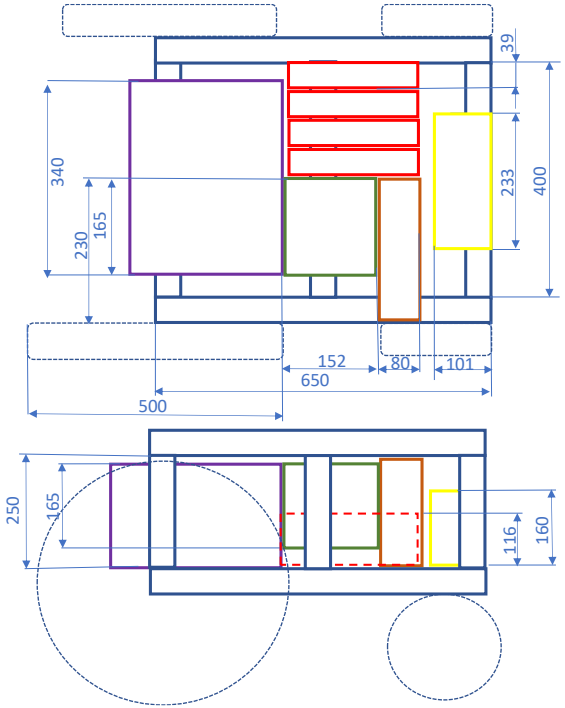
- Mass reduction → AM approach, materials with lower density, less overdimensioned
- Broader field of application
  - Mowing
  - Mulching
  - Trimming
  - Defoliation
  - Cultivating
  - …



[Pel]

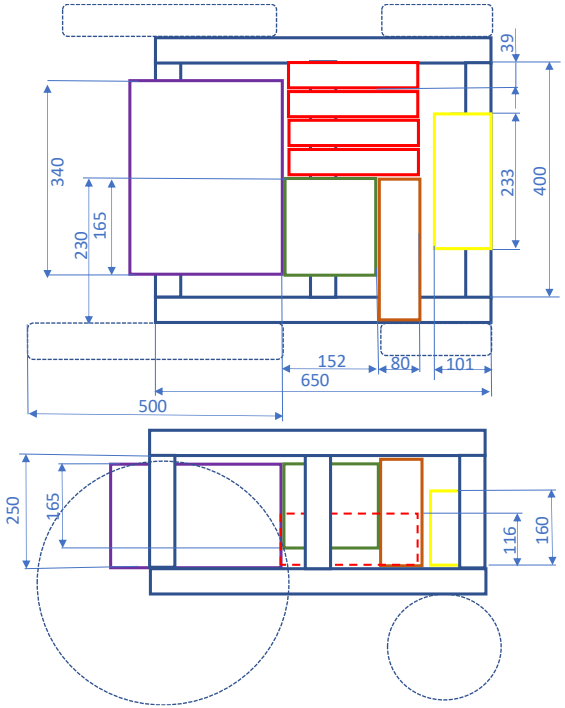
→ Modular principle: 50kg base frame 100 kg attachment

Base Frame



Part	Color
Winch	Purple
Winch Motor	Green
Battery	Brown
Chassis	Blue
Power electronics wheels	Red
Power electronics winch	Yellow

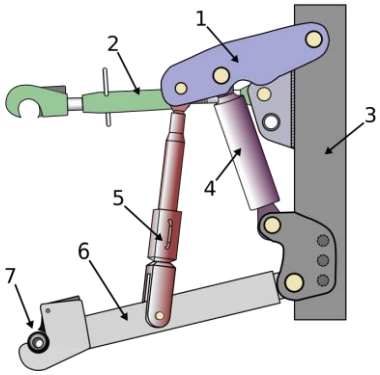
Base Frame



Part	Old weight	Optimized weight
Winch	51.00 kg	13.45 kg
Rope	6.00 kg	0.66 kg
Chassis	20.00 kg	5.10 kg

Modular Principle - Hitches

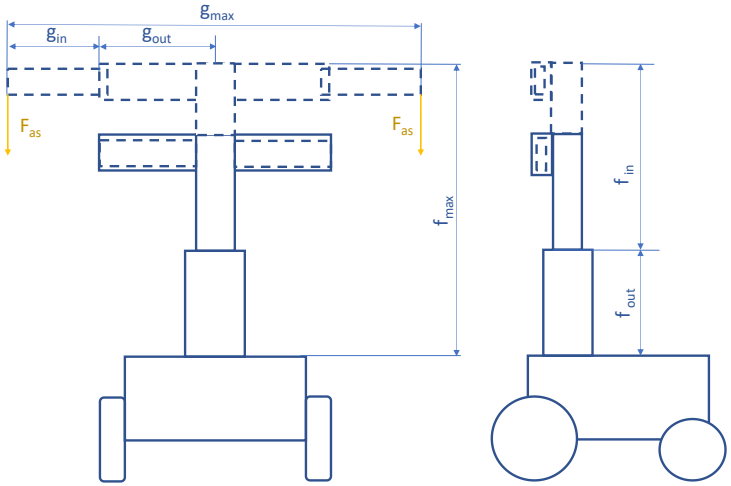
Ground cultivation



[Bru]

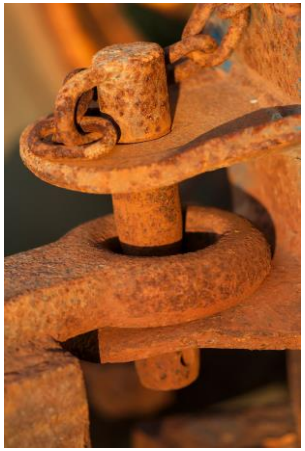
$m_{three-point}$ = 8.5 kg

Top mounted attachments



m_{mast} = 11 kg

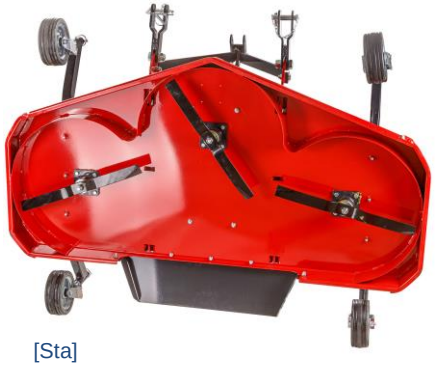
Static hitch



[Tow]

Attachments Ground Cultivation

Lawn Mower



[Sta]

32 kg

Flail mulcher

[MDl]

43 kg

Cultivator

[Sta]

To high forces!

Top mounted attachments

Defoliator

[Ero]

110 kg

Trimmer

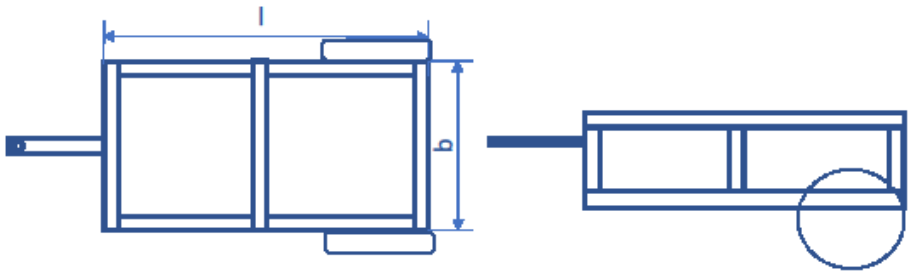
[Nik]

35 kg

→ Problem: Stability because of CoG

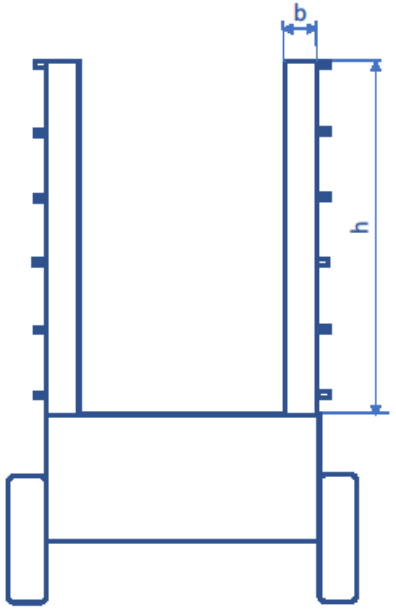
Static Hitch

Carrying device



22 kg

Spraying tower



18 kg

Thank you for your attention!

APPENDIX

CUA

		Enhanced Ackermann																	
Criteria	Weighting	concept 1		concept 2		concept 3		concept 4		concept 5		concept 6		concept 7		concept 8		concept 9	
-	-	p	w v	p	w v	p	w v	p	w v	p	w v	p	w v	p	w v	p	w v	p	w v
Weight	0.2	7	1.4	7	1.4	6	1.2	7	1.4	7	1.4	6	1.2	5	1.0	5	1.0	4	0.8
Spatial arrangement	0.05	8	0.4	8	0.4	8	0.4	8	0.4	8	0.4	8	0.4	8	0.4	8	0.4	8	0.4
Mobility	0.05	6	0.3	6	0.3	8	0.4	6	0.3	6	0.3	8	0.4	6	0.3	6	0.3	8	0.4
Stability against backward tilting	0.15	7	1.05	7	1.05	6	0.9	6	0.9	7	1.05	7	1.05	7	1.05	7	1.05	7	1.05
Stability against lateral tilting	0.2	8	1.6	8	1.6	8	1.6	8	1.6	8	1.6	8	1.6	8	1.6	8	1.6	8	1.6
Controllability	0.25	7	1.75	6	1.5	8	2	6	1.5	7	1.75	6	1.5	7	1.75	8	2.0	8	2.0
Ground contact	0.1	6	0.6	6	0.6	6	0.6	6	0.6	6	0.6	6	0.6	6	0.6	6	0.6	6	0.6
$\sum$	1	-	7.1	-	6.85	-	7.1	-	6.7	-	7.1	-	7	-	6.7	-	7.05	-	6.85

CUA

		Tricycle				Differential							
Criteria	Weighting	concept 10		concept 11		concept 12		concept 13		concept 14		concept 15	
-	-	p	w v	p	w v	p	w v	p	w v	p	w v	p	w v
Weight	0.2	8	1.6	8	1.6	8	1.6	8	1.6	9	1.8	9	1.8
Spatial arrangement	0.05	6	0.3	6	0.3	8	0.4	8	0.4	8	0.4	8	0,4
Mobility	0.05	7	0.35	7	0.35	9	0.45	9	0.45	9	0.45	9	0.45
Stability against backward tilting	0.15	7	1.05	7	1.05	7	1.05	7	1.05	7	1.05	5	0.75
Stability against lateral tilting	0.2	2	0.4	2	0.2	8	1.6	8	1.6	2	0.4	1	0.2
Controllability	0.25	2	0.5	2	0.5	4	1	4	1	3	0.75	3	0.75
Ground contact	0.1	3	0.3	3	0.3	4	0.4	4	0.4	2	0.2	2	0.2
$\sum$	1	-	4.5	-	4.5	-	6.5	-	6.5	-	5.05	-	4.55

CUA

		Skid						Articulated					
Criteria	Weighting	concept 16		concept 17		concept 18		concept 19		concept 20		concept 21	
-	-	p	w v	p	w v	p	w v	p	w v	p	w v	p	w v
Weight	0.2	7	1,4	1	0,2	2	0,2	8	1,6	8	1,6	8	1,6
Spatial arrangement	0.05	8	0,4	4	0,2	4	0,2	1	0,05	1	0,05	1	0,05
Mobility	0.05	9	0,45	9	0,45	9	0,45	8	0.4	8	0.4	8	0.4
Stability against backward tilting	0.15	7	1,05	9	1,35	5	1,35	7	1,05	7	1,05	7	1,05
Stability against lateral tilting	0.2	8	1,6	7	1,4	7	1,4	5	1	5	1	5	1
Controllability	0.25	5	1.25	7	1.75	7	1.75	6	1.5	6	1.5	6	1.5
Ground contact	0.1	6	0,6	10	1	8	0,8	6	0,6	6	0,6	7	0,7
$\sum$	1	-	6.75	-	6.35	-	6.15	-	6.2	-	6.2	-	6.3