Einsatzgebiete künstlicher Intelligenz und Anwendung zur Steuerung von Erdbaugeräten

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Ozan Demir

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Hochschule Osnabrück – Baubetriebstage 2024

Einsatzgebiete künstlicher Intelligenz und Anwendung zur Steuerung von Erdbaugeräten

Agenda

- Der Bosch Konzern und die Rolle der Forschung
- Forschung bei Bosch, weltweite Aufstellung
- Unser Campus in Renningen
- Anwendungen und Beispiele von KI bei Bosch
- Die Arbeitsgebiete der Gruppe CR/AAS4 (Advanced Autonomous Systems, Robotik)

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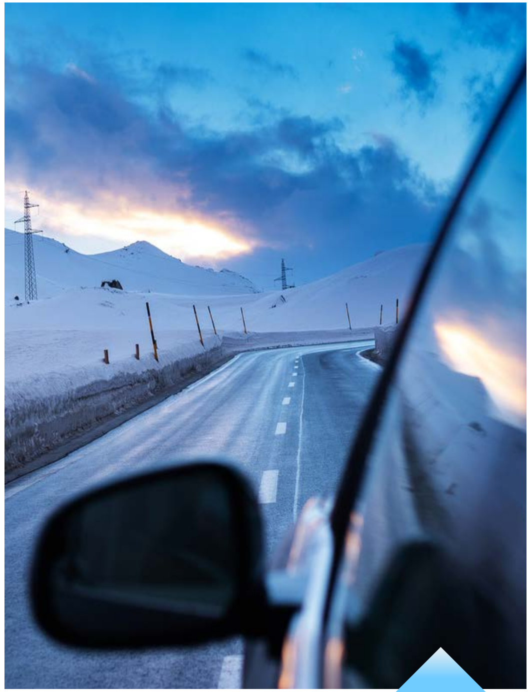
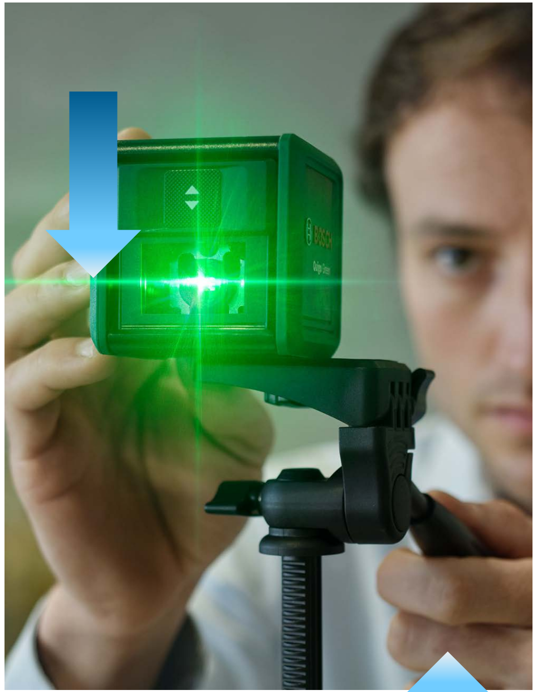
Who we are
Our business sectors



Mobility

Industrial Technology

Energy and Building Technology



Consumer Goods

Corporate Research (CR)

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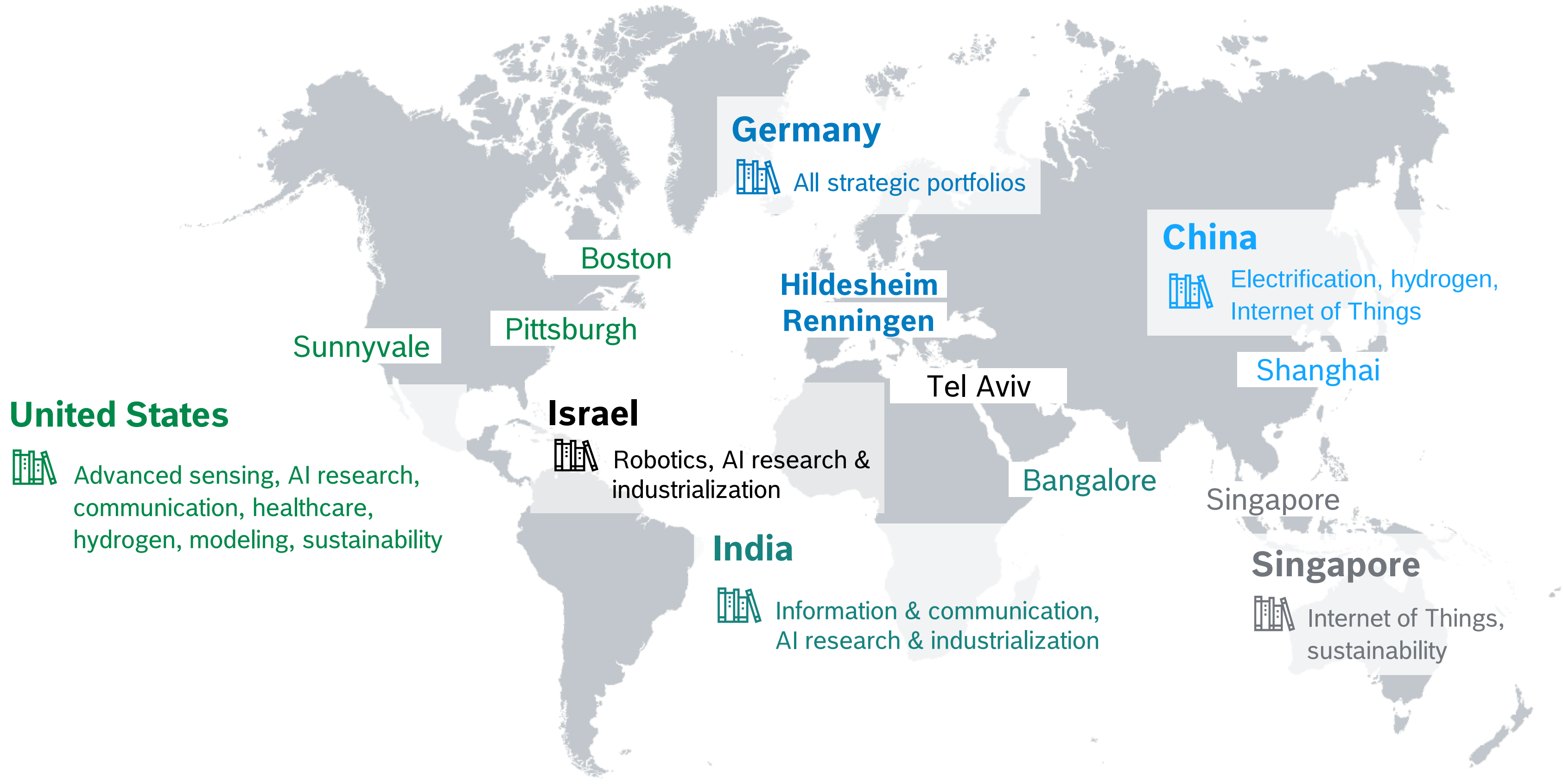
Bosch Research

Leveraging our international setup



Connect to the best

Connect to RB local

Local Tech markets

Regional economics & talents

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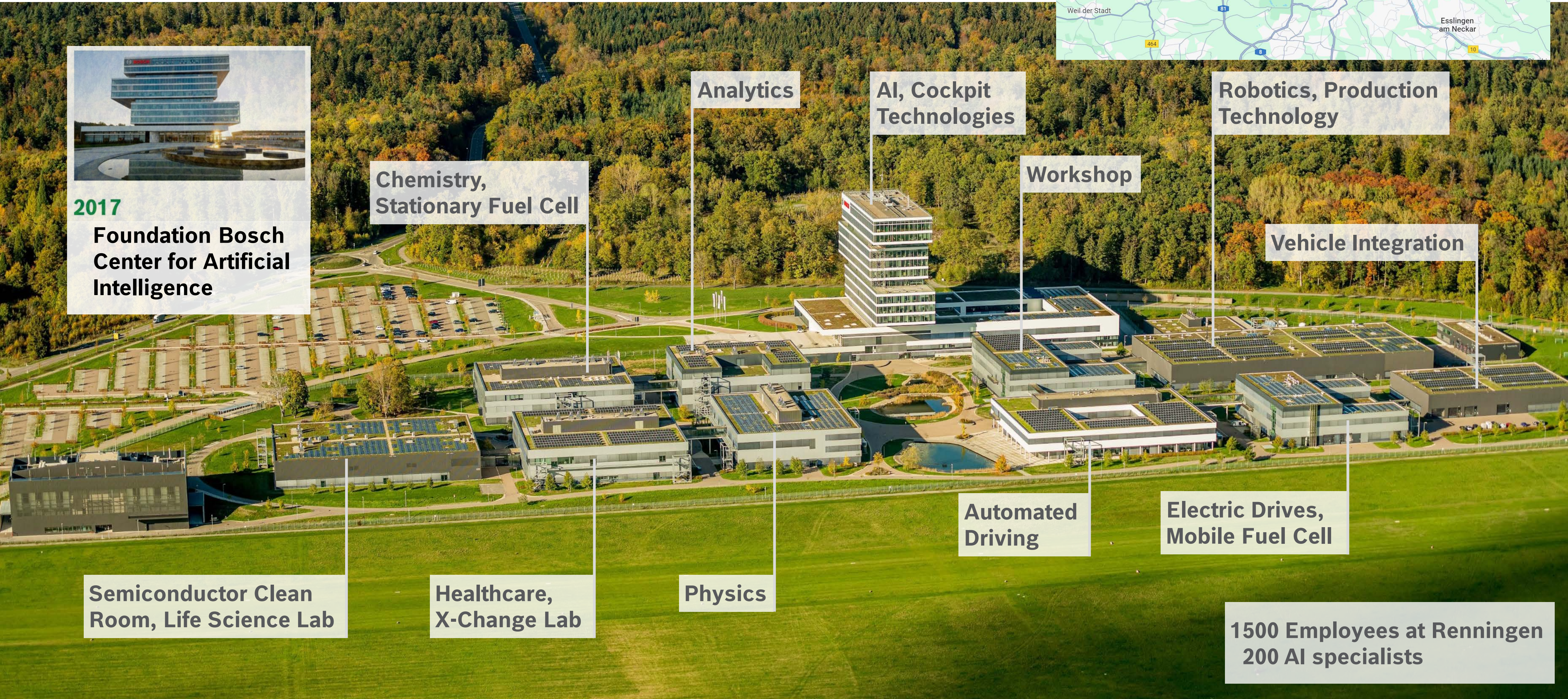
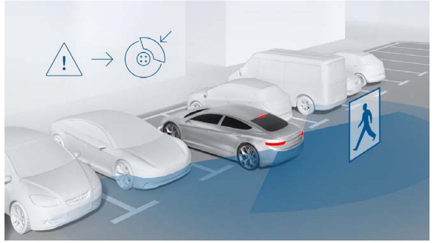
Renningen Research Campus
Facilities

2017
Foundation Bosch Center for Artificial Intelligence

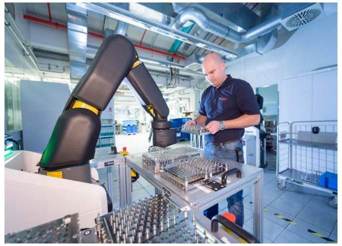


1500 Employees at Renningen
200 AI specialists

Application areas of AI at Bosch
AI-based Smart Products



Driver Assistance

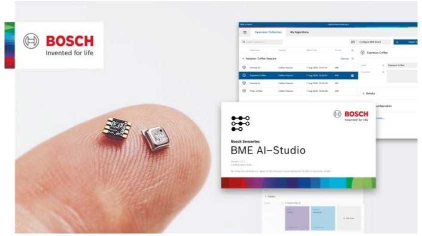


Industrial Robotics

Home Robotics

Video Surveillance

Smart Home



Smart Sensors

Vivalytic (Diagnostics)

Software-defined Vehicle

Search / Summarization
Make information accessible

Chatbots
Facilitate interaction with customers

Content Creation
Create high-quality documents, automatize tasks

Software Development
Automate code generation

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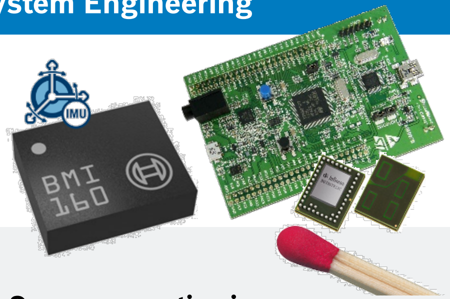
CR/AAS4: Sensing, Control & Motion
Topics and Competency

Sensors, Hardware, System Engineering



- **Sensor expertise in**

  GNSS, IMUs, Radar, Lidar, magnetic field sensors, mobile networks, etc.
- **Hardware and embedded software**

  Electronic design & test, low level drivers, Linux-enabled embedded systems, time-critical control applications
- **System Engineering**

  Design of complete robotic systems

Programming

3D-Renderings, Mechanical Design, Prototype Systems

- Design of **3D models** for robotic simulations (Blender)
- Construction and built up of mechanical components (CAD)
- Professional **3D-print** manufacturing
- Creation of **evaluation platforms**

Sensor data fusion

Behavior and Motion Planning, Navigation

- **Path and motion planning**, optimization and integration, including **multi-agent path finding**
- **Navigation** and behavior control in mobile robotics
- Focus: Navigation in **industrial environments**
  e.g. DC ActiveShuttle

e.g. obstacle avoidance

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CR/AAS4: Sensing, Control & Motion
Topics and Competency

Autonomous driving
Test vehicle hardware

- **Control sub architecture** for autonomous driving with vehicles
- **Function development** of highly automated driving (HAD) features
- **System integration and testing**
- **HD-Map development**
- **Vehicle setup**

  Sensor and Hardware integration

Sensor data fusion

Applied AI for Offroad Machinery & E-Mobility

- **Hybrid** and **data-based models**
- **Neural** Ordinary Differential Equations (**ODE**) for hybrid modelling
- Efficient Design of Experiment (DoE) & **Safe Active Learning**
- **Online learning** / adaptation of data-based controllers
- **Scalability:** Transfer functions to different systems & domains

Control engineering

Manipulation and Control, Grasping, AI Based Methods

- **Control stack** for industrial robot arms
- Own AI-based software stack including **AI grasping**
- **Smart Item Picking** (SIP) for warehouse automation
- **Visual learning**

Obstacle detection

Learning Hybrid Models for Smart Working Machines

Ozan Demir, CR/AAS4, 23.02.2024

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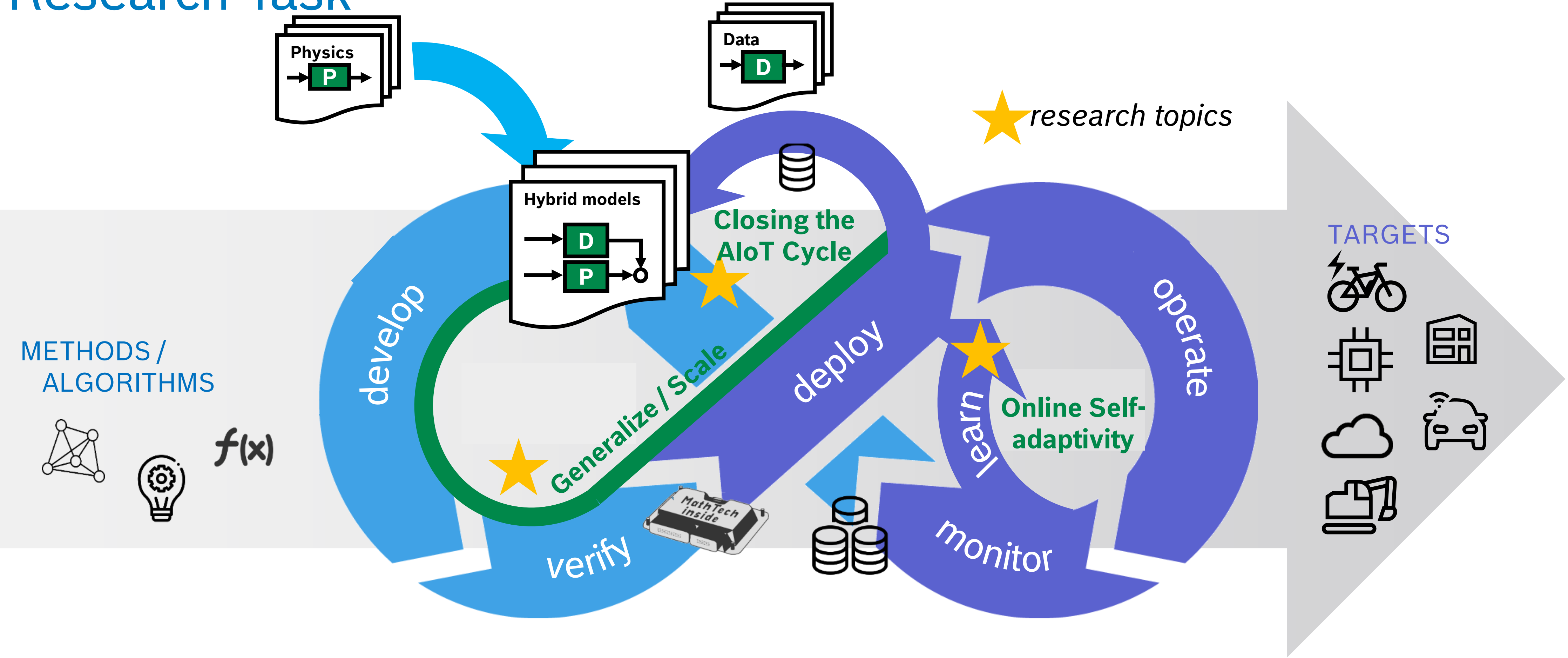
Learning Hybrid Models for Smart Working Machines
Research Task



Boost intelligence to create Self-Adaptive AIoT Products

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Agenda

- Research Task: Create Self-Adaptive Products
- Lead Application: Learning Control for Mobile Machinery Assistance Functions
- Problem Setup & System Structure
- Research Questions:
  - DoE
  - Training Data-Based Controllers
  - Controller Design using Data-Based Models
  - **Online Adaptation of Data-Based Controllers**

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Learning Hybrid Models for Smart Working Machines
Motivation

Challenges:

- High requirements on assistance functions
- Complex and highly-nonlinear system dynamics
- Systems with unknown (non-Bosch) components
- Production tolerances, environmental effects, aging
- Low volume & high mix domain

Tasks:

- Reduce the time to apply the control strategy on a new machine
- Reduce the calibration effort for different variants of the same machine
  - Online fine-tuning on the target device
- Providing tools for better usability and reproducibility of the learning pipeline

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Learning Hybrid Models for Smart Working Machines

Link to Video:
YouTube
BoschTube

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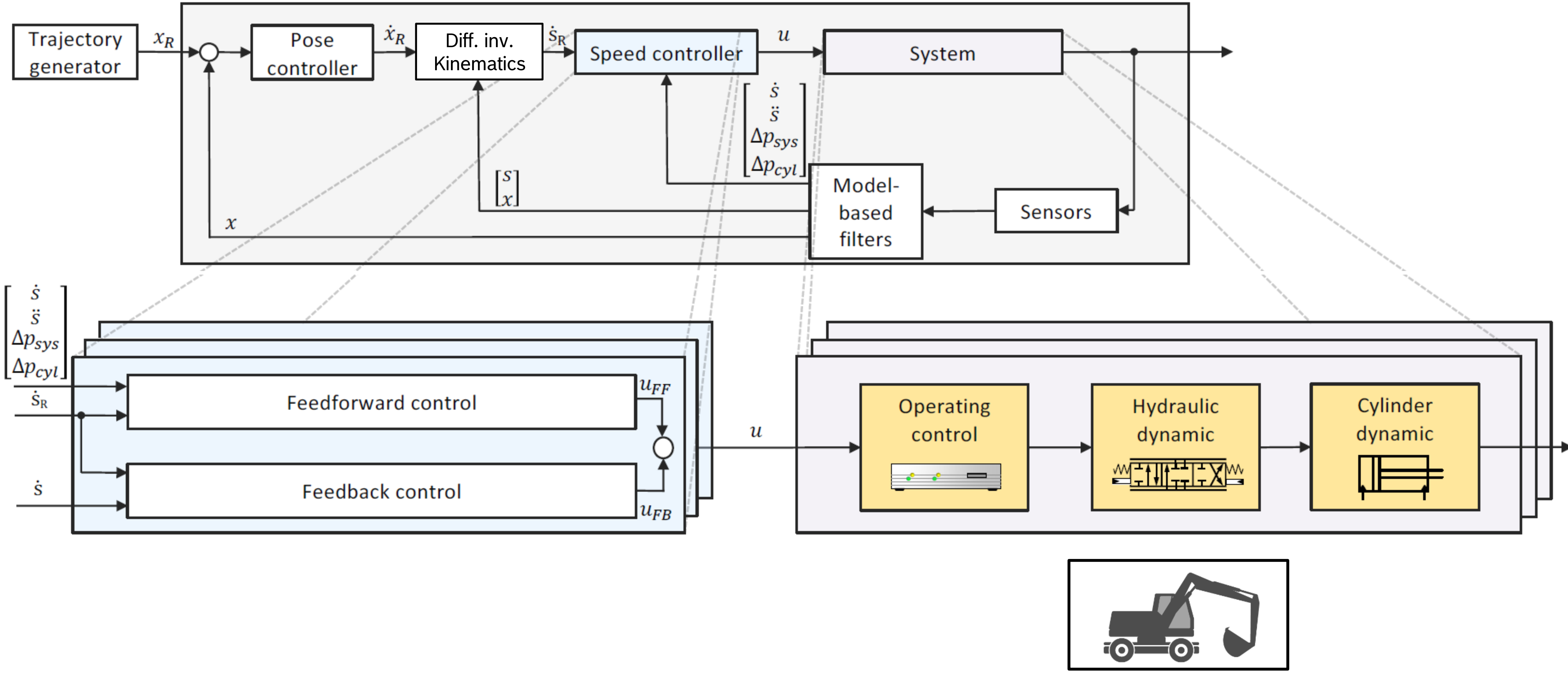
Learning Hybrid Models for Smart Working Machines

System Structure



CR/AAS4 | 23.02.2024

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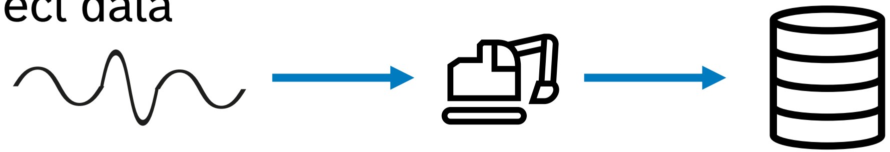
Learning Hybrid Models for Smart Working Machines

From Data to Control – 2 approaches

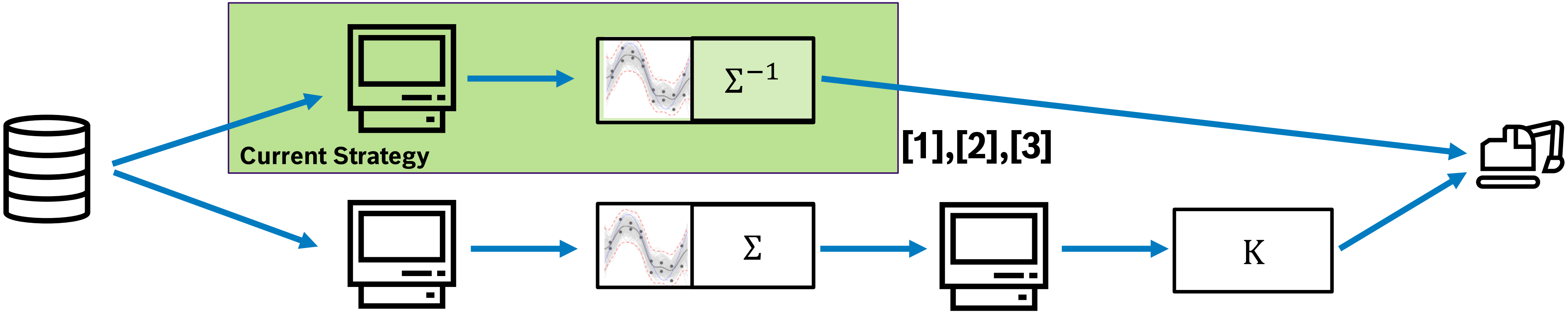
1. Collect data



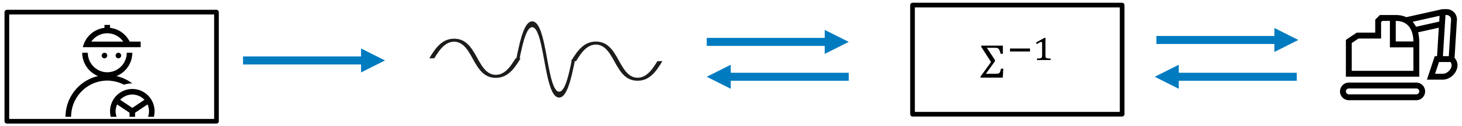
Trajectories can be generated:

- Randomly (Multi-Sine, A-PBRS)
- Using active learning **[4]**

2. Learn controller



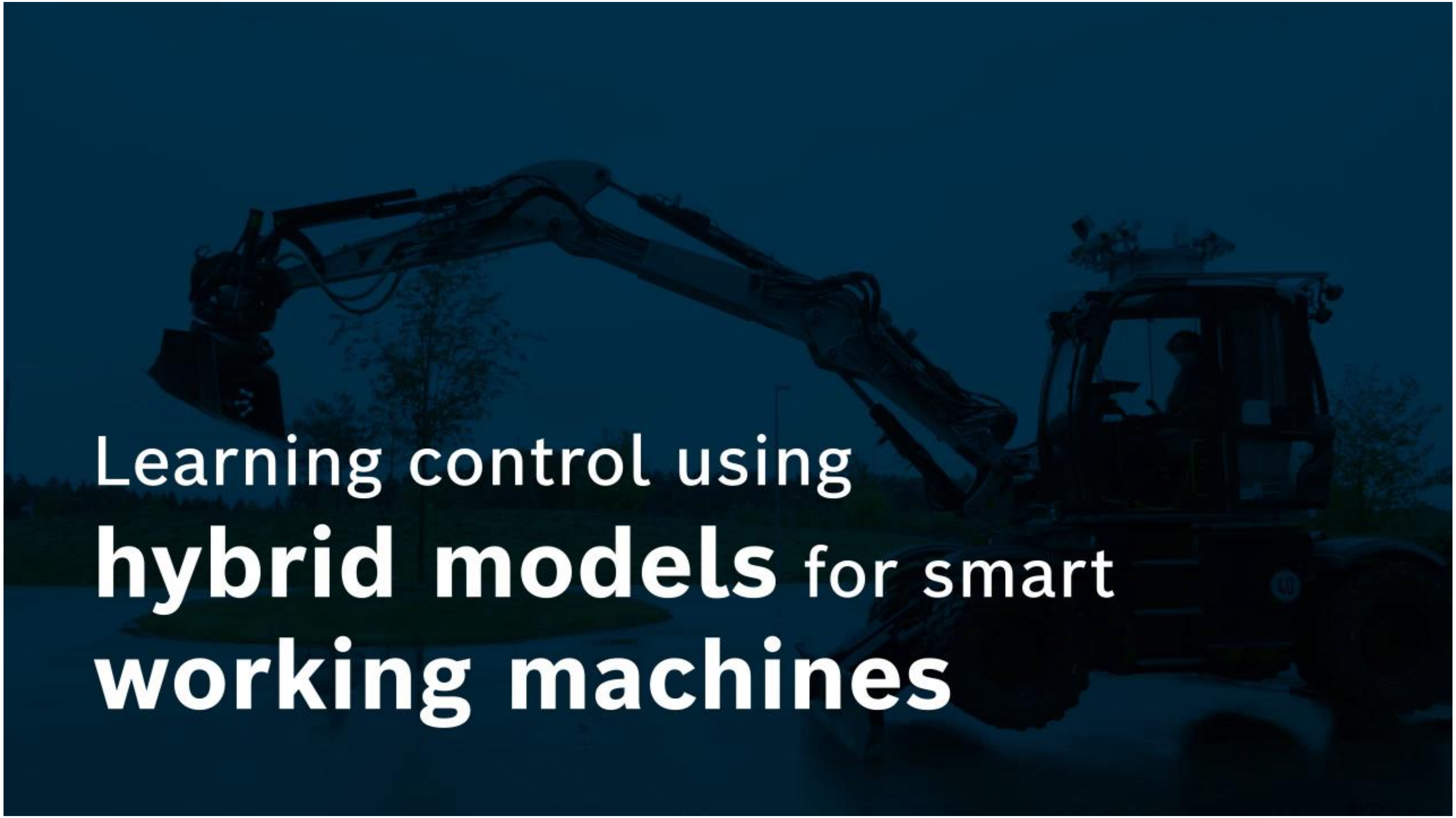
Update / Adjust nominal controller (Online)



Learn on the embedded device with online data.

[5]

Learning Hybrid Models for Smart Working Machines



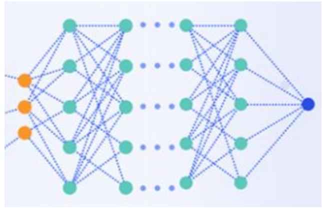
Link to Video:
YouTube
BoschTube

Learning Hybrid Models for Smart Working Machines

Solution approach (I): Learning a hybrid controller

- Replace model-based hydraulics-controller with AI model
  → **hybrid control structure**

- Training pipeline:
  - collect 2-3h of data
  - train data-based models on PC
  - write back to embedded SW



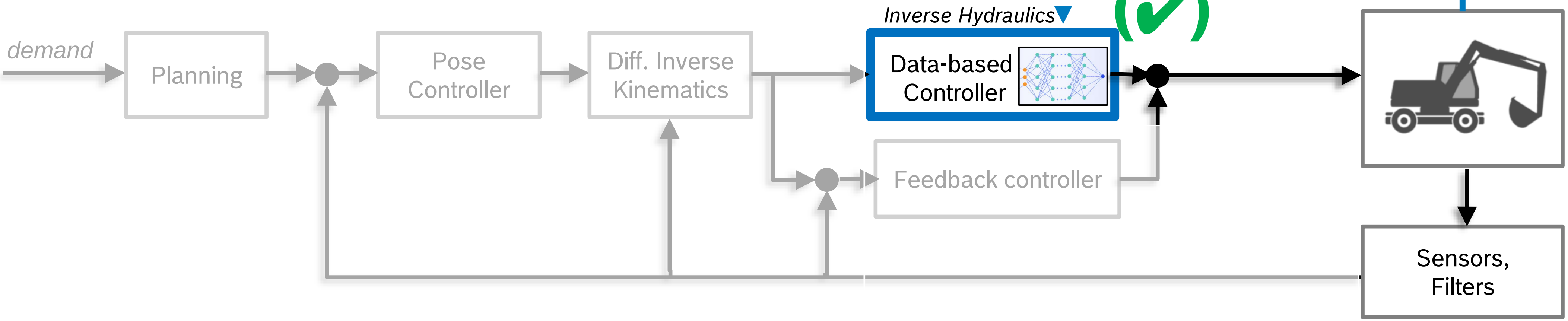
State-of-the-Art AI-model (Deep neural network)

Effort:

5-20h

per iteration; not suitable for
- fast engineering iterations ϟ
- EoL calibration ϟ
- aging compensation ϟ

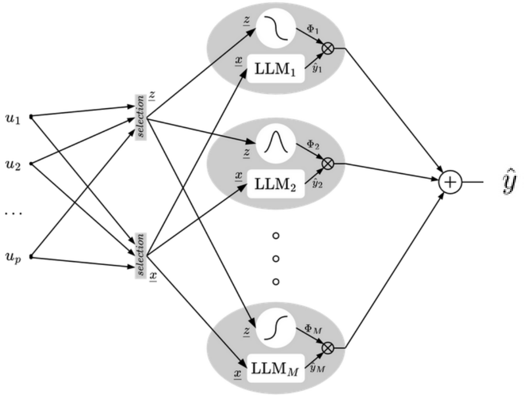
On-device training required!

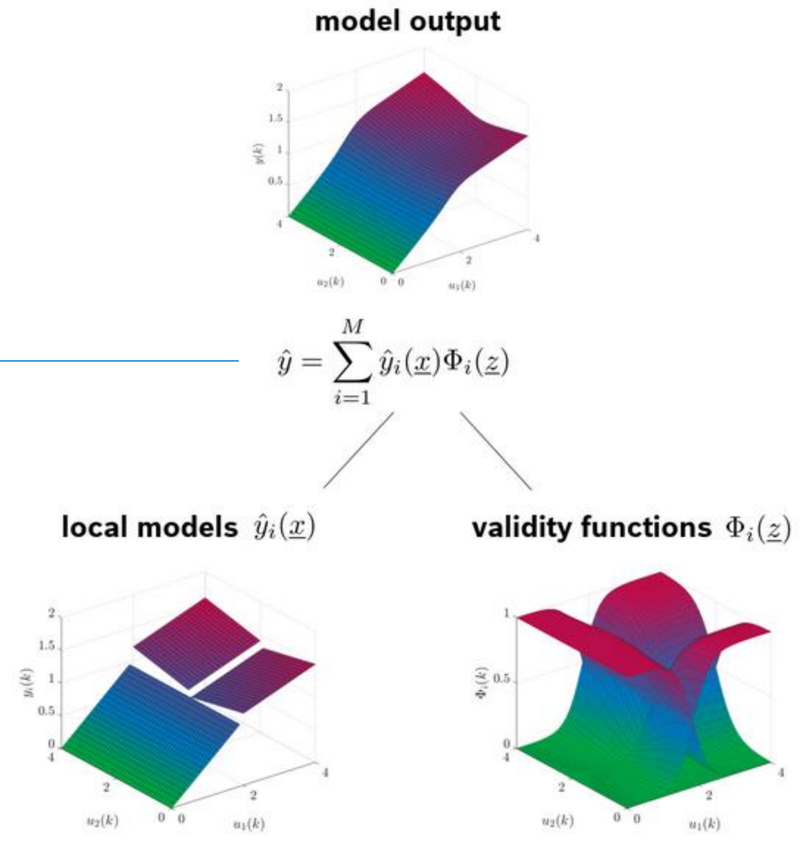


Learning Hybrid Models for Smart Working Machines
Solution approach (II): Online Learning (Adaptation)

Challenges for on-device learning:

- **Limited resources** (memory, computation)
- **Classical machine learning approaches not possible** (high-dimensional optimization problem)





Solution:

- **Adaptive control** using "**Local model networks**"
- Two-stage learning:
  - Offline: **input space partitioning** (validity functions), incorporation of expert knowledge possible
  - On-device: **recursive adaptation** of local models weights

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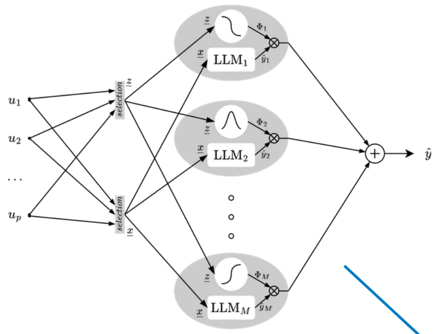
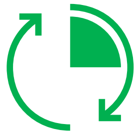
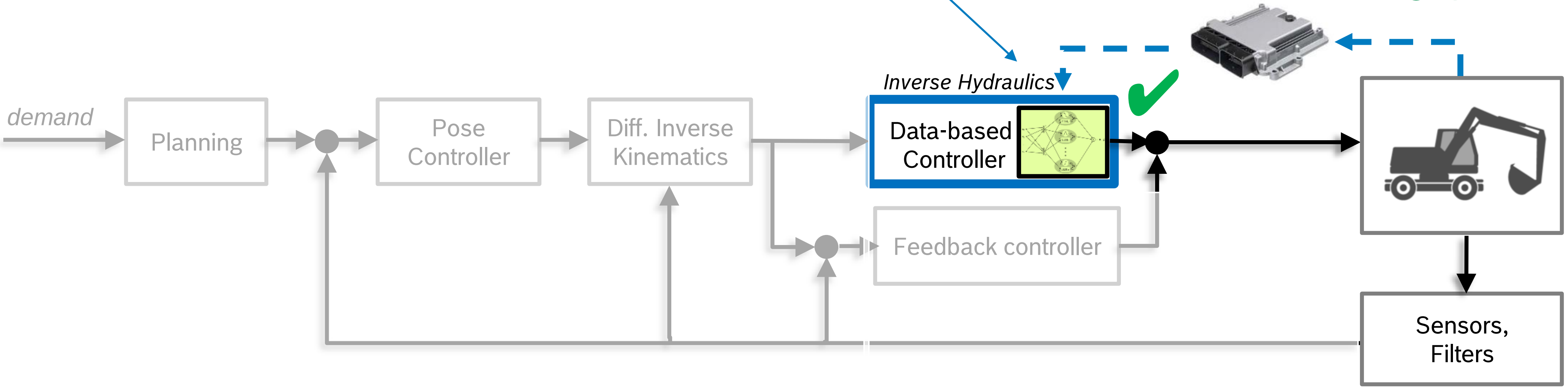
Learning Hybrid Models for Smart Working Machines
Solution approach (II): Online Learning (Adaptation)

Implementation of local model networks and online adaption





Effort: ✔
minutes
training on ECU during operation



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Learning Hybrid Models for Smart Working Machines
Further Work

[1] „Hybrid data-driven modelling for inverse control of hydraulic excavators," in Proceedings of the International Conference on Intelligent Robots and Systems (IROS), 2021, J. Weigand, J. Raible, N. Zantopp, O. Demir, A. Trachte, M. Ruskowski

[2] „Data-Driven Feed-Forward Control of Hydraulic Cylinders using Gaussian Process Regression for Excavator Assistance Functions", in Conference on Control Technology and Applications (CCTA), 2022, G. Rabenstein, O. Demir, A. Trachte, K. Graichen

[3] „Learning Based Feed-forward Control for Advanced Excavator Assistance Functions", in Int. Fluid Power Conference (IFK), 2022, O. Demir, B. Ehlers, F. Bender, A. Trachte

[4] "Safe Active Learning and Probabilistic Design of Experiment for Autonomous Hydraulic Excavators", in Proceedings of the International Conference on Intelligent Robots and Systems (IROS), 2023, M. Dio, O. Demir, A. Trachte, K. Graichen

[5] "Online Learning of Cylinder Velocity Controllers for Excavator Assistance Functions using Local Model Networks", in Int. Fluid Power Conference (IFK), 2024, O. Demir, B. Hartmann, N. , F. Bender, B. Ehlers, M. Mehren

Thanks for your interest!