Autonomous Mobile Robots (AMR)

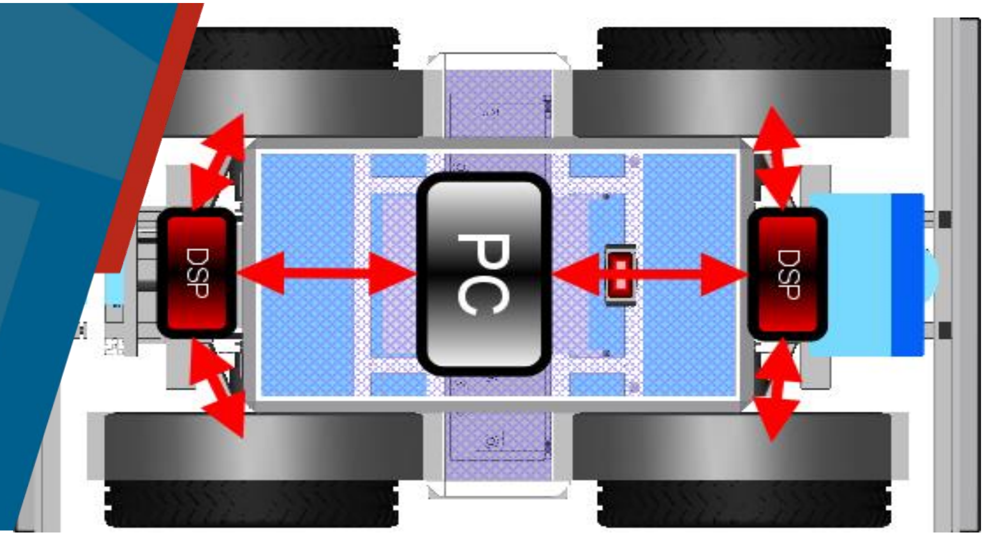
2. AMR Systems

Prof. Dr. Karsten Berns
Robotics Research Lab
Department of Computer Science
University of Kaiserslautern, Germany

Technische Universität Kaiserslautern

Contents

System Components

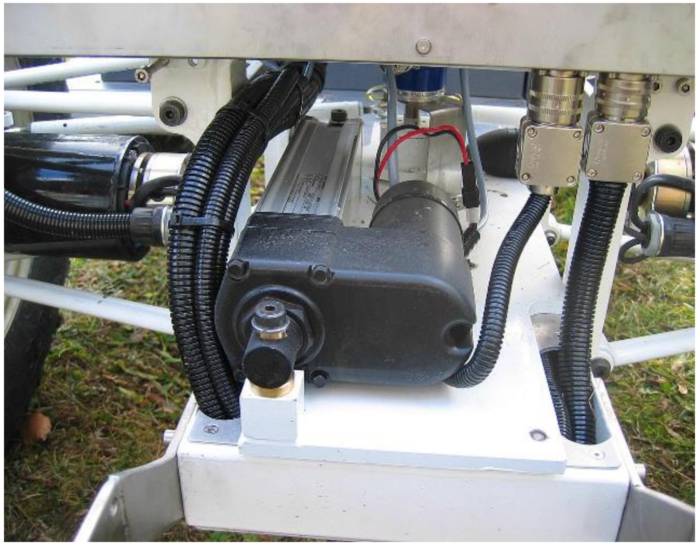


Embedded System: Offroad Robot RAVON

Actuators for Wheels and Steering

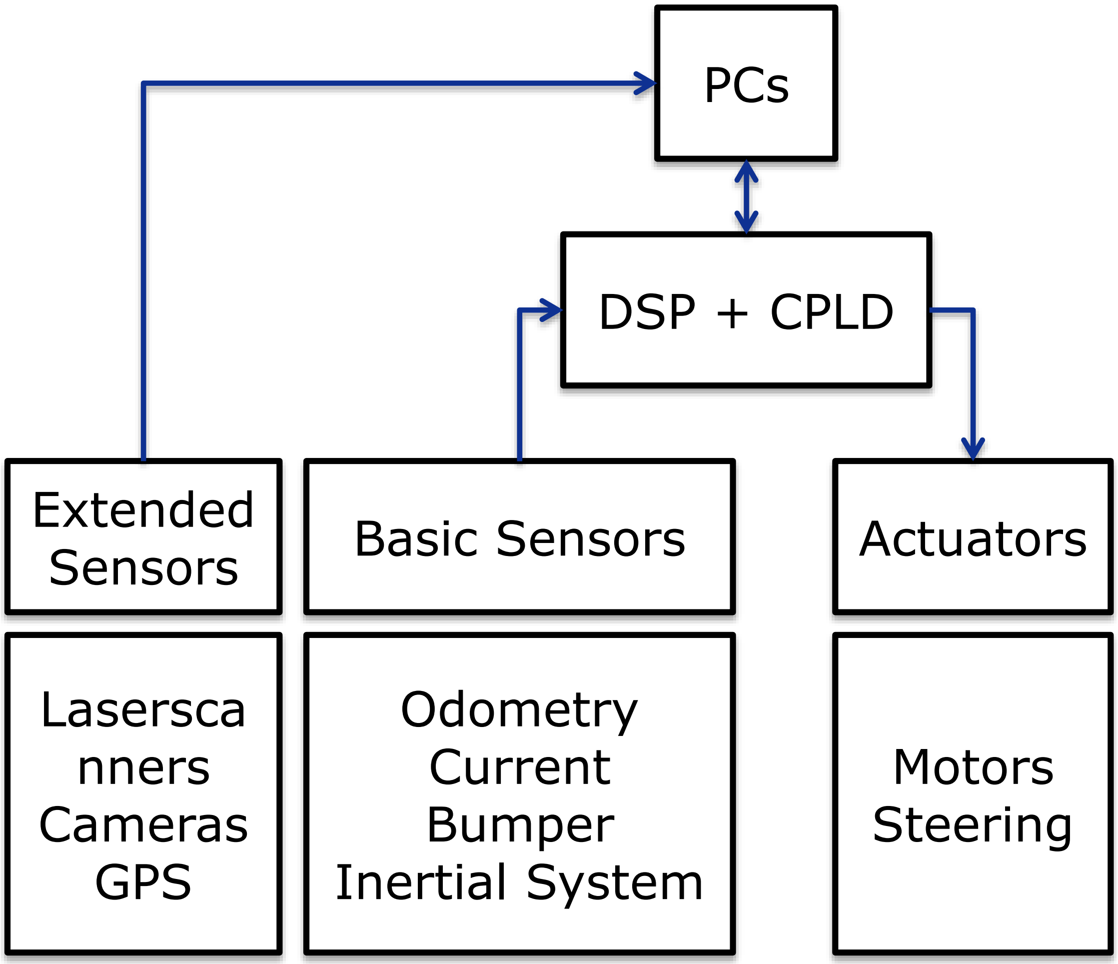
- Four independent DC motors
  - 48 V DC
  - 1700 Watt
  - 3200 U/Min
- Electromagnetic brakes

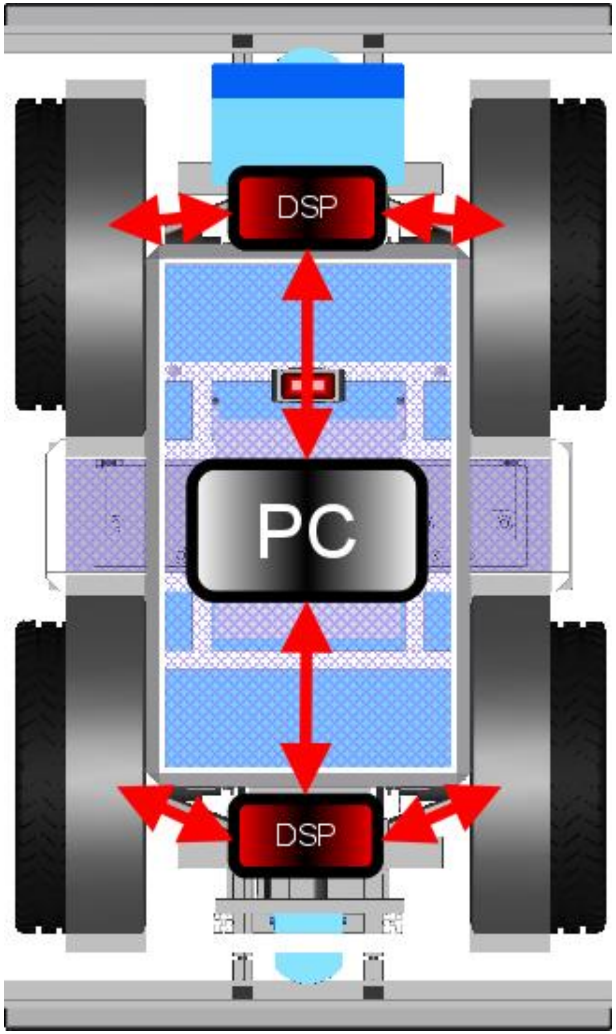
Propulsion motors of RAVON



Linear steering motor

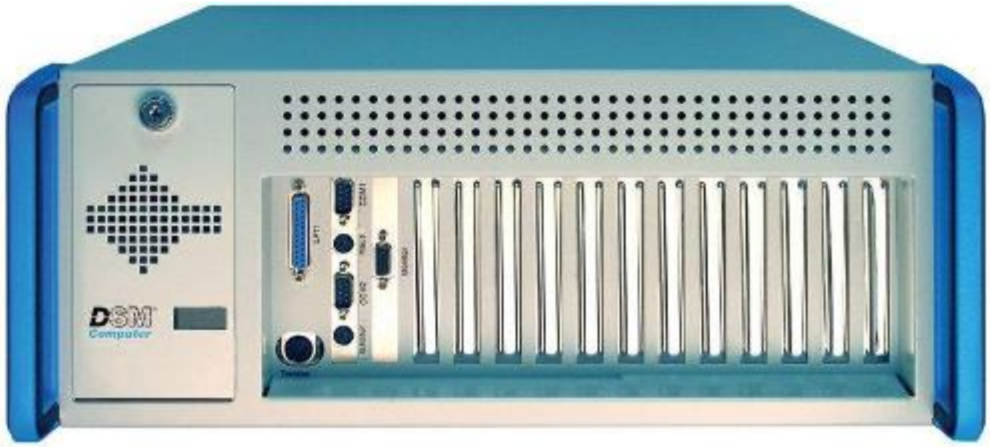
Electronic Hardware on RAVON





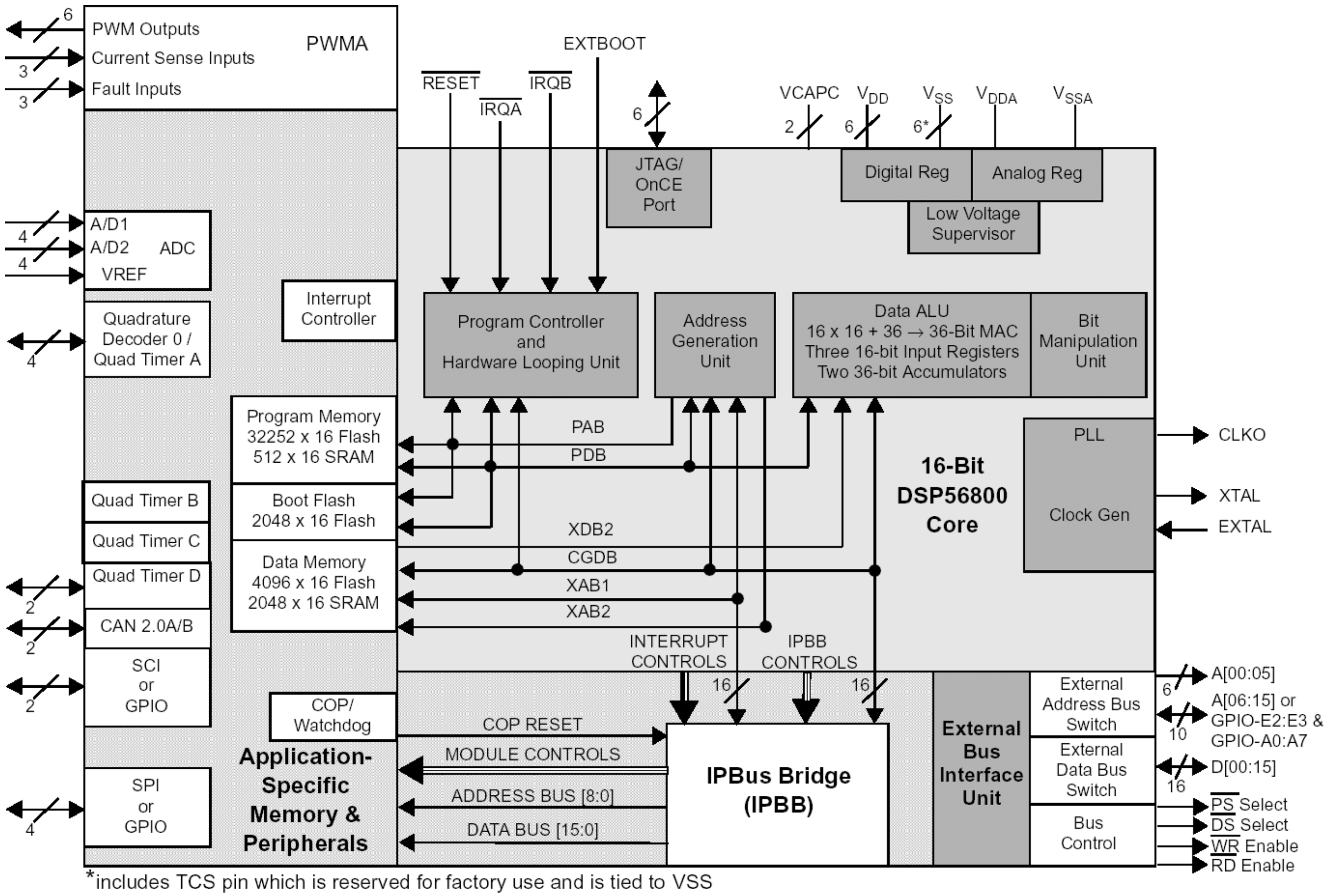
Hardware

- Embedded industrial PC (19 inches)
- Backbone with extension cards
  (SBC – Single Board Computer, PCI, ISA) for max. 2 SBC
- 48 V DC input voltage
- SBC with Intel Pentium 4
- Ruggedized hardware



Industrial PC

Hardware



Layout of a DSP56F803

Communication

- CAN-Bus
  - Sensor communication and vehicle control
  - CAN 2.0 A
  - 1 MBit/s
- Firewire cameras
- Serial interface to laser scanner
- Shielded connections necessary
  (EMV due to high motor currents)

Electronics

THE ROBOTICS RESEARCH LAB

Actuation System

TECHNISCHE UNIVERSITÄT KAISERSLAUTERN

Electrical Actuators

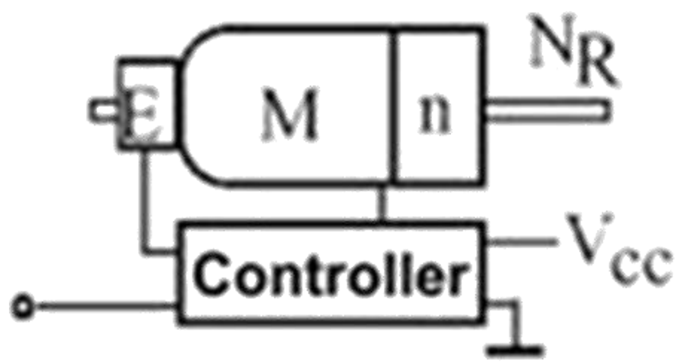
- Actuator energy: electrical
- Pro
  - Little required space
  - Compact
  - Good controllability of revolutions and torque
  - High positioning-/repeat-accuracy, hence even driving on surfaces and curved paths is possible very precisely
- Contra: power very limited
- Application: small robots for tasks that require precision, e. g. for printed circuit board assembly

Types of Electrical Actuators

- DC motors
  - Brushless/brush-type DC-motors
- Step motors
  - Rotating in impulse steps, per impulse rotation with a fixed angle ($0.5° - 5°$) is performed, max. 2000 impulses
  - Angle can be set precisely because of fixed resolution
  - Complex control, high energy consumption while idle

Types of Electrical Actuators

- AC motors
  - Alternating current $220\,\mathrm{V}$ (low power)
- Three phase current $3 \times 380\,\mathrm{V}$ (high power)
- Servo motors
  - Motor + transmission + encoder + controller
  - Angle ~ controller output/
    revolutions ~ output is not load affected



DC motor with controller

Characteristics of DC Motors

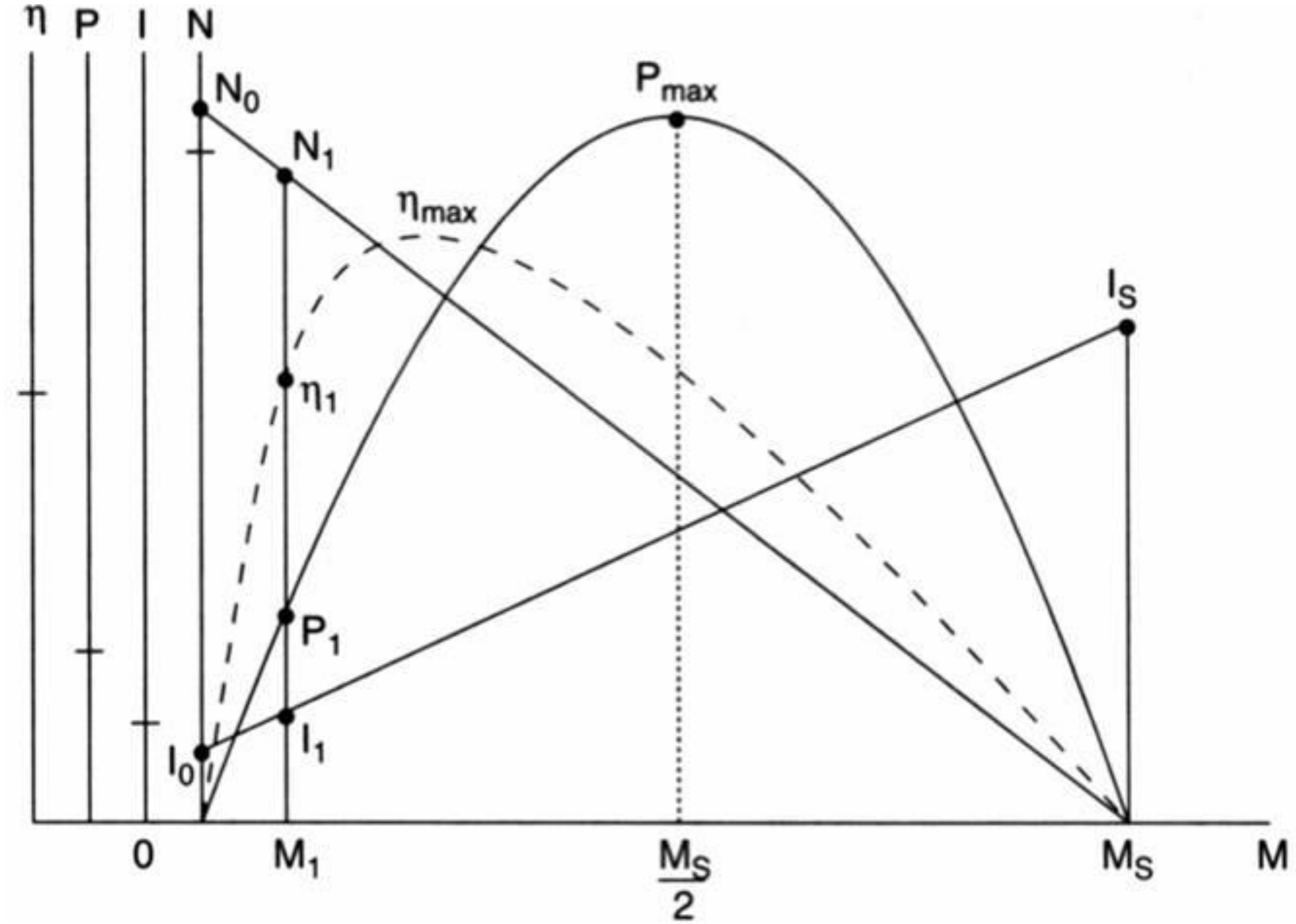
- Maximum efficiency: $\eta = \frac{P_{mech}}{P_{el}}$
- Power output/input: $P_{mech} = M \cdot \omega,\ P_{el} = U \cdot I$
- Idle revolutions: $\omega_{max} = \frac{U}{k}$
- Idle current/current while blocked: I_0/I_S
- Maximum torque: $M_S = k \cdot I_S$
- Nominal voltage: $U = U_R + u_L$

Characteristics of DC Motors

- Motor is series connection of inductor and resistor
  - $U = U_R + u_L$
  - $U = I \cdot R + k \cdot \omega$
  - $U = \frac{M \cdot R}{k} + k \cdot \omega$
- Motor revolutions with load: $\omega = -\frac{M \cdot R}{k^2} + \frac{U}{k}$
- Idle revolutions: $\omega_{max} = \frac{U_{max}}{k}$
- Calculation of the output curve

$$P_{mech} = M \cdot \omega = -\frac{R}{k^2} \cdot M^2 + \frac{U}{k} \cdot M$$

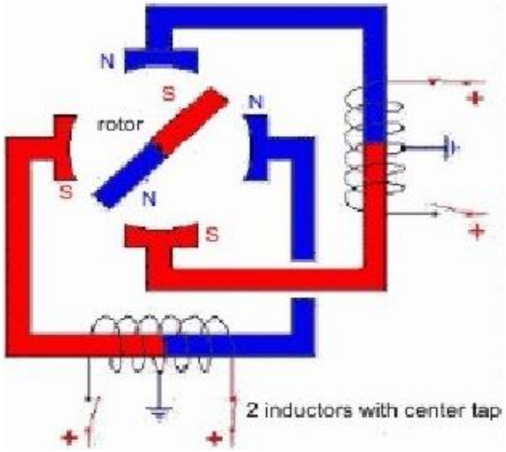
Characteristics of DC Motors



Current / power / efficiency characteristics of a typical DC motors

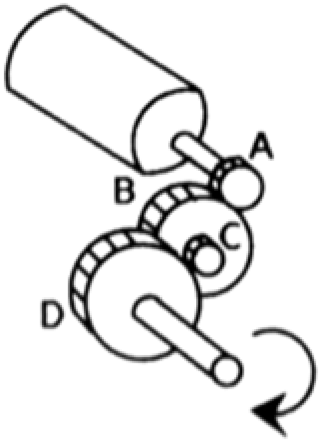
Stepper Motors

- $1.8°$ per step
- Switching of the inductor causes change in orientation of the magnetic field
- Rotor as permanent magnet
- $0.03\ \mathrm{Ncm} - 2500\ \mathrm{Ncm}$
- Diameter $6\ \mathrm{mm} - 110\ \mathrm{mm}$
- Revolutions $3000/\mathrm{min}$



Schematic diagram of stepper motors
(Source: wolfgang-back.de)

Transmissions

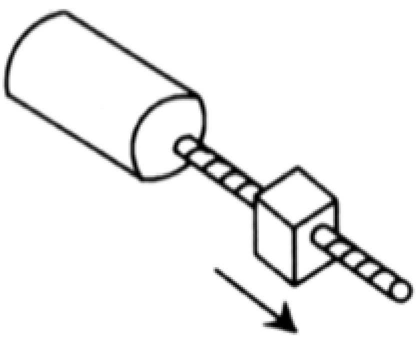


Spur gear

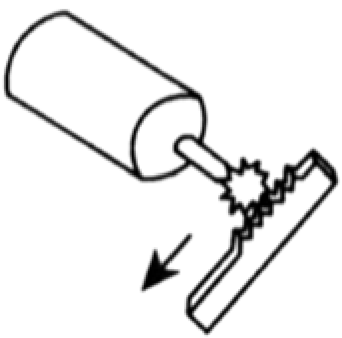
Planetary gear

Worm gear

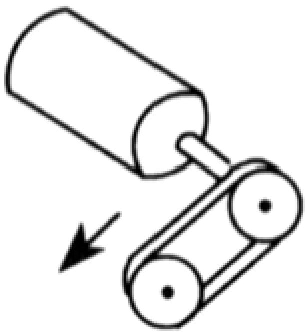
Harmonic drive



Lead screw and nut



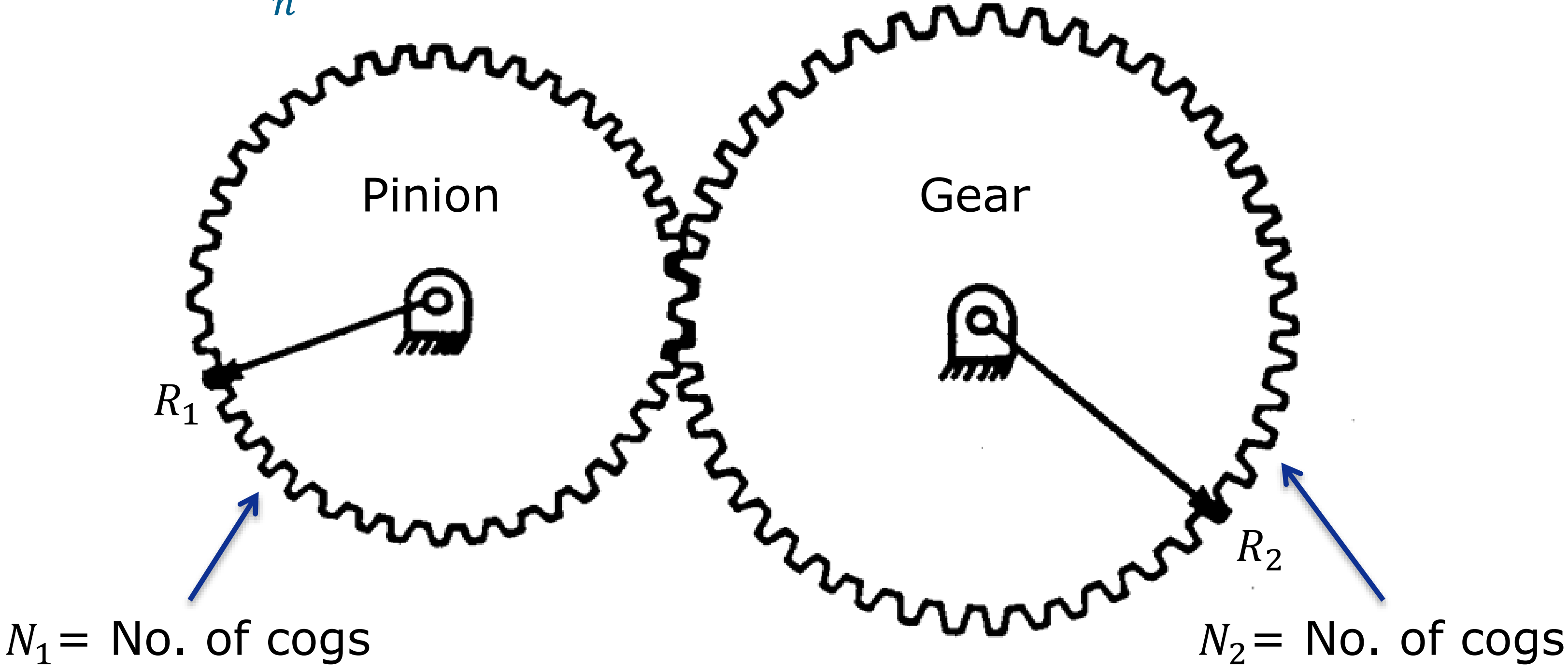
Rack and pinion gear



Belt- and pulley gear

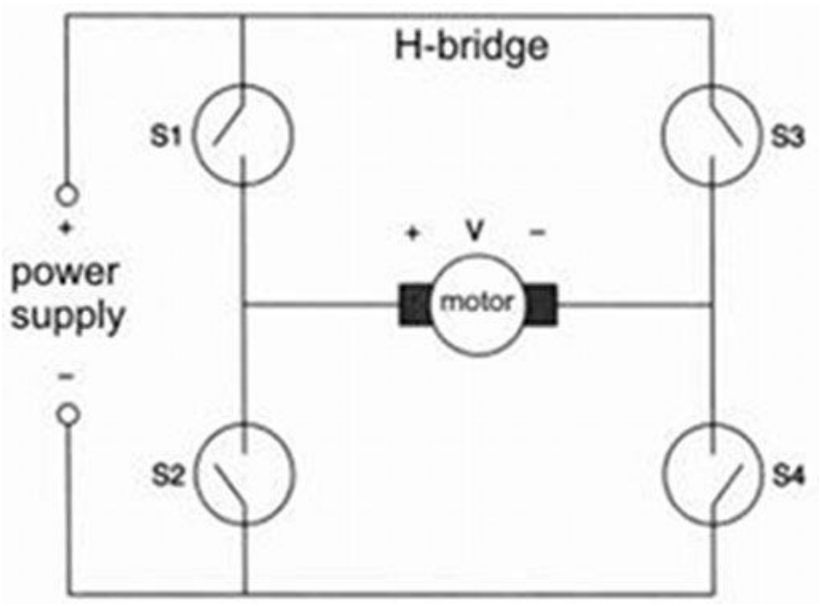
Spur Gear

- Gear reduction $n = \frac{N_1}{N_2}$
- Angular velocity $\Omega_2 = n\Omega_1$
- Torque $T_2 = \frac{T_1}{n}$



Power Electronics: Motor Control

- Direct control by micro controller not possible
- Micro controller only suited for small motors
- Power electronics required
- Use of H-bridge-circuit for control purposes



H-bridge-circuit

Power Electronics: Motor Control

- Elements of a H-bridge-circuit: relays of transistors
- Relay only switches on/off or changes polarization
- Transistors allow control of revolutions
- Transistor at partial load use causes high power loss

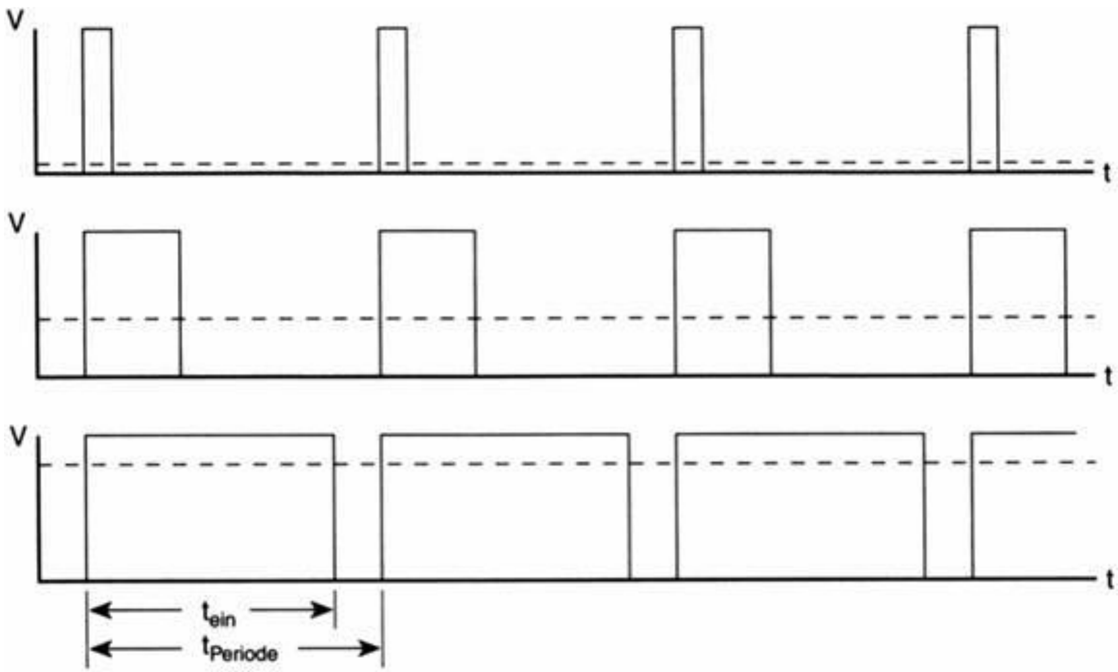
$$P_L = U_{voltagedrop} \cdot I_{motor}$$

- Power loss possibly even bigger than power output

Power Electronics: Motor Control with PWM

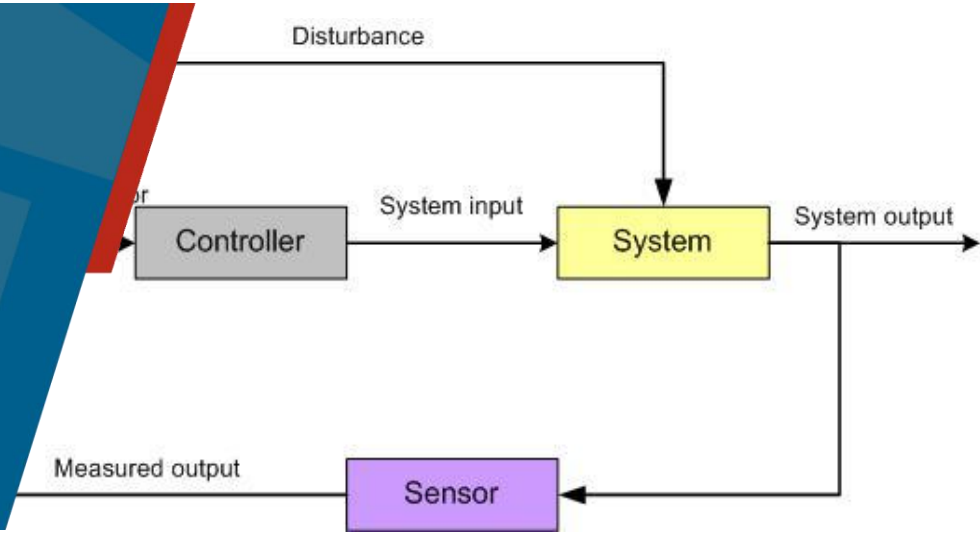
- Application of PWM
- Microcontroller or DSP
- Median voltage at motor

$$U_{motor} = U \cdot \frac{t_{in}}{t_{period}}$$

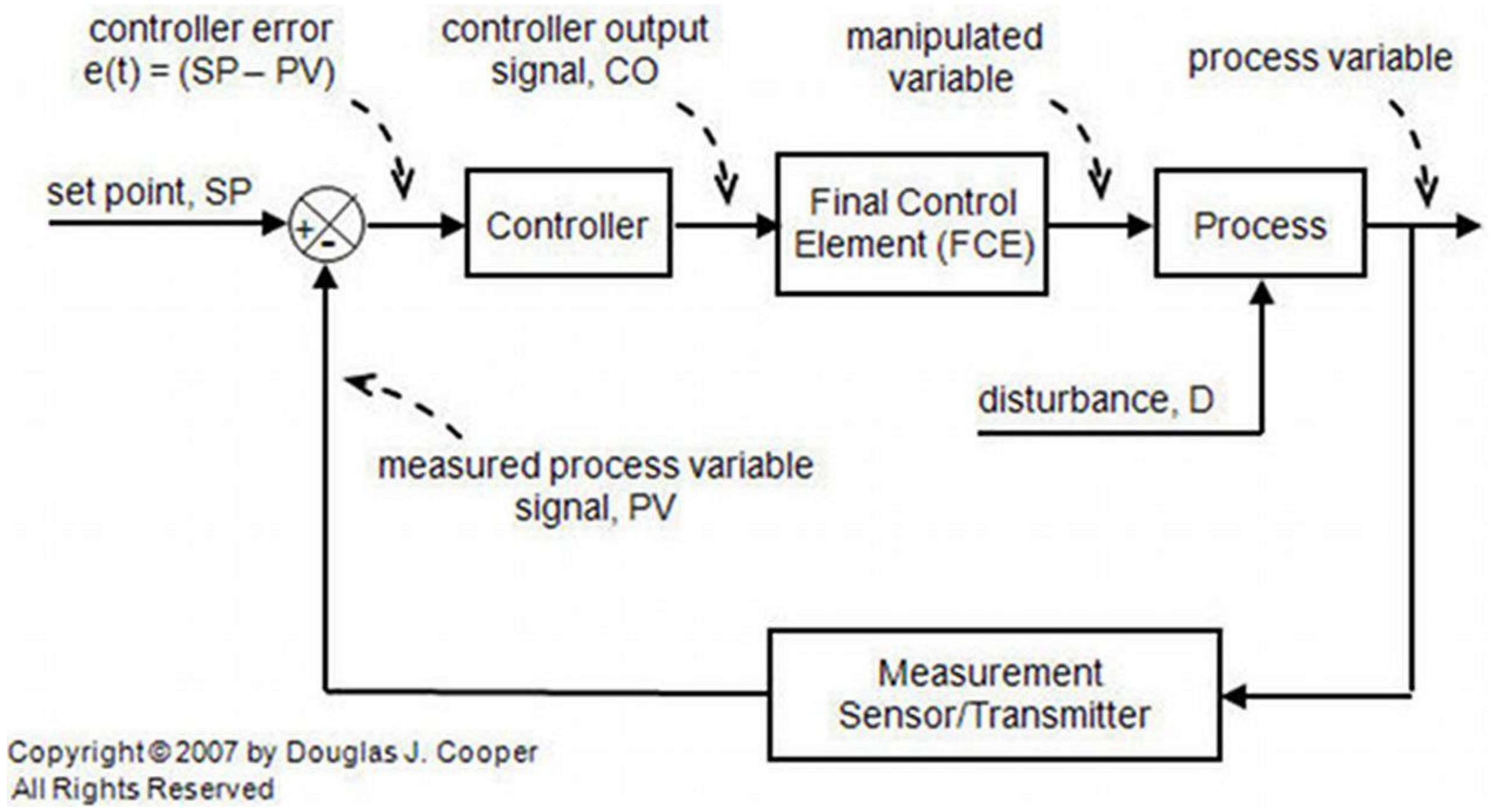


Pulse width modulation (PWM)

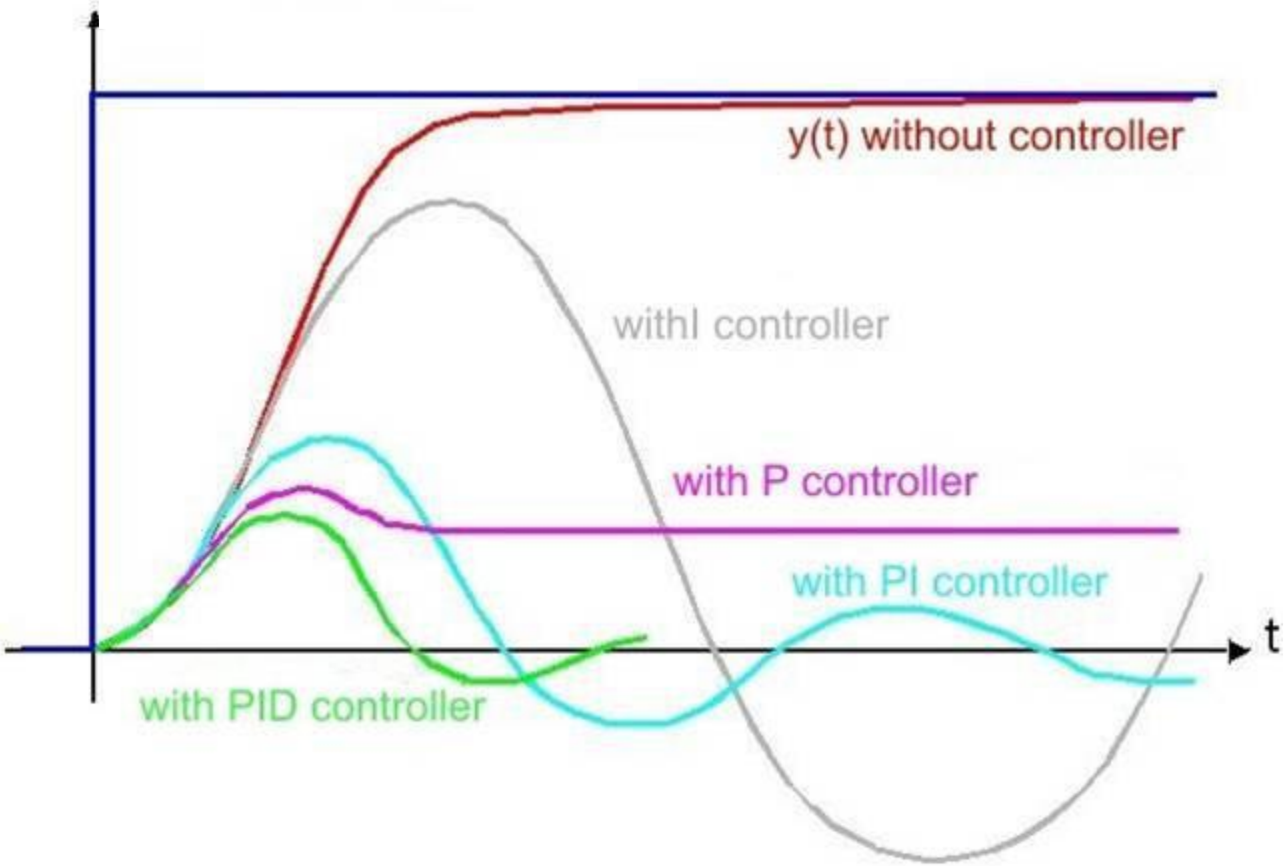
Closed-Loop Control



General Control Loop Block Diagram



Standard Controller Types

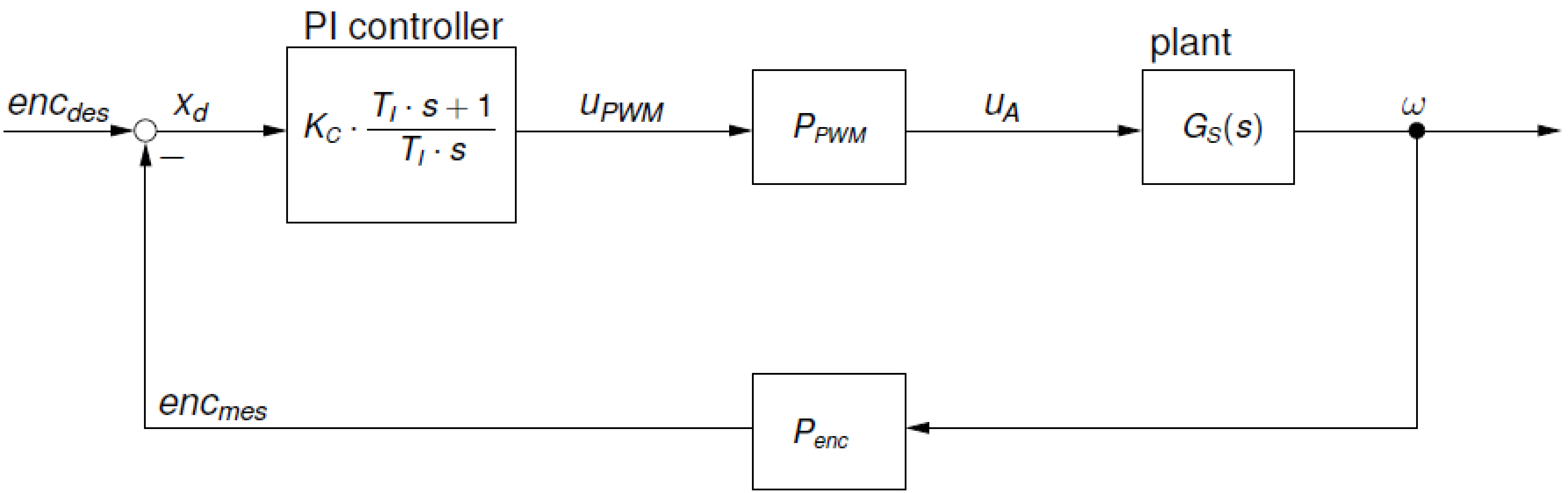


Standard Controller Types

Using of PI controller results in good steady state accuracy at lower complexity compared to a PID controller.

Control Loop with PI Controller and DC Motor Plant

$$G_{PI}(s) = K_C \cdot \frac{T_I \cdot s + 1}{T_I \cdot s}$$



Block diagram of the closed control loop with PI controller and DC motor as plant

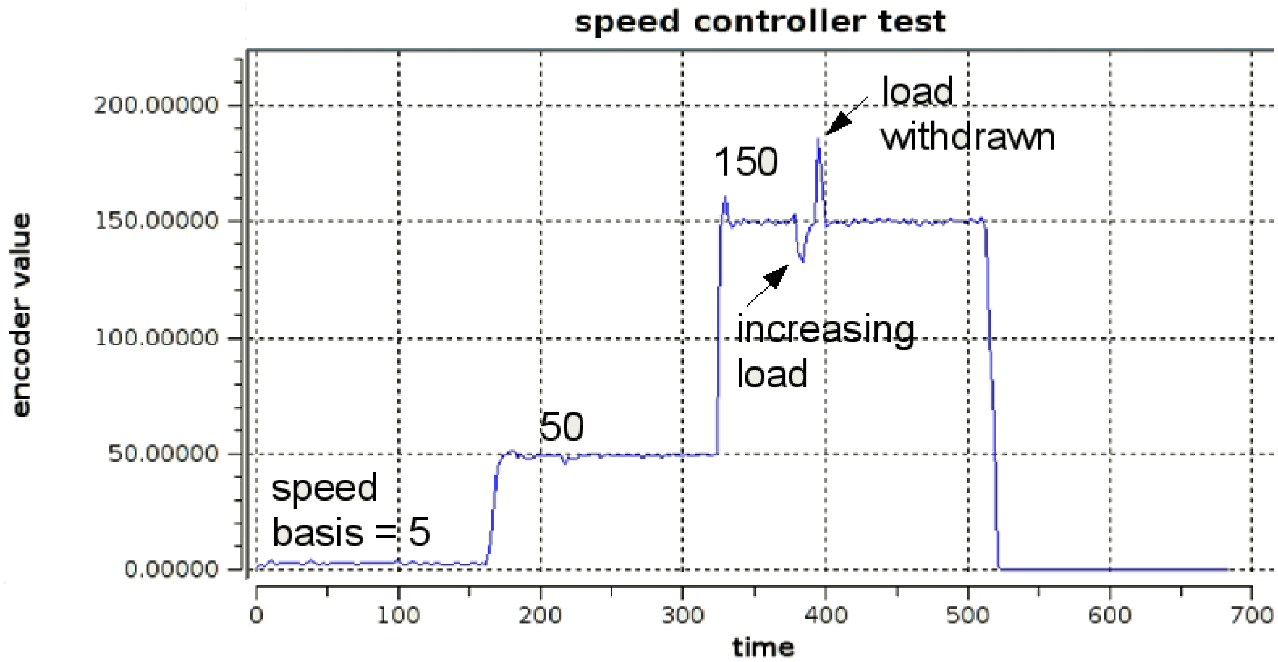
Goals and Attributes of a Closed Loop Control

Selection of controller type and calculation of its parameters for …

- Steady state accuracy: control difference vanishes for $t \to \infty$
- Speed: actual value follows desired value as good/fast as possible
- Stability: no instability of control system due to feedback of system output
- Robustness: small changes of parameters of the control plant do not change the properties of the control system
  $\rightarrow$ approximations for calculation of control parameters are feasible

Test of the Velocity Controller

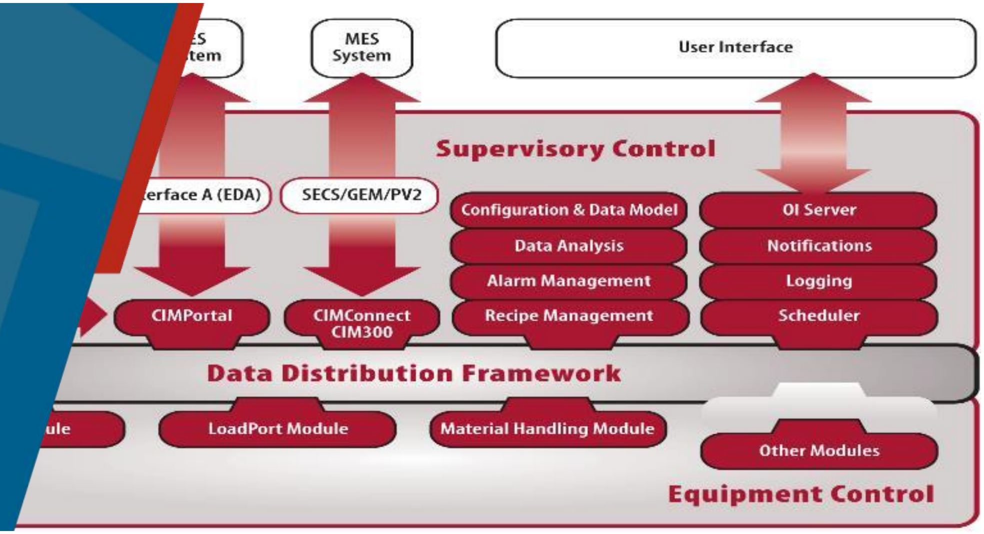
- Measurements in encoder values/ms
- Significant overshoots: controller not optimized since non linear motor characteristics



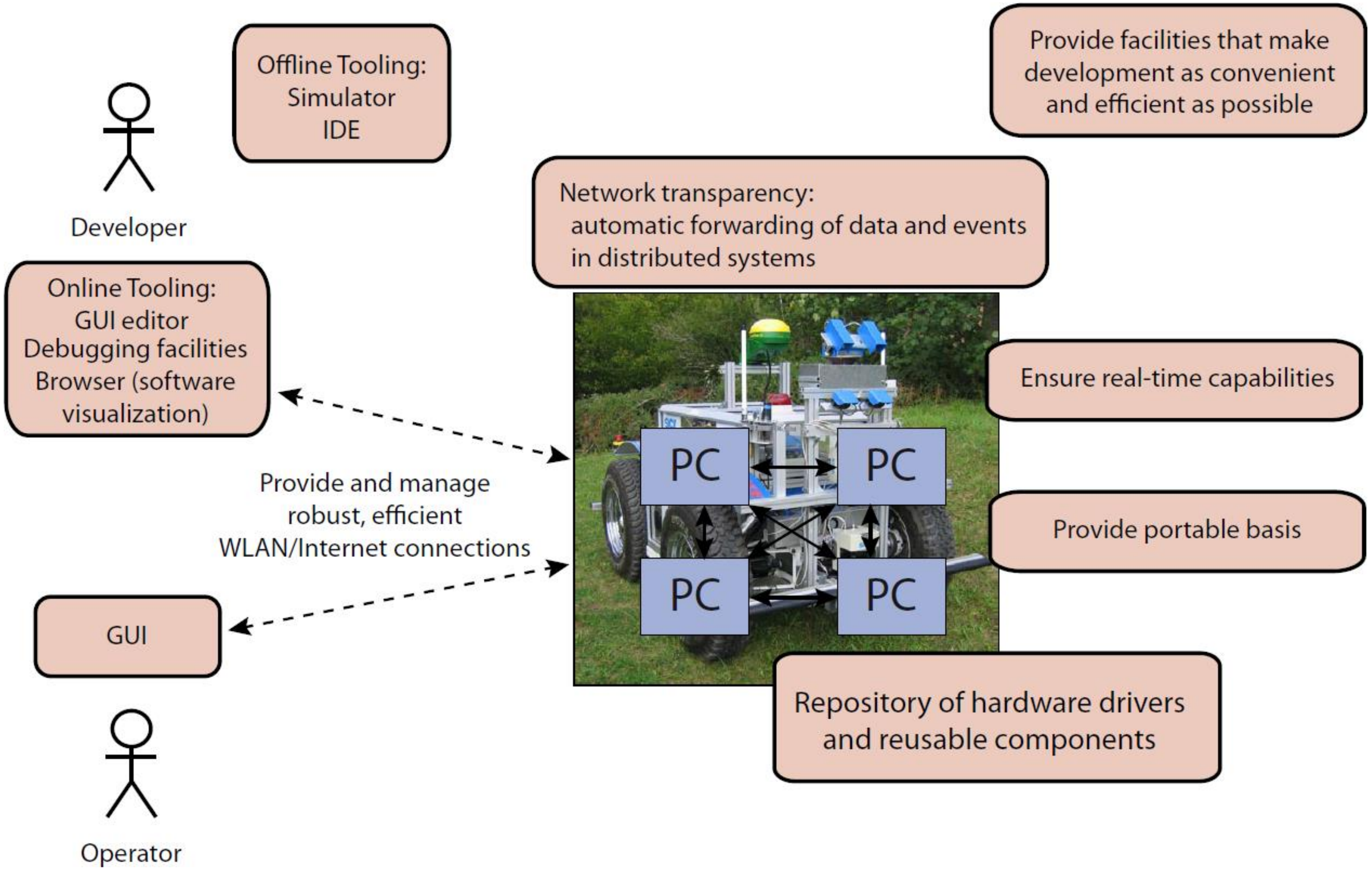
Reaction of the velocity controller on jumps at system input and on different disturbances

Applying Velocity Control to a Climbing Robot

Robot Control Software



Robotics Software Framework



Framework support in robotics software development

Various Challenges

- Inherent Complexity of application and environment
- Highly parallel and asynchronous nature
- Robustness and Reliability
- Distributed systems, Network communication
- Efficiency and Scalability
- Real-time requirements, ensure safety
- Changeability, Maintainability and Flexibility
- Software Reuse
- Interoperability, Portability

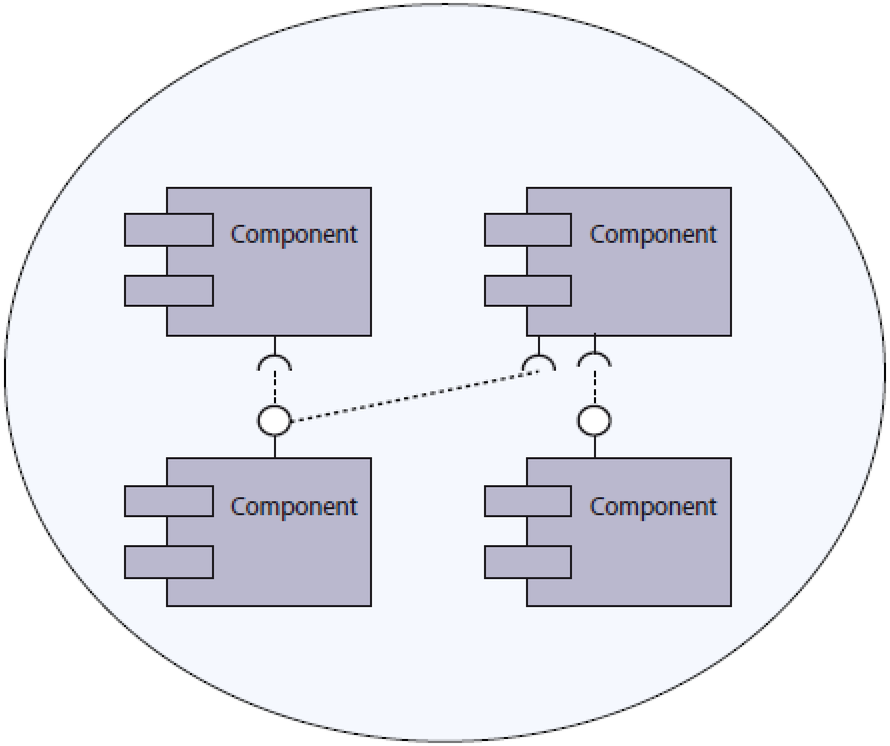
Robotics Software Development

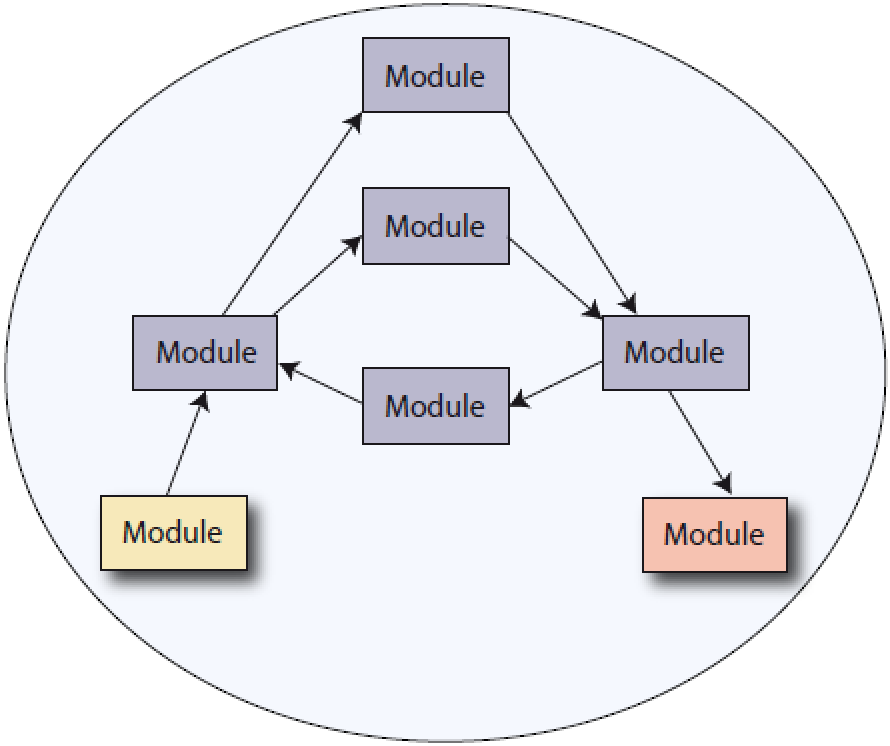
- Developing software for autonomous robots from scratch is difficult, time-consuming and error-prone
- Robotic frameworks provide facilities and tools to tackle many of the issues raised above
- Selected Framework has critical impact on development effort and software quality
- Many general-purpose robotic frameworks exist
  - No solution is clearly superior
  - Focus on different topics

System Decomposition and Overall Architecture

- How should a robotic application be structured?
  - Monolithic vs. Modular approaches
  - Monolithic typically more efficient
  - Modular more maintainable, flexible, and reusable due to clear separation of concerns
- Frameworks have modular architectures
  - Entities often referred to as Modules, Components, or Services
- Two major groups
  - Network Transparent Data Flow Graphs
  - Entities are nodes with connector-style interfaces
  - Entities have object-oriented interfaces

System Decomposition and Overall Architecture





Component-based and data-flow-oriented approaches

Simulation of AMRs

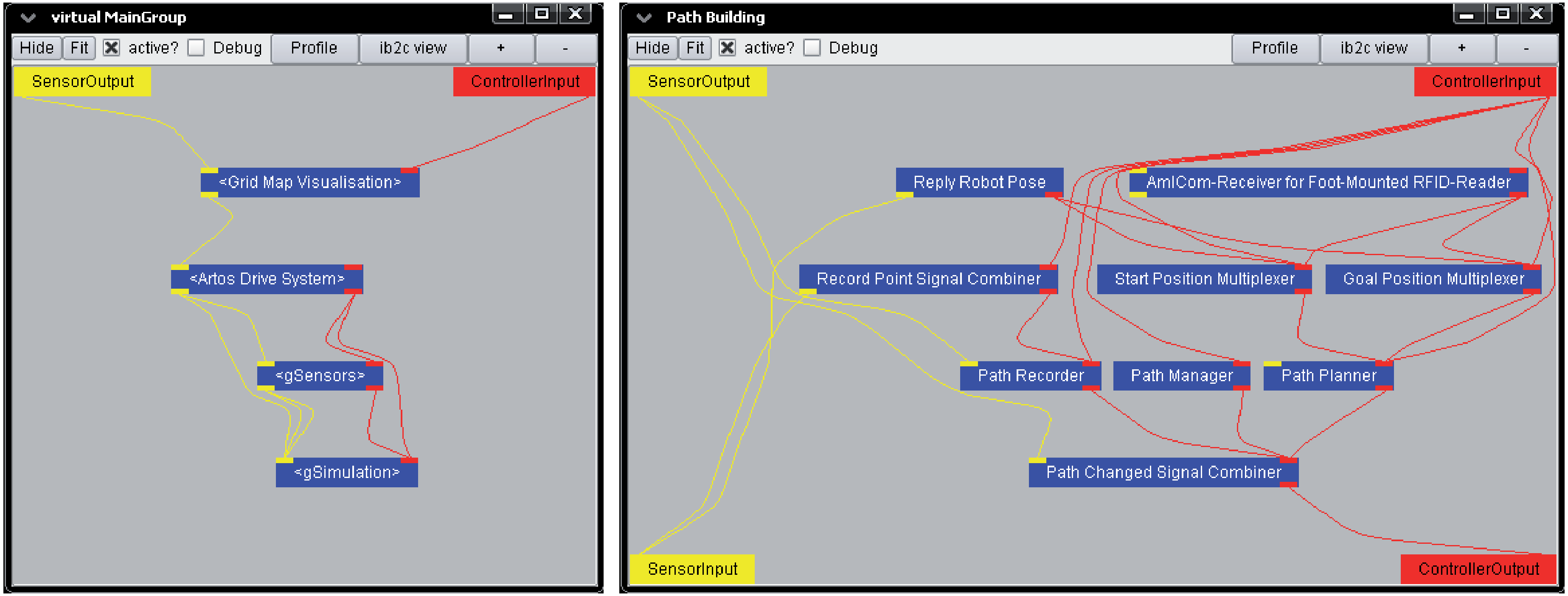
Road Construction Simulation of the B10 Highway
in the Unreal Engine

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

AMMCOA
Autonomous Mobile Machine
Communication for Off-Road Applications

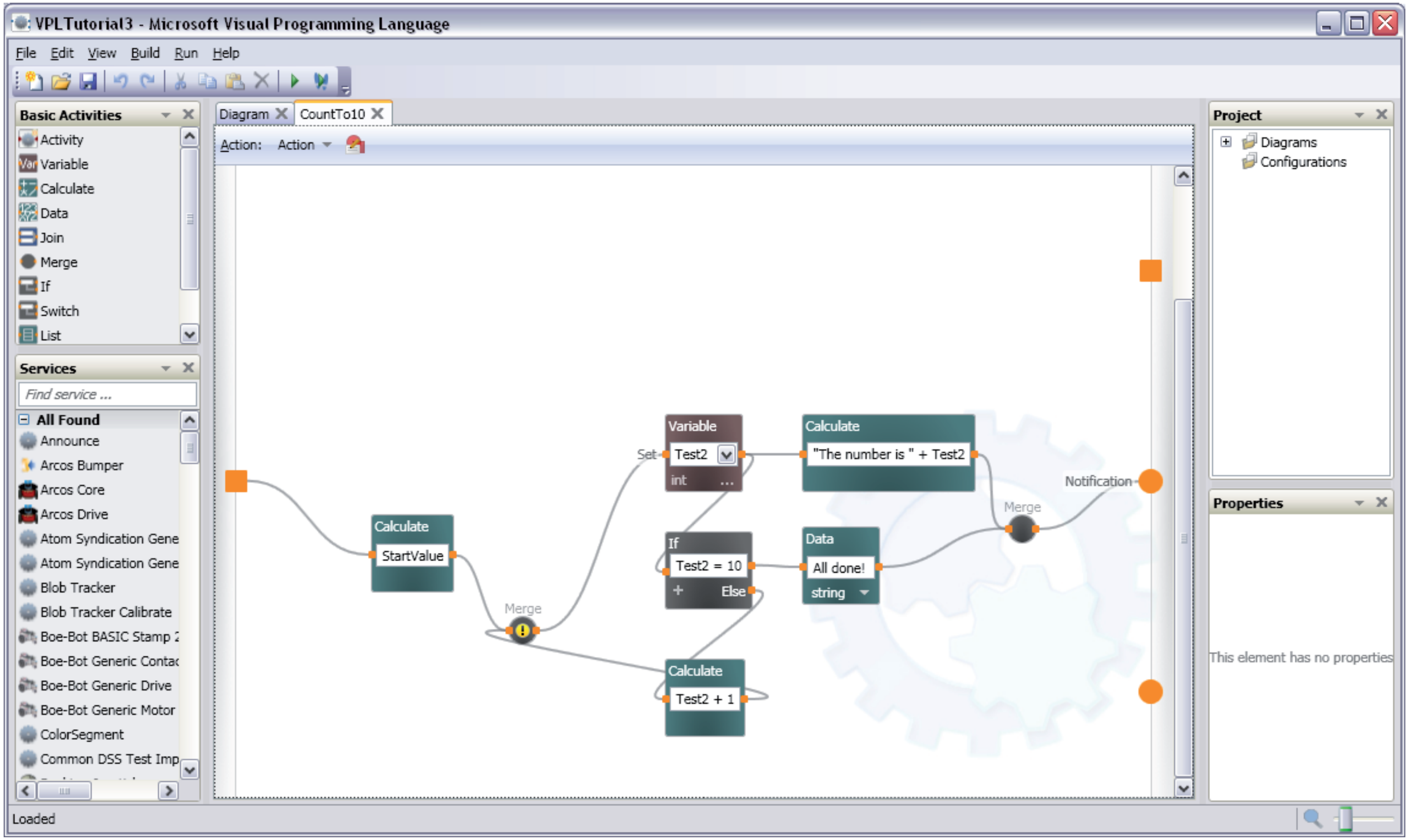
RRLAB
THE ROBOTICS RESEARCH LAB

Software Visualization



MCABrowser visualizing MCA2 application

Graphical Programming



Microsoft Visual Programming Language IDE

Coming Next

Sensor Systems