Fraunhofer IOSB-INA

Dr. Holger Flatt, CIIT-Techtalk, 30.09.2022

Intelligente Sensorsysteme in der Smart Factory und Smart City – Technologien, Herausforderungen und Praxisbeispiele

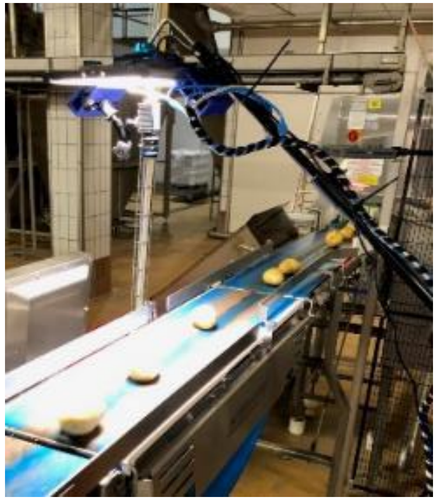
Smart Sensor Systems in Smart Factory and Smart City

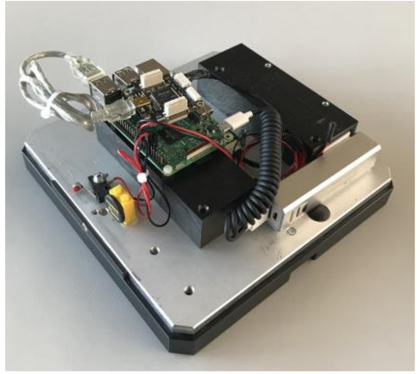
Agenda

- Introduction
- Challenges, technologies, and application examples
  - Smart factory
  - Smart city
- Outlook
- Conclusions

Introduction

- In modern applications (e.g. Industrie 4.0 based) sensors and measurement technology are key elements for cyber physical production systems [1]
- E.g. quality plastics processing rely on the local environment as well as on their respective process data
- Smart sensor systems help to adapt processes dynamically to changing environmental conditions [2]



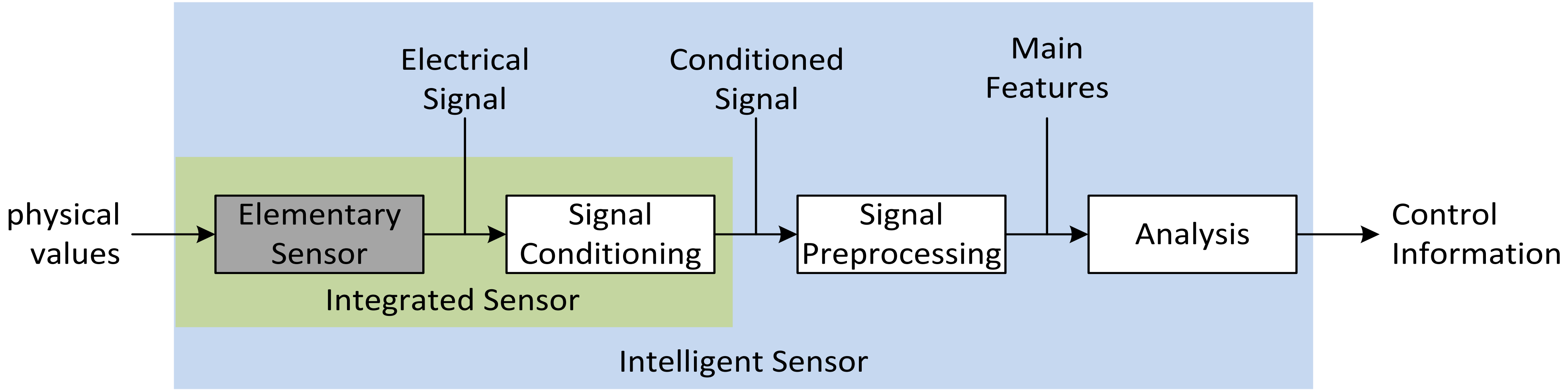


Matched combination of sensors and smart real-time data processing supports advanced sensor applications! [3]

[1] Imkamp, D. et al.: Challenges and trends in manufacturing measurement technology – the “Industrie 4.0” concept, J. Sens. Sens. Syst., 5, 325–335, 2016
[2] B. Schulte, H. Flatt et al.: „Automatisierte Qualitätskontrolle als Retrofit: Potenzialanalyse in realer Produktion“; 08/2022 ATP-Artikel
[3] Schütze, A. et al.: "Sensors 4.0–smart sensors and measurement technology enable Industry 4.0." Journal of Sensors and Sensor systems 7.1 (2018): 359-371.

Sensor Classification via Integration Levels

- Sensors convert different types of physical values into electric signals
- Different possibilities of sensor integration possible



- Intelligent sensors support the output of control information!

Sensor related Challenges in Smart Factories

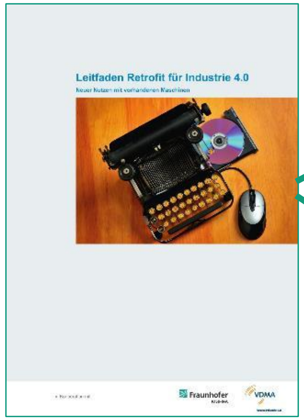
- Getting detailed and real-time energy transparency as fundament for plant optimizations
- No or limited access to sensor data of existing machines / plants
- Quick sensor implementations for existing plants (e.g. few hours)
- In-line measurement of difficult process parameters (e.g. moisture of plastic raw material)
- General Data Protection Regulation (GDPR) (e.g. if using video optical technologies or possibilities of measuring worker performance)

Example: raw material storage for plastic processing with moisture measurement

Technologies for Addressing Sensor Challenges in Smart Factory: Retrofit

- Possible approach for Industry 4.0 Retrofit:

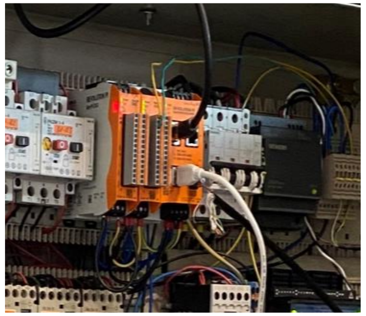
Demand



Initial analysis (e.g. checklist [4])

Data acquisition for potential analysis

Real-time data visualization and potential analysis using open source technologies*



Permanent installation

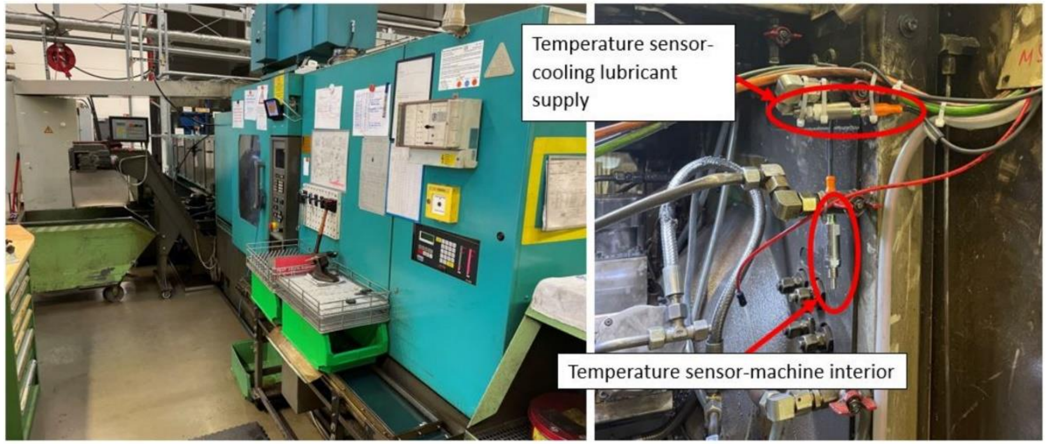
- Proprietary solutions market available vs. open-source technologies without vendor lock-ins
- Still hard to get access to special hidden processes (e.g. coating chambers)

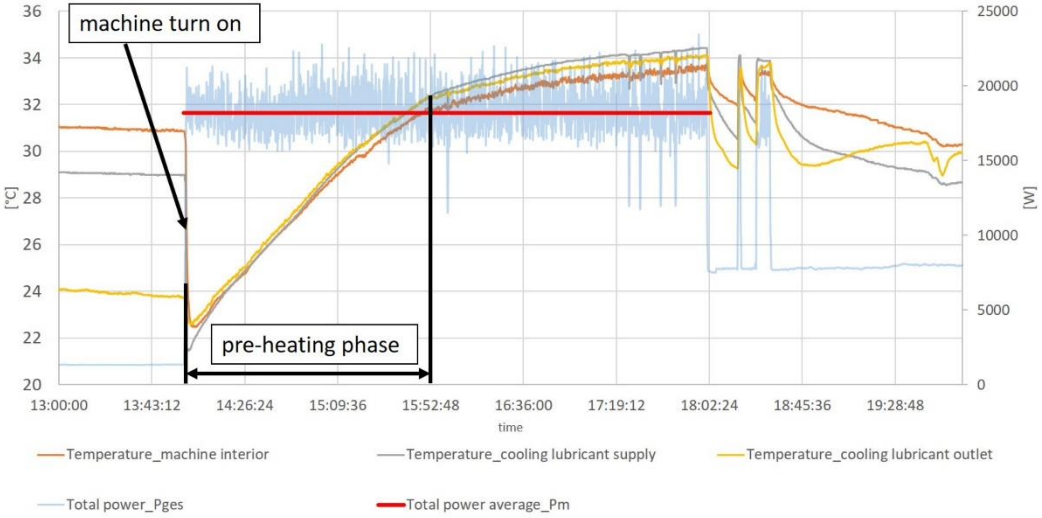
* e.g. Influx DB, Node Red, Grafana

[4] Friesen, Andrej; Flatt, Holger; Jasperneite, Jürgen: Guideline Retrofit for Industrie 4.0 - New benefits with existing machines. In: VDMA Forum Industrie 4.0, Frankfurt am Main, 2021

Technologies for Addressing Sensor Challenges in Smart Factory: Energy

- Energy optimization as important use case
- Example: Lathes and milling machines [2]
  - During pre-heating phase dimensions of work pieces do not fulfill requirements
  - Potential for using pre-heating phase for production in order to avoid waste of energy by smart machine control
- Outlook: Taking new interface standard for energy consumption data into account [5]





[5] PNO: „New Interface Standard for Energy Consumption Data". In: https://profinews.com/2022/06/new-interface-standard-for-energy-consumption-data/, 06/2022

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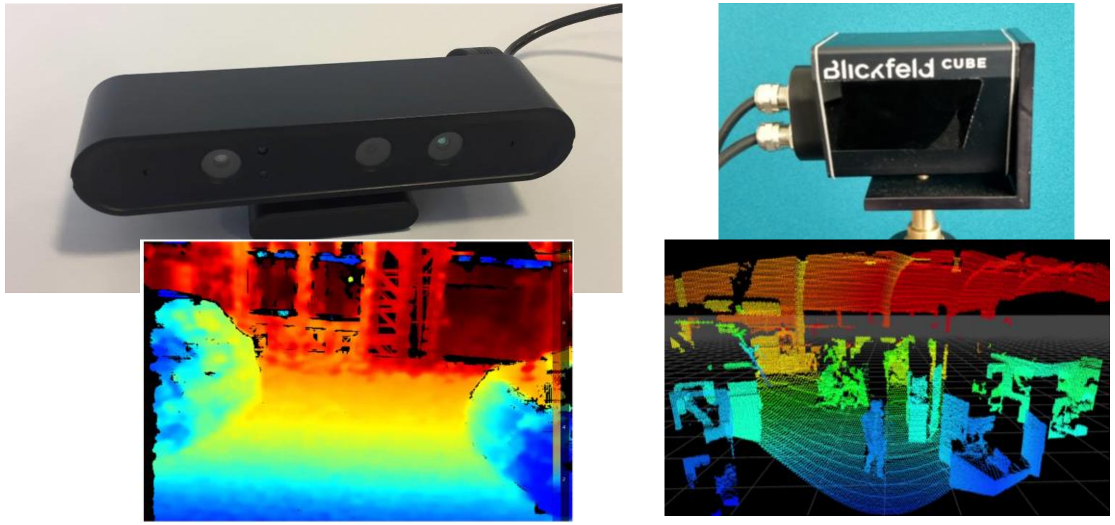
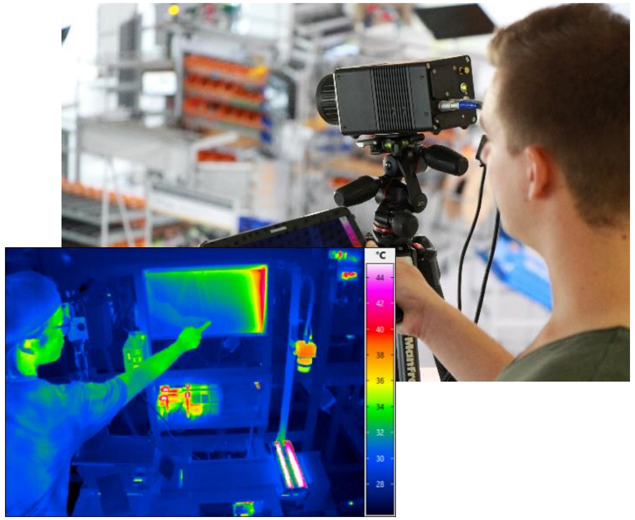
Technologies for Addressing Sensor Challenges in Smart Factory: Inspection

- Optical technologies as fundament for scene and object analysis:

Video-optical quality control



Depth camera and LiDAR sensors for scene analysis, e.g. safety



TIR camera for thermal anomaly detection

- Further technologies for advanced applications, e.g. hyperspectral sensors
- AI based real-time edge processing proposed for application development

Using Deep Learning as Technology for Object Detection: Overview

- AI-based approaches deliver the best results in object detection (e.g. [6], [7])
- Deep learning approaches to detecting objects are based on multi-layered neural networks (deep neural networks, DNN)
- Separation in two phases [8]:
  - Training: The training of the DNN using annotated data sets
  - Inference: The application of the DNN to previously unseen images

[6] Ren, S. et al.: "Faster R-CNN: Towards Real-Time Object Detection with Region Proposal Networks", Advances in neural information processing systems, 28, 91–99, 2015
[7] Bochkovskiy, A. et al.: "Yolov4: Optimal speed and accuracy of object detection"; arXiv preprint arXiv:2004.10934, 2020
[8] Goodfellow, I. et al.: "Deep Learning", MIT Press, 2016

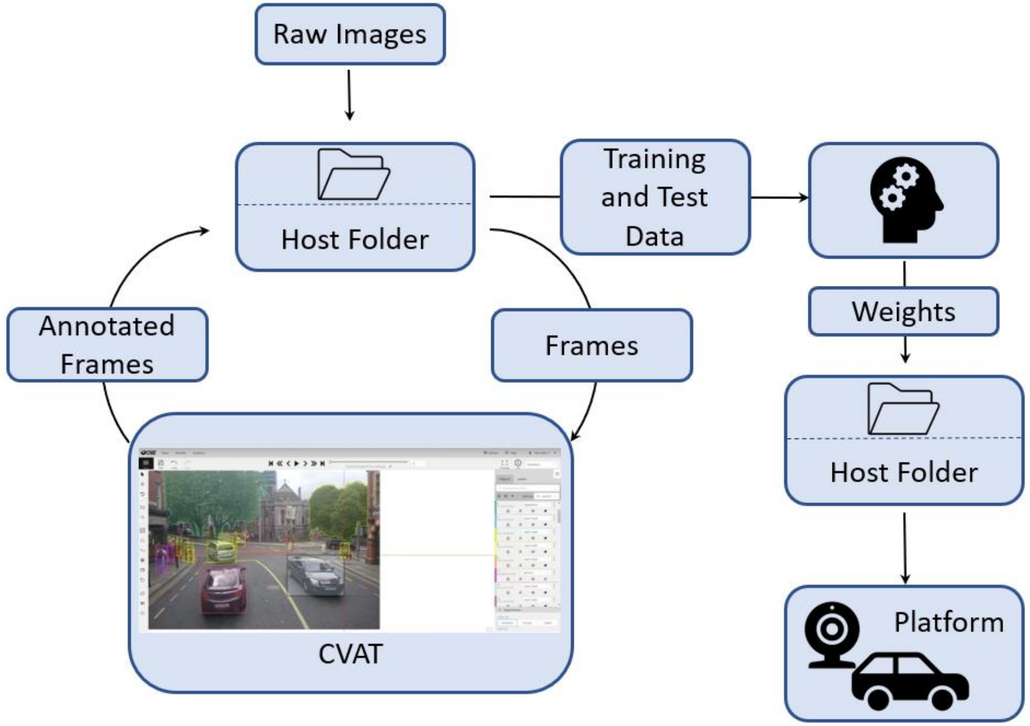
Using Deep Learning as Technology for Object Detection: Training

- Training the neural networks on large annotated datasets
  - Each image in the data set has an annotation corresponding to the problem
  - Here: set of rectangles and class affiliation per image
- Issue: Data sets mostly for non-commercial purposes (research), e.g. vehicle detection [9], [10]
- For commercial purpose creation of own annotated data set required
- Challenges: Coverage of scene and object variance, e.g. weather, lighting, color, …

[9] MIO-TCD dataset, https://tcd.miovision.com/challenge/dataset.html
[10] UA-DETRAC, https://detrac-db.rit.albany.edu/

Using Deep Learning as Technology for Object Detection: AI Pipeline

- Possible minimal setup from training to execution:
  - Host folder for data storage
  - CVAT as an annotation tool
  - Darknet framework for training YOLO model
  - TensorFlow + TensorFlowLite + Edge TPU compiler for optimized inference



- Issues:
  - High effort for generating training data in case of unknown object appearance
  - Established for video-optical sensors, PoCs for other senor types required

Application of Retrofit at Fraunhofer IOSB-INA

Project example: Support for Industry 4.0 Retrofit on a Cutting Machine

- Task
  - Consistent introduction of I4.0 retrofit at company
- Approach
  - Execution of a training for employees issuing smart sensor systems
  - Temporary retrofit with INAsense
  - Preparation of a permanent retrofit using commercial HW & open source SW*
  - Workshop for employees issuing retrofit at shop floor
- Added values
  - Ready to use permanent data acquisition and visualization
  - Enabling employees to scale solution to other machines

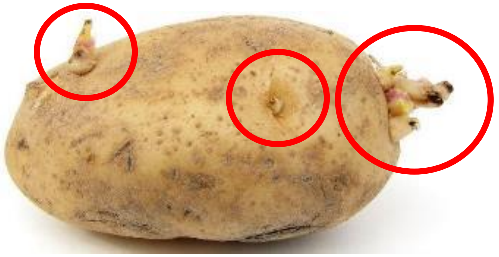
Workshop

Installation at shop floor

* e.g. Influx DB, Node Red, Grafana

Application of optical quality inspection at Fraunhofer IOSB-INA

Project example: Deep learning-based optical inspection of natural objects [11]



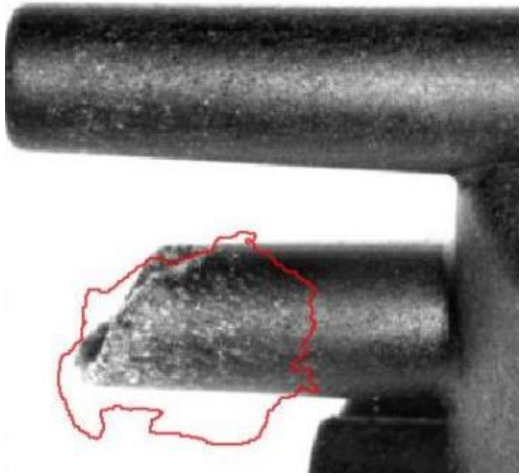
- Task
  - Integration of an optical quality control in a robot gripper
  - Focusing on natural objects like potatoes
- Approach
  - Use of deep learning mechanisms to detect quality defects
  - Generation of a training data set with different error classes (for example sprouts)
- Added value
  - End-to-end solution from mechanics up to PLC interface
  - Checking objects whose exact appearance and shape are unknown (primarily natural objects)

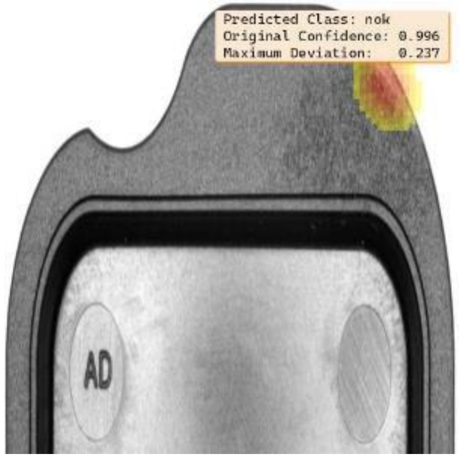
[11] Gutknecht-Stöhr, M.; Friesen, A.; Flatt, H.; Habeck, T.; Großehagenbrock, J.: Automatisierte Qualitätskontrolle: Kartoffeln, KI und Roboter. Atp magazin 10/2019, S. 72 ff, 2019

Application of optical quality inspection at Fraunhofer IOSB-INA

Project example: DL-based quality check of plastic and metal products [12][13]

- Task
  - Quality inspection for injection molding plastics and metal parts
  - Meeting automotive requirements
  - Generic quality inspection of different products
- Approach
  - Use of different DL techniques
  - Classification & Anomaly Detection
- Added value
  - Same inspection routine for multiple product types
  - No image processing expert knowledge required
  - Small amount of OK and not OK samples sufficient (min. 30 each)

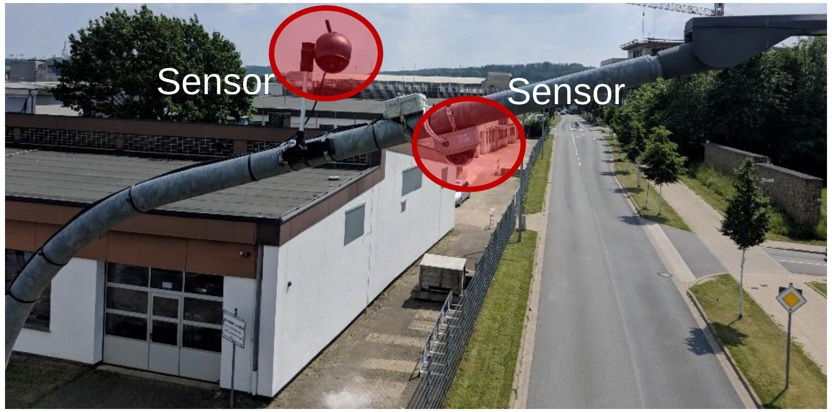




[12] https://www.its-owl.de/projekte/transferprojekte/details/back-643/bewertung-von-selbstlernenden-optischen-verfahren-zur-qualitaetskontrolle-von-erzeugnissen-aus-kunststoff/
[13] https://www.its-owl.de/projekte/transferprojekte/details/back-643/analyse-von-loesungsansaetzen-zur-automatisierten-pruefung-von-dreh-und-fraesteilen/

Sensor related Challenges in Smart Cities

- Suitable and generic sensor system platforms for application development
- Power supply
  - Often no permanent power supply available
  - No 24/7 availability of regenerative energy (e.g. PV)
  - Using lanterns for sensor installation may only provide power at night
- Specific regulations and permissions for hardware installation in public areas (e.g. location, appearance)
- GDPR and citizen acceptance regarding video-optical sensor technologies
- Damages and vandalism
- Reliable mobile high band-width data communication



Technologies for Addressing Sensor Challenges in Smart Cities

- Example: Fraunhofer IOSB-INA CV demonstrator
- Detection accuracy for vehicles > 90%

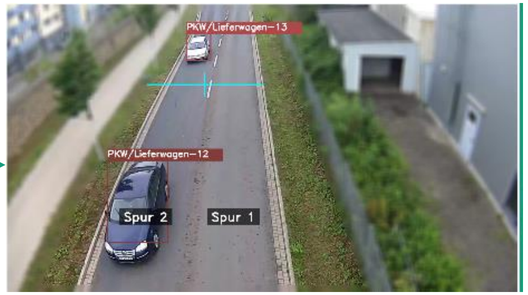
Optical sensor

Lemgo, Bunsenstr.

Control box

- LiFePo4 battery night-loaded via lantern
- Edge PC with AI accelerator for real-time processing
- Possibilities for processing object detection on edge
- Communication (e.g. WLAN, 4G,5G, LoRaWAN)
- GDPR conform if no video streams are stored and only anonymous results are transferred (e.g. object count values)

Urban data platform
e.g. FiWare based

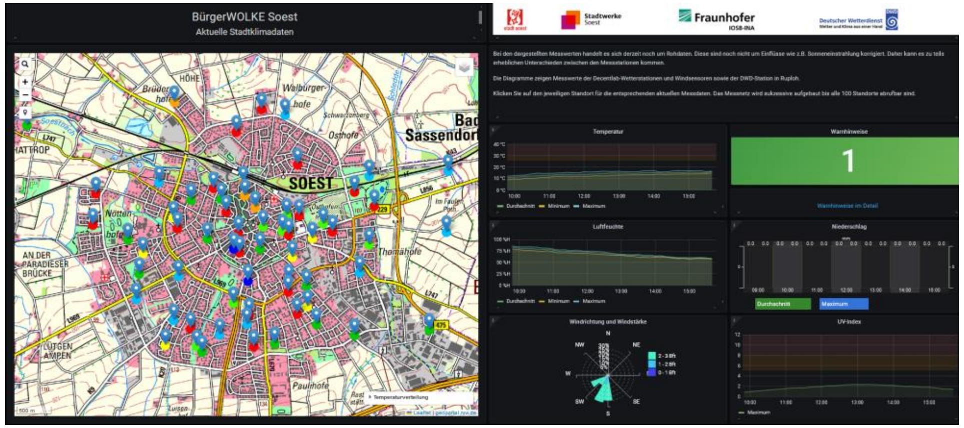


End device
e.g. visualization

Application of optical quality inspection at Fraunhofer IOSB-INA

Project example: Citizen Cloud Soest (Bürgerwolke Soest)

- Task
  - Detection of the microclimate
  - Design of a monitoring and warning systems for citizens
- Approach
  - Acquisition of micro climate via 100 low-cost climate sensors
  - Sensor locations at public and citizen buildings
  - AI based sensor data correction in order to avoid e.g. fans
  - Public dashboard for citizens
- Added value
  - Public climate monitoring, e.g. temperature and perceived temperature
  - Citizen Warnings, e.g. for specific heat (under development)
  - Side effect: Measuring world-wide air pressure fluctuations caused by 2022 Tonga volcano explosion [14]



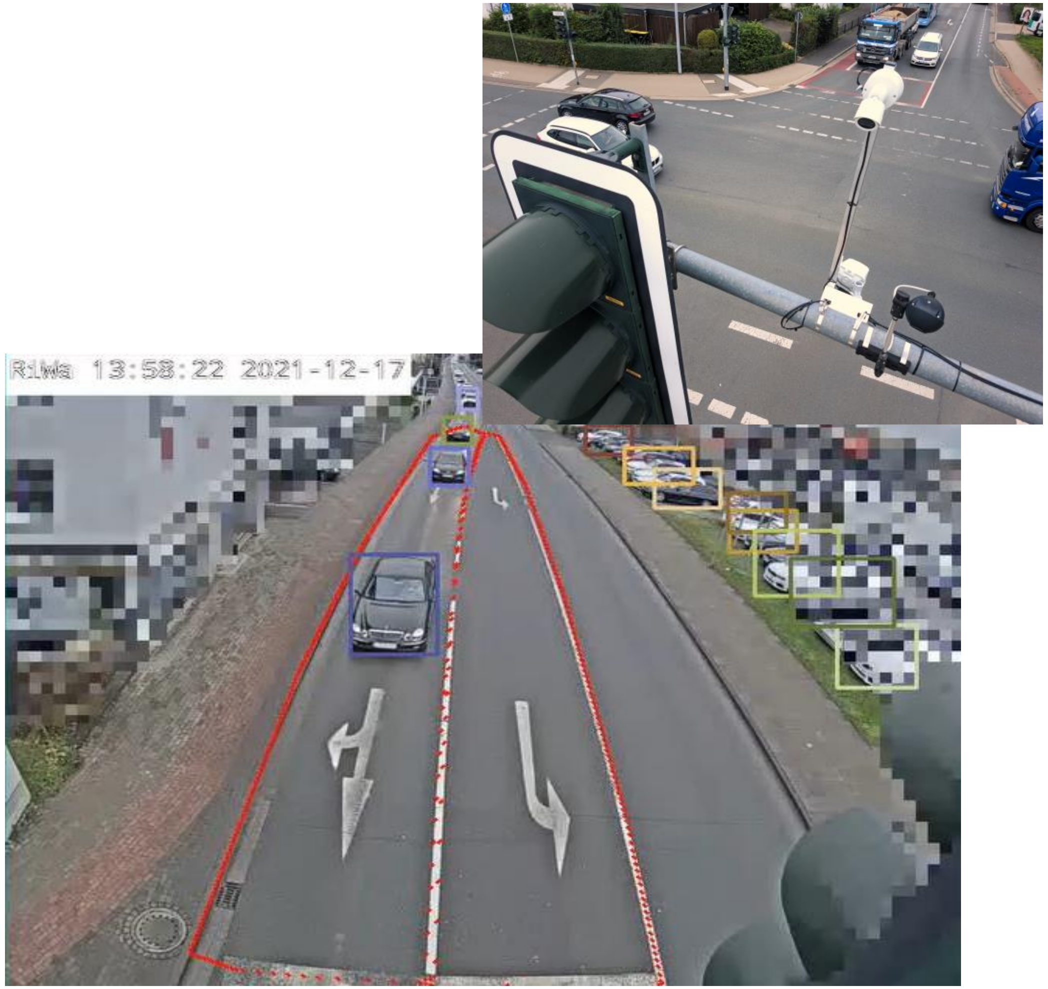
https://urbanedaten-soest.de/

[14] Till Brand: Lemgoer „spüren“ Tonga-Druckwelle. In: Lippische Landeszeitung, 19.01.2022

Application of optical quality inspection at Fraunhofer IOSB-INA

Project example: Artificial Intelligence for Traffic Lights (KI4LSA) [15]

- Task
  - Optimizing the control of traffic lights for vehicles
  - Reducing traffic jams and CO_2 emissions
  - Integration into existing infrastructure
- Approach
  - Real-time traffic monitoring based on optical sensors
  - Using of reinforcement learning for optimized control
- Added value
  - Tracking the number of vehicles and travel times by AI
  - GDPR compliance
  - Intended as upgrade for existing traffic lights

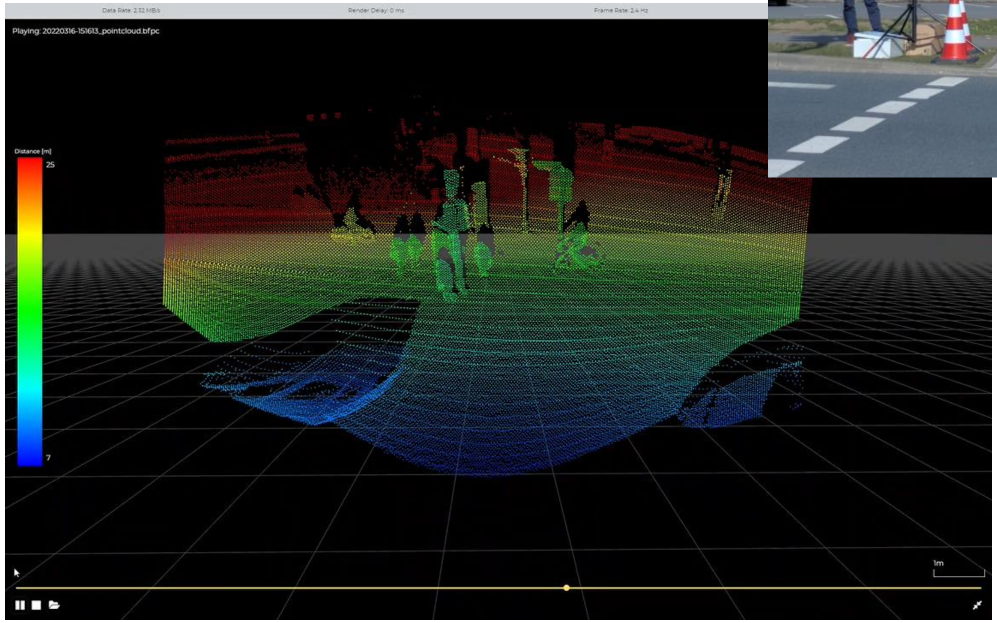


[15] Müller, Arthur et al.: Towards Real-World Deployment of Reinforcement Learning for Traffic Signal Control. In: 20th IEEE International Conference on Machine Learning and Applications (ICMLA), p.507-514, Pasadena (California), December 2021

Application of optical quality inspection at Fraunhofer IOSB-INA

Project example: Artificial Intelligence for Pedestrian Traffic Lights (KI4PED)

- Task
  - Optimizing the control of traffic lights for pedestrians
  - Reducing crossing times and dangerous crossings
- Approach
  - Potential analysis
  - Using LiDAR sensors in combination with AI [16]
- Added value
  - GDPR compliance by design
  - Mainly independent from illumination
  - Intended as upgrade for existing traffic lights



[16] Dennis Sprute, Tim Westerhold, Florian Hufen, Holger Flatt, Florian Gellert: DSGVO-konforme Personendetektion in 3D-LiDAR-Daten mittels Deep Learning Verfahren (Talk). In: BVAu 2022, Lemgo, Nov. 2022

Outlook to Future Sensor Concepts: Quantum Sensors

- Based on physical laws of quantum mechanics
- Benefits
  - low size
  - high precision
  - very low detection thresholds
- First industrial sensors in evaluation [17]
- Applications
  - Optimized magnetic resonance imaging
  - Measuring of magnetic fields, pressure or temperatures
  - Measurements of particles in gases, liquids or powders that are not possible with today's measurement technology
  - Quality check of coffee as an example

[17] https://www.produktion.de/technik/zukunftstechnologien/quantentechnologie/erste-industriefaehige-quantensensoren-sind-im-einsatz-44-344.html

Conclusions

- Sensors systems are necessary for all automation systems
- Sensor system requirements vary strongly dependent on the application sector
- Increasing importance of smart combination of sensor and AI based data processing
- Open-source tool chains support to avoid vendor lock-ins
- Addressing applications with new sensor technologies in future, e.g. quantum sensors

Numerous of sensor applications show feasibility of
current technologies (e.g. for smart factory and smart city) !

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