Energy efficiency and autonomy in off-road vehicles in future worksites

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Content

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Content

Introduction

Motivation

Energy efficiency

Autonomy

Situational awareness

Autonomous navigation

Autonomous working actions

Conclusions and outlook

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Thinks to take into account

Application

Changing environment/terrain

Changing loading condition

Different working actions

Recovering from faulty situations

Safety

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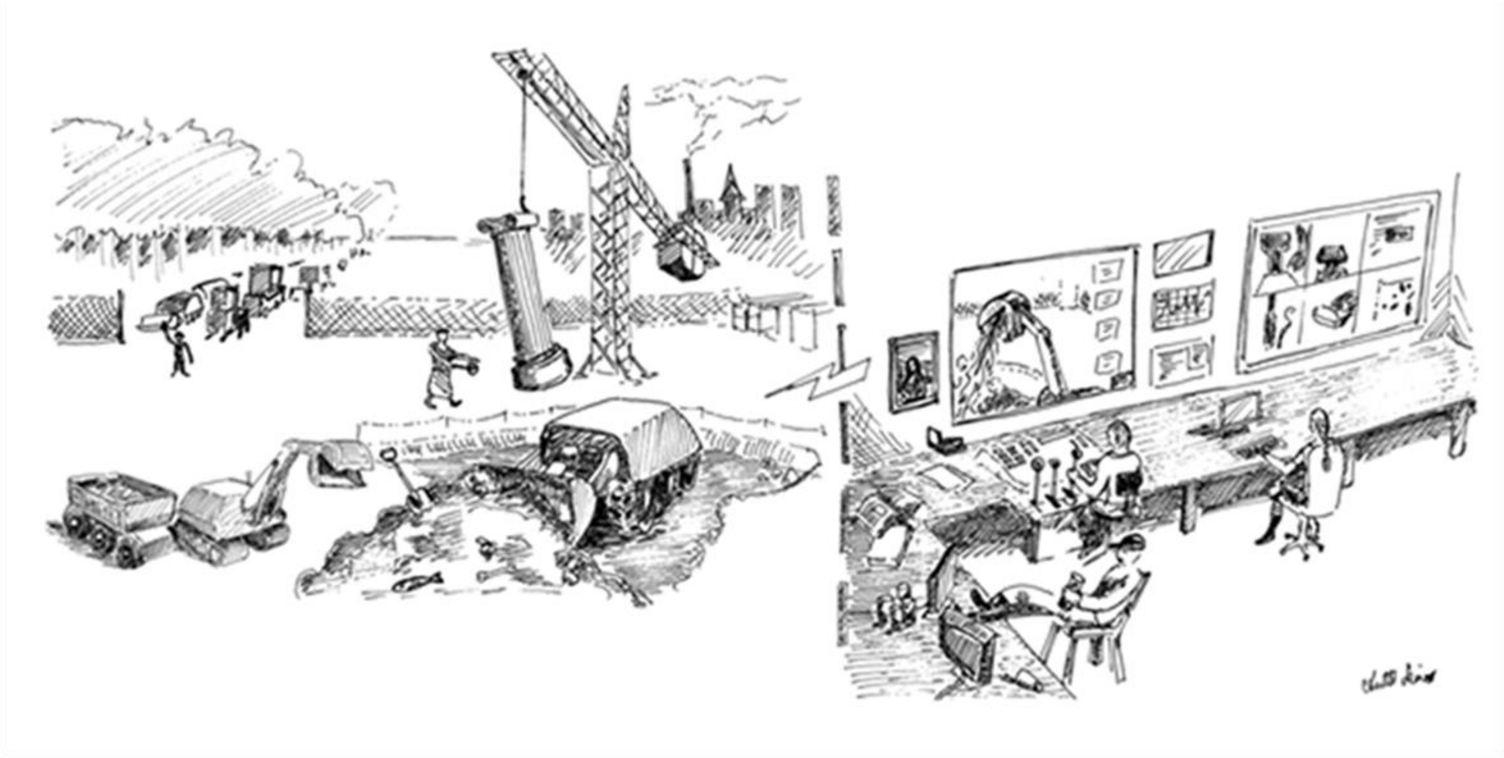
Vision of future worksite



Content

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Motivation

Common aspects

- Automation will be every day life in e.g. mobile machines
- Motivating work conditions to humans
- Energy efficiency is one of the driving forces for development of off-road vehicles

Challenging research/development problems to solve

- Interdisciplinarity
- Harsh and changing environment
- To mimic human and her/his behaviour when operating

Industry point of view

- Safety
- Productivity
- Lack of qualified operators
- Energy efficient and 24/7 worksites
- Must

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Content

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Situational awareness

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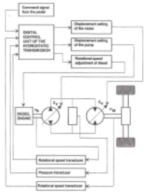
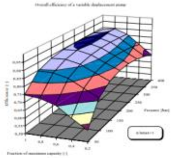
Base work for the energy efficiency

Idea of controlling all the drive components parallel

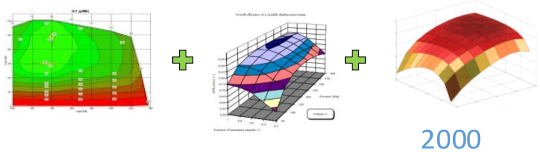


1990

Detailed study of drive train components



First test drives with the control of whole drive train components parallel



2000

Steady State Models

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Increase of the number of terms

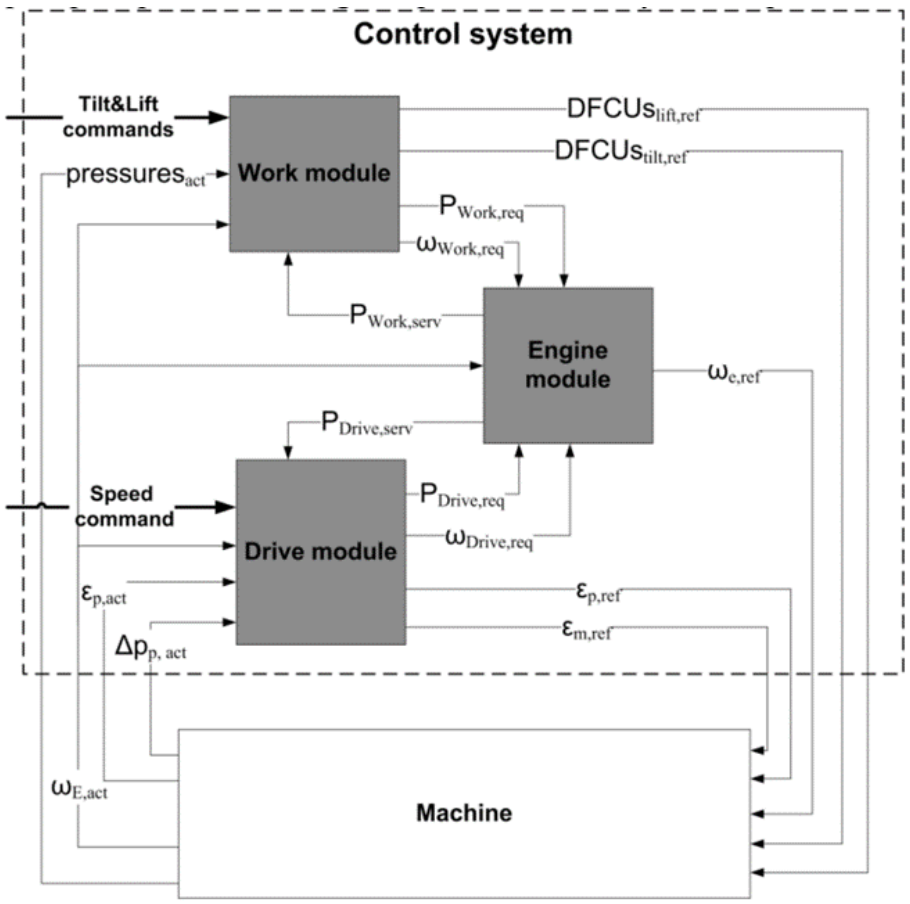
Zarotti and Nervegna, 1981	Non-linear terms for both Q_S and T_S
Rydberg, 1983	Introduction of new terms without physical background
Dorey, 1988	Non-linear terms for both Q_S and T_S, using also variable coefficients
Bavendiek, 1987	Totally 22 loss terms for Q_s and T_S
Ivantysyn and Ivantysynova, 1993	First pure mathematical approach

Huhtala, 1997 – two line model

Ivantysynova, 1999 - Polymod

© Dr. Monika Ivantysynova 27 *Design and Modeling of Fluid Power Systems, ME 597/ABE 591*

Power management



Control system consists of three moduls

- **Diesel engine module**
- **Drive module**
- **Work module**

Modularity

Communication

Interfaces

Distibuted and centralized computing

Wrapping

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Compared test set ups

- Serial wheel loader with driver
- Wheel loader with optimised control with drive
- Autonomous wheel loader with serial machine control without driver
- Autonomous wheel loader with optimised control without driver

Work cycle test

Comparison between Serial wheel loader with driver and Wheel loader with optimised control with driver

Work cycle 135 s

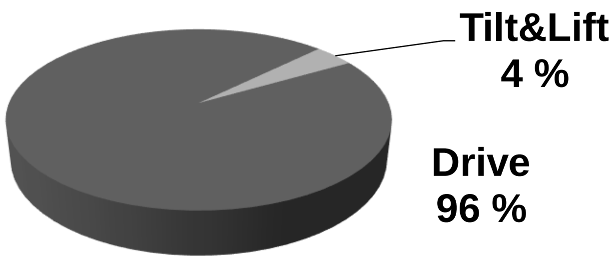
Load weight 1500 kg

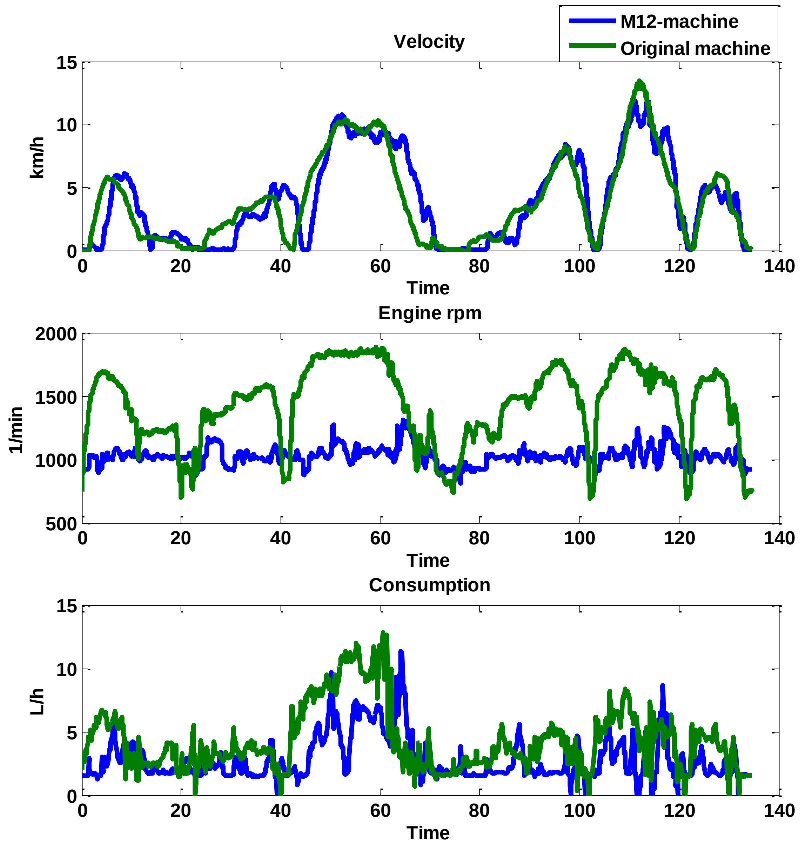
Consumption

- Original machine 0,162 L
- M12-machine 0,104 L

→ Fuel saving 36%

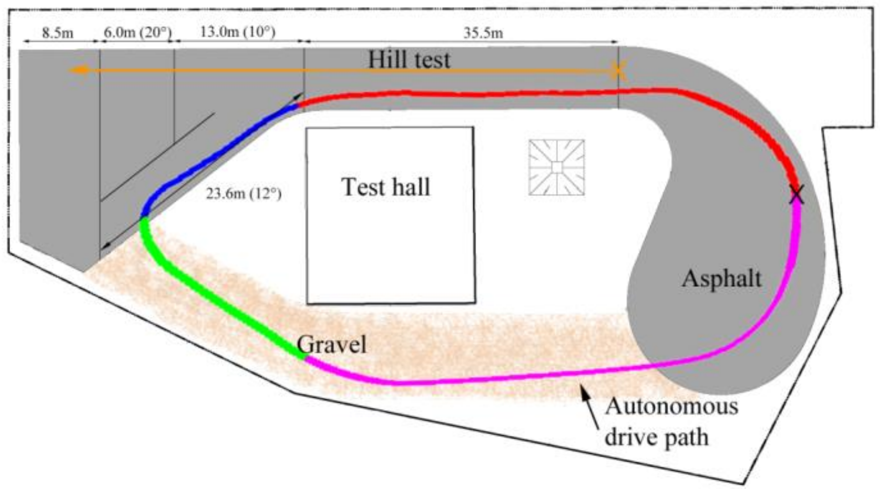
Energy distribution of unloading



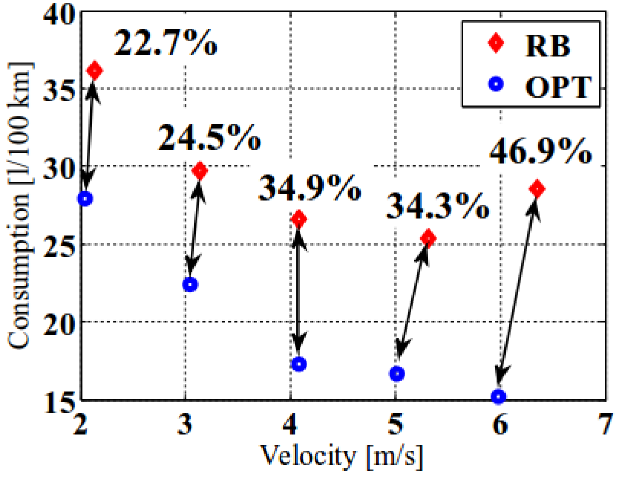


Example of results

Comparison between Autonomous wheel loader with serial machine control without driver and Autonomous wheel loader with optimised control without driver



22 - 45 % less fuel consumption in driving



Joni Backas, Reza Ghabcheloo, Seppo Tikkanen & Kalevi Huhtala (2016): Fuel optimal controller for hydrostatic drives and real-world experiments on a wheel loader, International Journal of Fluid Power, DOI: 10.1080/14399776.2016.1202081

Joni Backas, Reza Ghabcheloo, Kalevi Huhtala (2017): Gain scheduled state feedback velocity control of hydrostatic drive transmissions, Control Engineering Practice 58 (2017) 214–224

Content

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Steps towards autonomy

Pure operator driven machines

Remote operated machines

Machines with Operator assistance system included visualization

Machines with Operator assistance system included intervention

High automation; semi-autonomous system; sliding autonomy

Autonomous system with human-in-the-loop

Fully autonomous system

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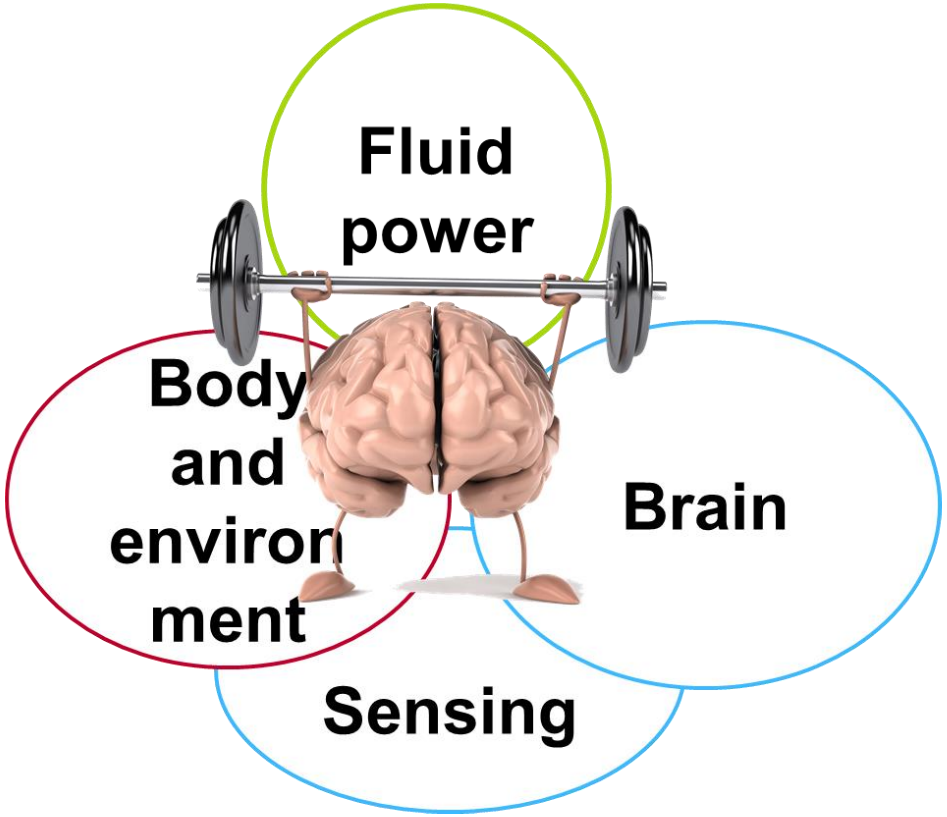
Holistic approach



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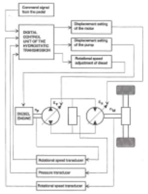
Timeline towards autonomy

Idea of controlling all the drive components parallel



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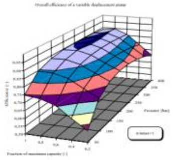
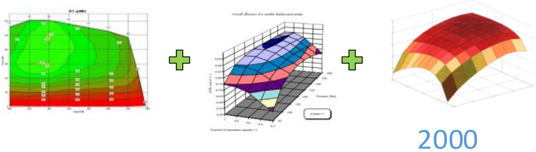


First test drives with the control of whole drive train components parallel

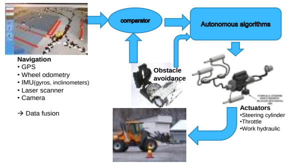


2000

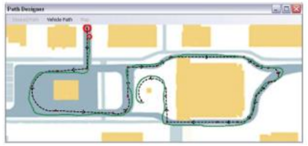
Autonomous pallet picking

2012

Autonomous drive with vision



Automated drive (path following)

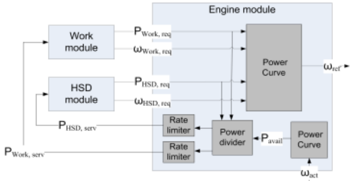


2009

Remote operated wheel loader

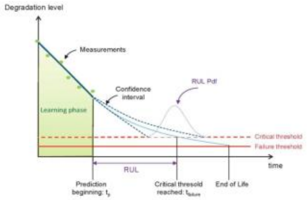
2003

Power and information management

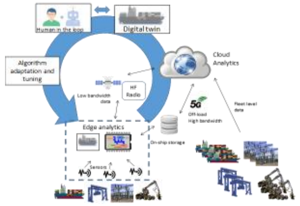


Autonomous driving and working actions with wheel loader

Predictive analytics



Edge computing



2013

2018

Content

Introduction

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Sensing and perception

Machine internal state; Interoceptive

- Any of the senses that detect condition within the body
- E.g. pressure, rotational speed, IMU, angle

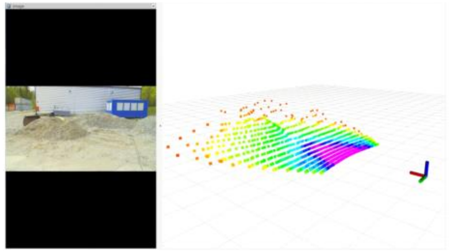
Perceptive; Exteroceptive

- The perception of environmental stimuli acting on the body
- E.g. radar, Ultra Sonic, Lidar, stereo camera, thermal camera, Laser Scanner

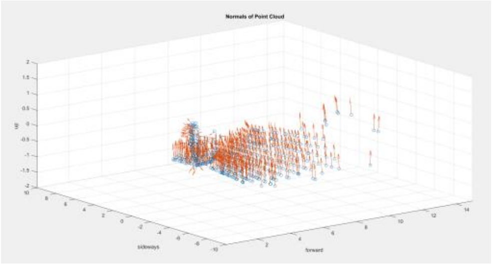
Fusion with internal and perceptive sensor informations is needed in autonomous machine case

Sensor data processing

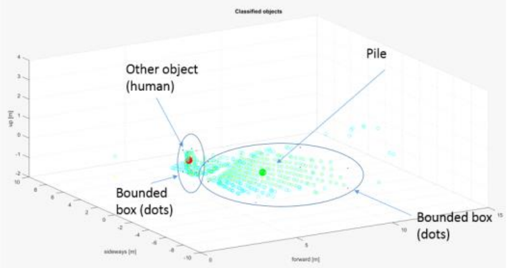
Raw data (point cloud)



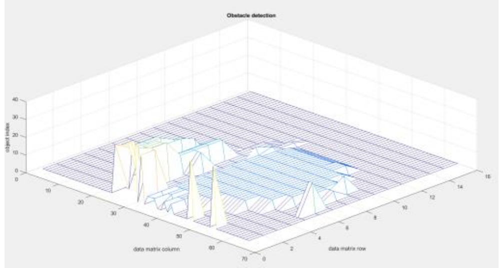
Plane normal calculation and filtering



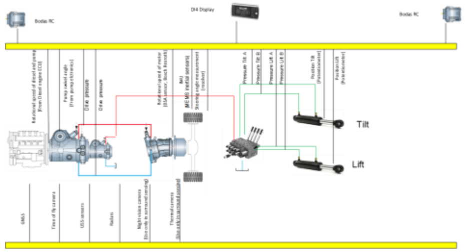
Object classification



Object detection



Sensor fusion



Data to control system

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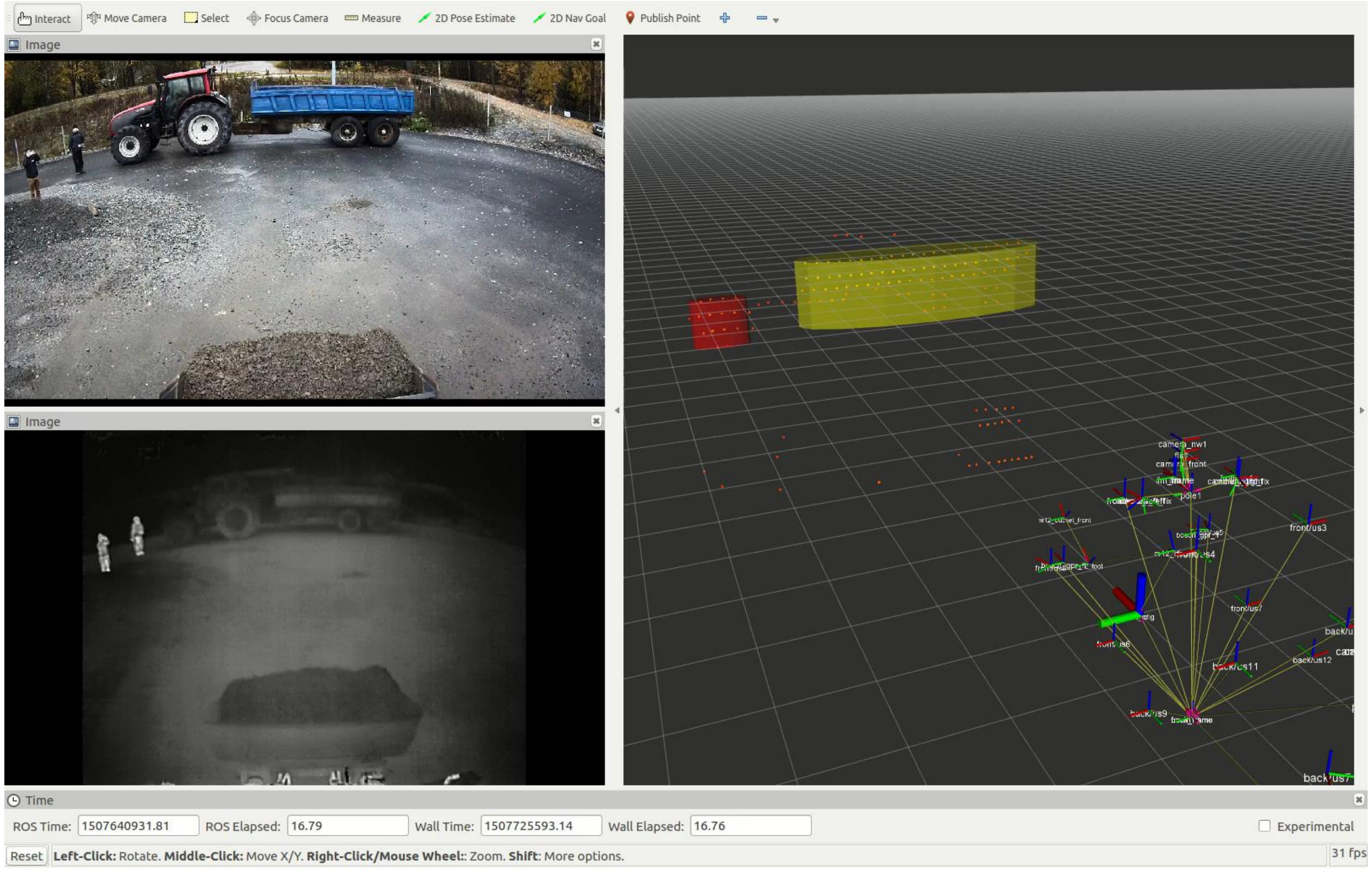
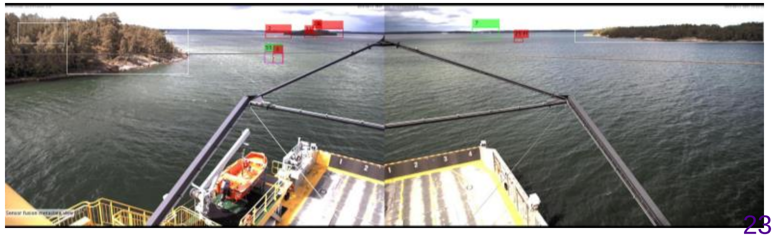
Sensor data processing in action



Take into account environment and application



Demands are different

- Influence to choice of sensor set
- What is needed information
- Needed information
- Sensor operation field e.g.
  - Distance
  - Accuracy
  - Speed
- Weather conditions
- Operations
- How safe sensor information is

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Content

Introduction

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Autonomous navigation

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Conclusions and outlook

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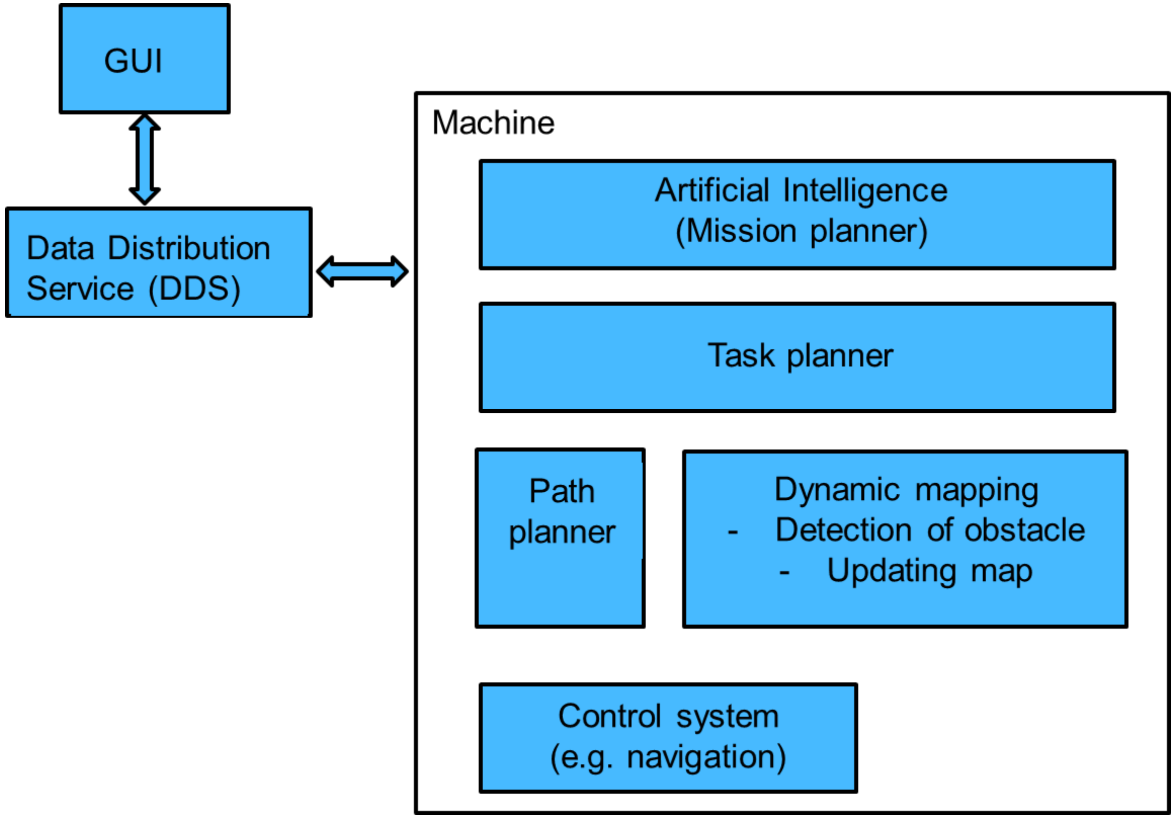
Control scheme of autonomous machine



Navigation

Local navigation

- Use of odometry (dead reckoning)
- Calculating the kinematic equations

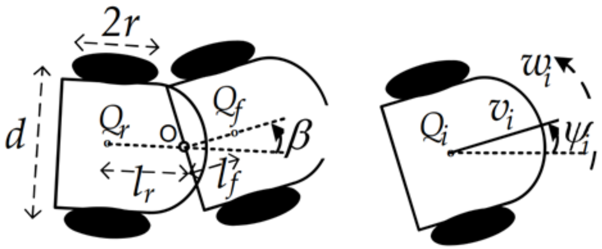
Global navigation

- Use of GNSS and odometry

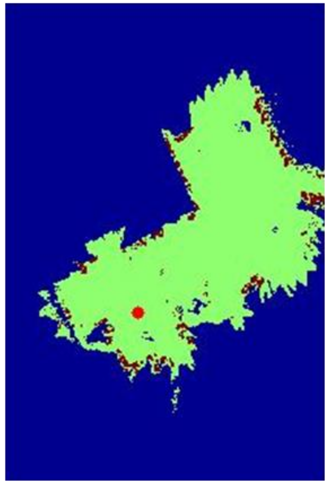
$$v_r = v_f \cos\beta + l_f \omega_f \sin\beta$$
$$l_r \omega_r = -l_f \omega_f \cos\beta + v_f \sin\beta,$$

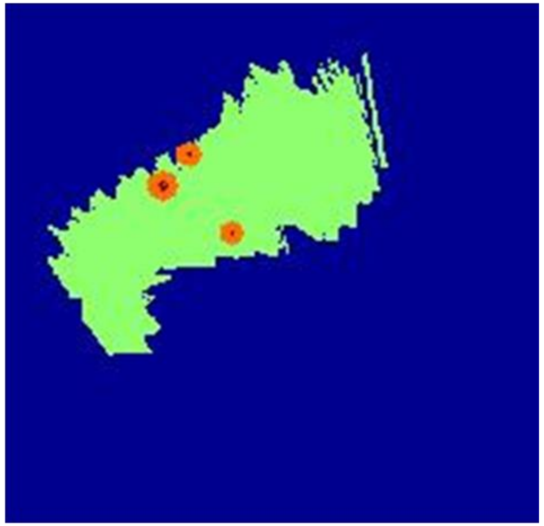
$$\omega_f = \frac{l_r \dot{\beta} + v_f \sin\beta}{l_f \cos\beta + l_r},$$

$$\omega_i = \frac{r}{2d}\left(w_{i,r} - w_{i,l}\right)$$
$$v_i = \frac{r}{2}\left(w_{i,r} + w_{i,l}\right).$$

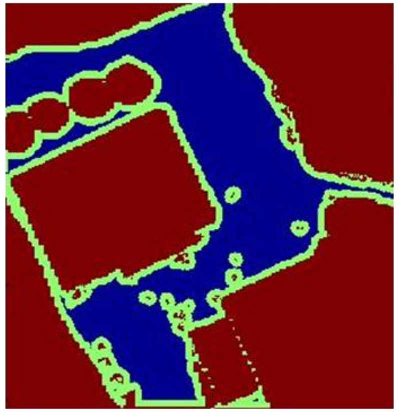


Static and dynamic mapping





Static map
(done before)



Final dynamic map

Dynamic map
(update online)

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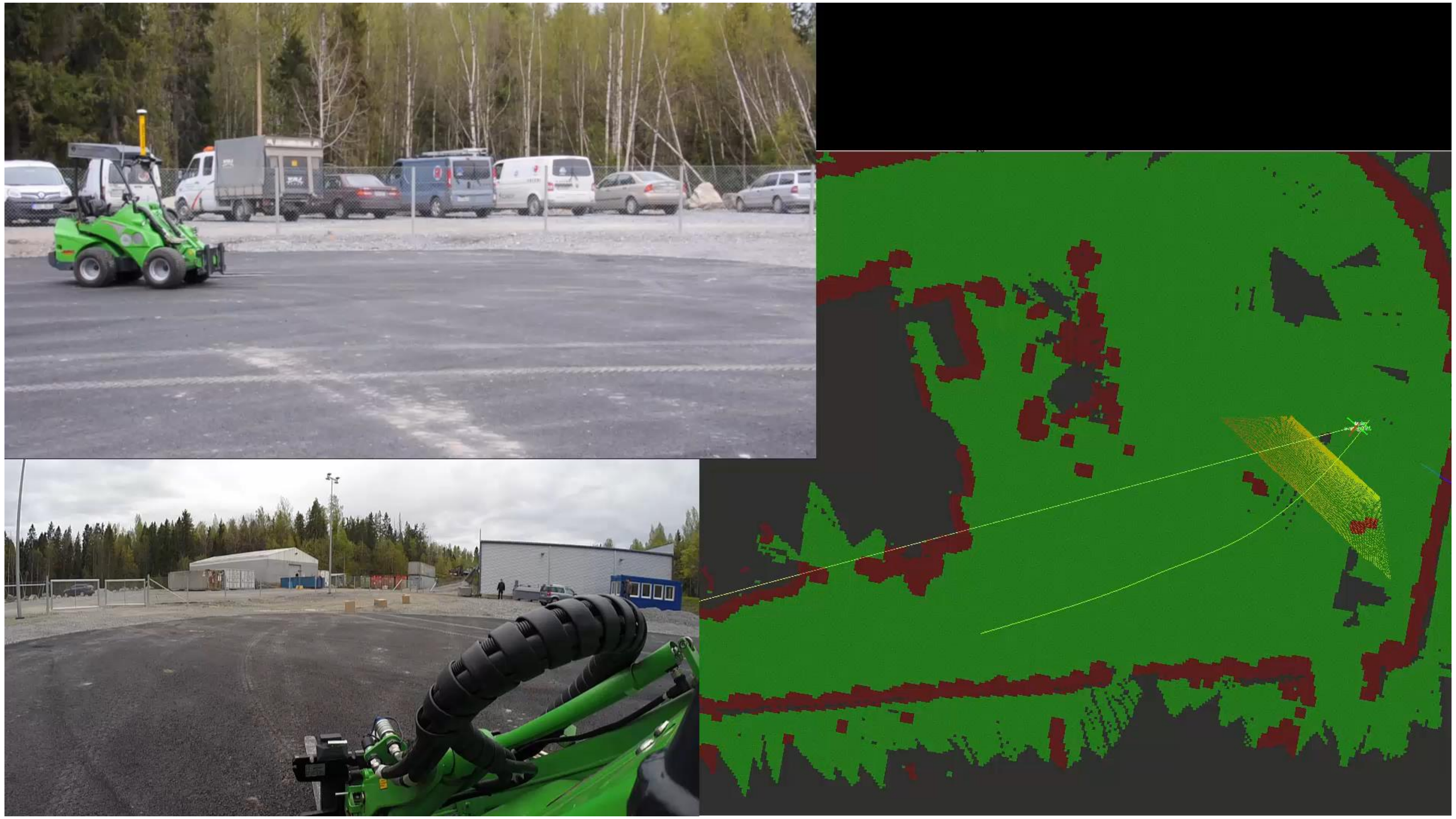
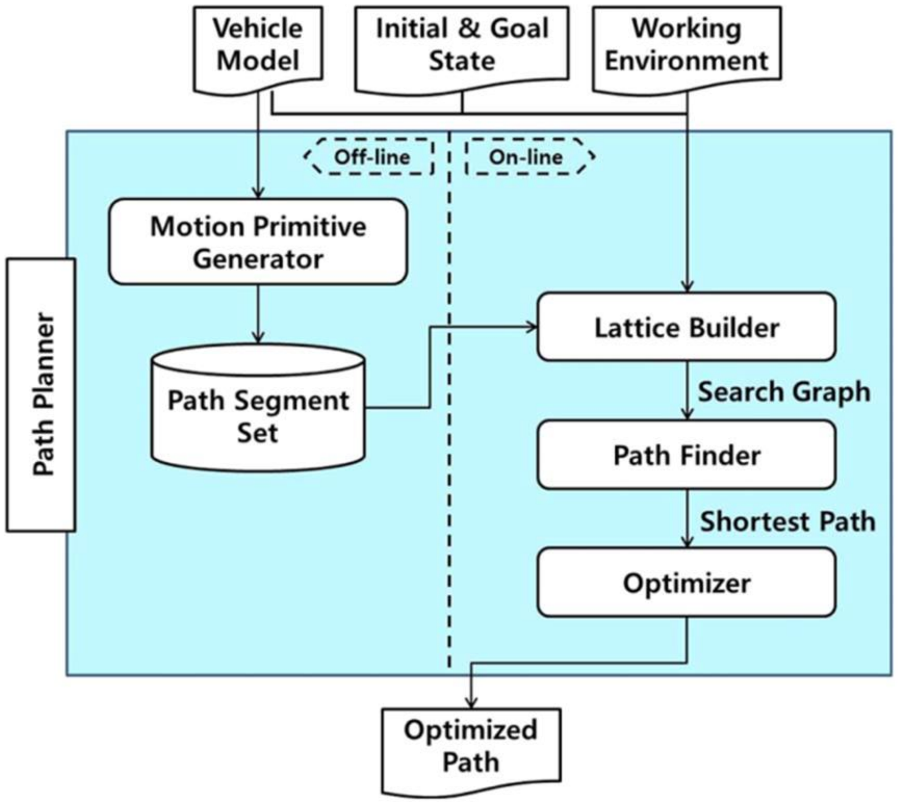
Mapping



Path-planning architecture



Constrained Global Path Optimization for Articulated Steering Vehicles, Choi, J-W. & Huhtala, K. 1 Apr 2016 In : IEEE Transactions on Vehicular Technology. 65, 4, p. 1868-1879

Constrained Path Optimization with Bézier Curve Primitives, Choi, J-W. & Huhtala, K. 2014 2014 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2014), September 14-18, 2014, Palmer House Hilton, Chicago, IL, USA. Institute of Electrical and Electronics Engineers IEEE, p. 246-251 6 p.

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Content

Autonomous working actions in different applications

How to teach the actions

- Rule based learning
- Supervised learning
- Role of domain knowledge in particular application

Used methods

- Artificial intelligence
- Machine learning
- Deep learning
- Neural networks
- Bayesian

Pallet picking

How it works


A Multistage Controller with
Smooth Switching for
Autonomous Pallet Picking
Tampere University of Technology
Department of
Intelligent Hydraulics and Automation
Center of Intelligent Mobile Machines
Tampere, Finland
contact for more information: m.aref@ieee.org

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Content

Conclusions and outlook

Safety and productivity are forcing first to operator assistance systems and towards autonomy in working machines in future

Automation is helping to more efficient way of working

Safety in autonomous systems has to be guaranteed

We have to ensure and rely on the sensor information e.g. in working actions

Autonomous working machines are technically possible to do

The autonomy has been solved in some clearly defined cases

Digital twin is a powerful instrument for tuning the parameters in autonomous systems

AI and learning methods are needed to solve more generic tasks

Thank you for the attention

https://research.tuni.fi/iha/