Quality Control by Autonomous Mobile Robot Demonstrated for Flush and Gap at Car Body

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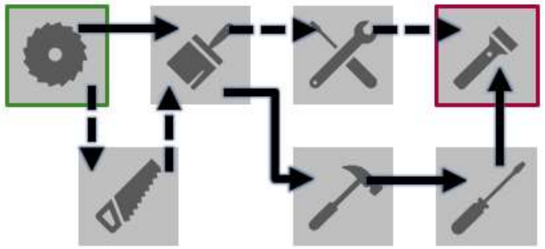
Individualized and large products demand flexible and scalable solutions for quality assurance in manufacturing

Trends in Manufacturing

Customization



Variable manufacturing process

Large products

Issues and Needs

- **varying demand**
  - over **time** (e.g., ramp-up of line)
  - at different **locations** (e.g., manuf. islands)
- **installation effort** for stationary tools
- handling/ logistics of **large products** (to/ from central QA/QC station; measurement volume)

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Trends in Manufacturing

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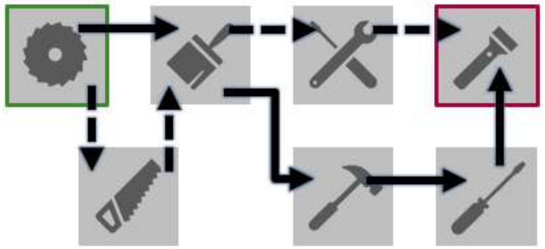

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What if we had a mobile tool?

demand-oriented, flexible
(whenever and wherever)

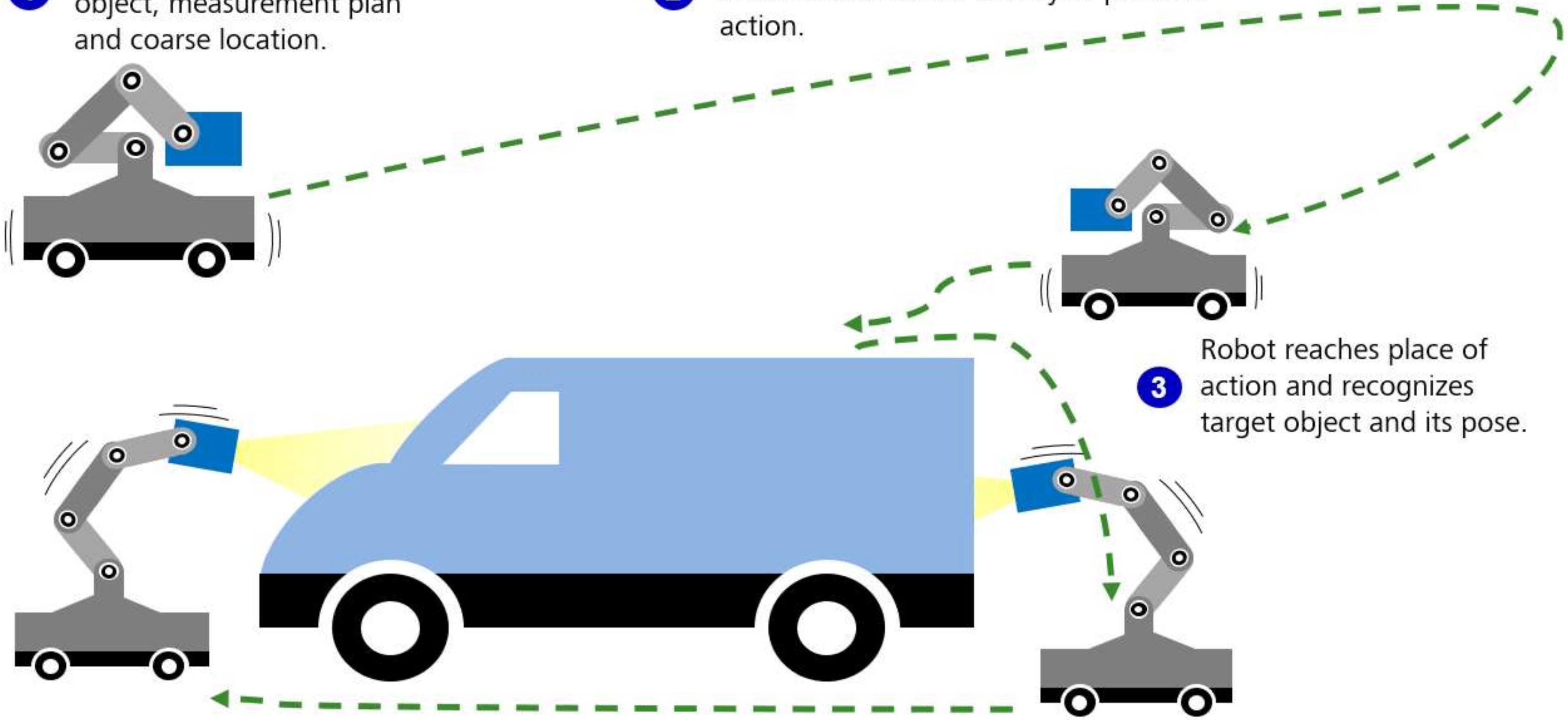
independent of object size
(moves around)

autonomous execution
(no operator).

scale-up potential
(swarm of mobile tools)

Basic idea of a mobile measurement robot for industrial manufacturing

1. Measurement job is triggered with info about target object, measurement plan and coarse location.
2. Mobile robot navigates autonomously and collision-free within factory to place of action.
3. Robot reaches place of action and recognizes target object and its pose.
4. Optical sensor measures sequentially at predefined measurement poses.
5. Mobile robot relocates itself for different measurement poses.



Consortium

Bundesministerium für Bildung und Forschung

Demo application

Flush & Gap of assembled car body

Overview of Presentation

1 Why autonomous system for quality control

2 What requirements for operation in industrial manufacturing

3 Architecture of autonomous mobile system

4 Implementation and performance for quality control

Requirements for safe and effective operation in industrial manufacturing

ZEISS

Safety

- Collision-free movement of robot
- Worker protection

Mobility

- Agility and dexterity
- Non-stuck in narrow spaces
- Floor plan navigation

Independence

- Unsupervised operation
- Sufficient energy capacity
- Onboard processing for non-continuous data communication
- Reliable task execution

Integrability

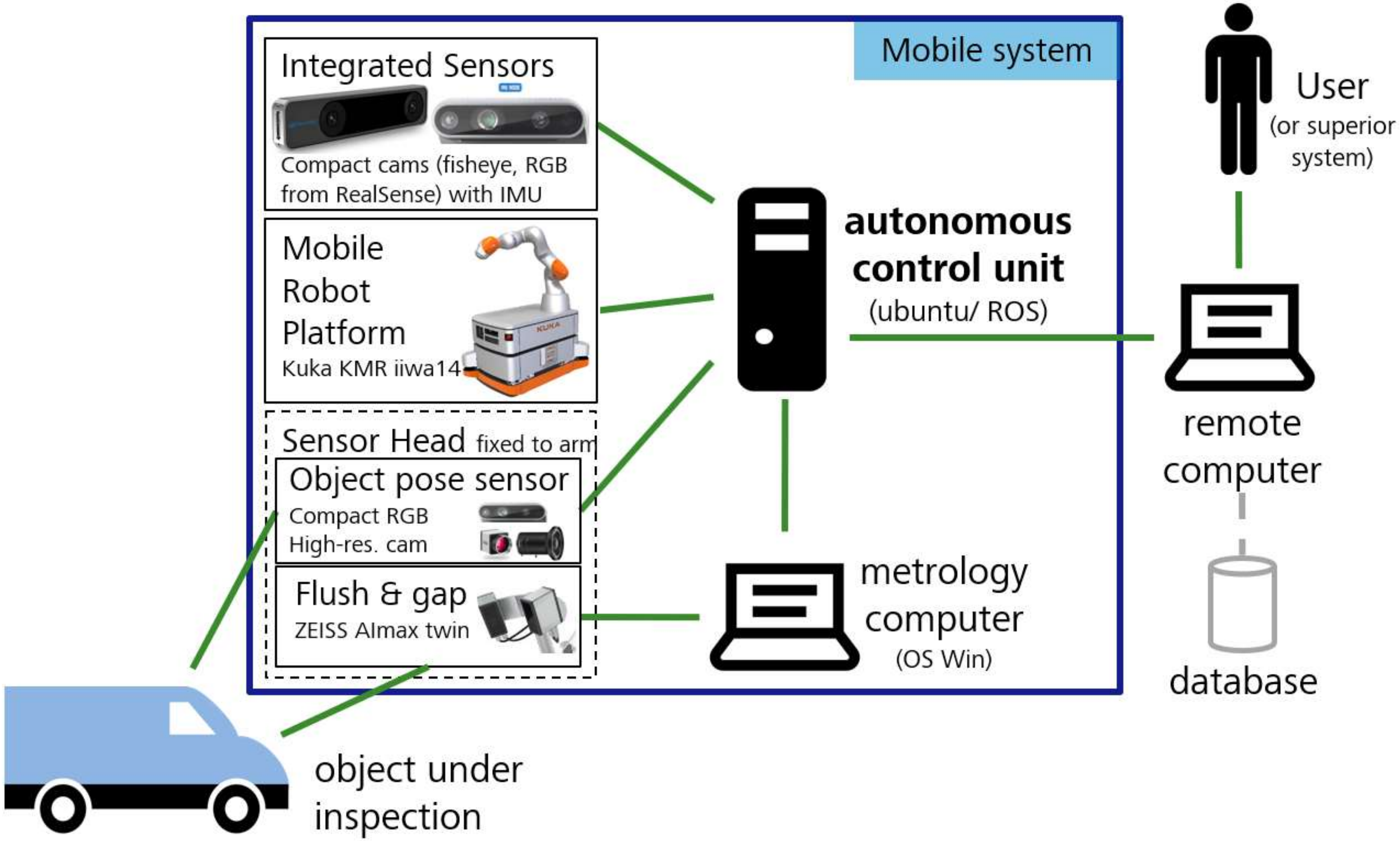
- Wireless communication
- Compatible data formats
- Software triggers via MES (manufacturing execution system)

Task definition with low effort

- Label-free objects
- Model-based target recognition
- Model-based object alignment

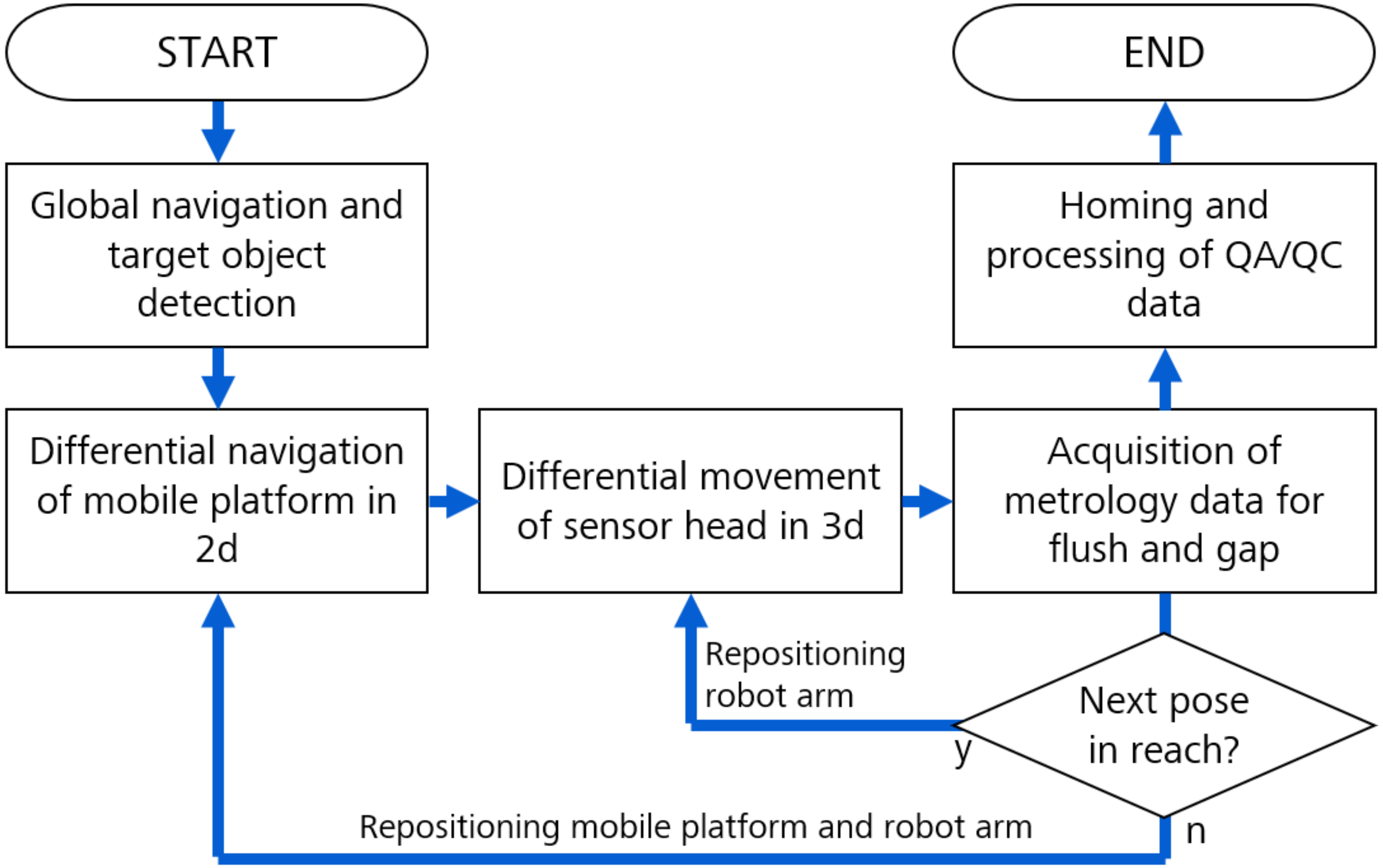
Hardware and system architecture

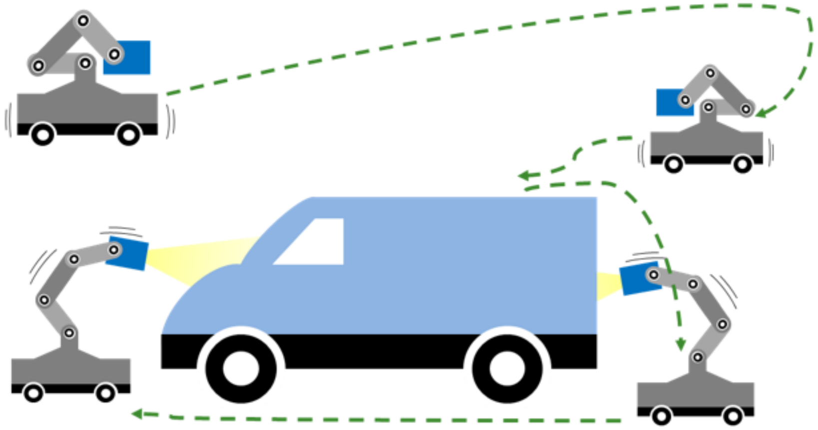
1. 2d lidar
2. Fisheye cam: FoV ~160°
3. High-resolution camera: FoV 50°
4. Metrology tool (AImax twin/ ILM)
5. Compact camera module
6. Compact camera module



Generic sequence for quality control workflow

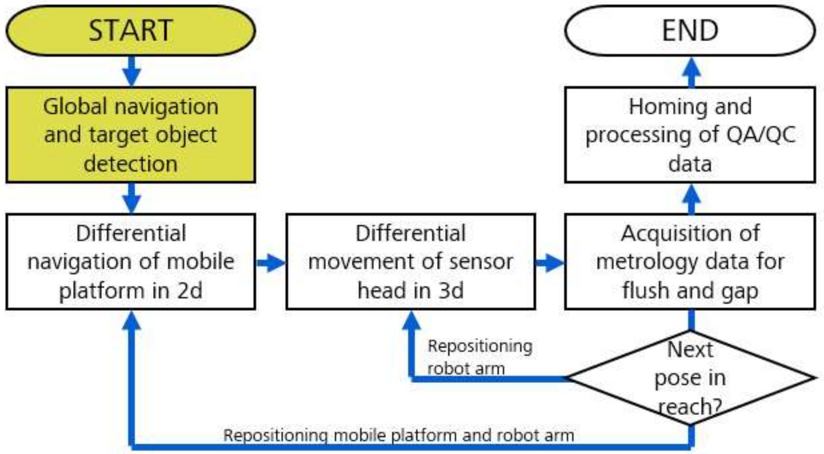
Global and differential platform navigation, robot movement, and local inspection

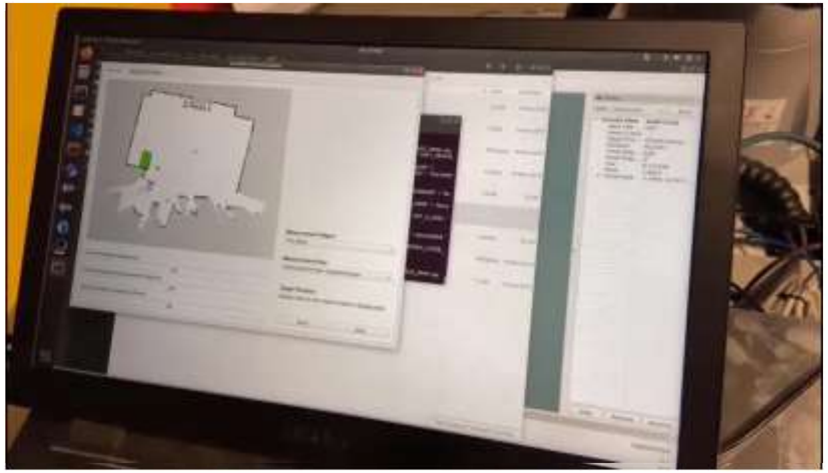




Implementation and performance

Mission definition, global platform navigation, and target object detection





Start by mission definition with 3 steps (simple GUI)

1. Selection of inspection object
2. Selection of inspection plan
3. Coarse position of target object: 3m radius sufficient due to object detection

Navigation with global map

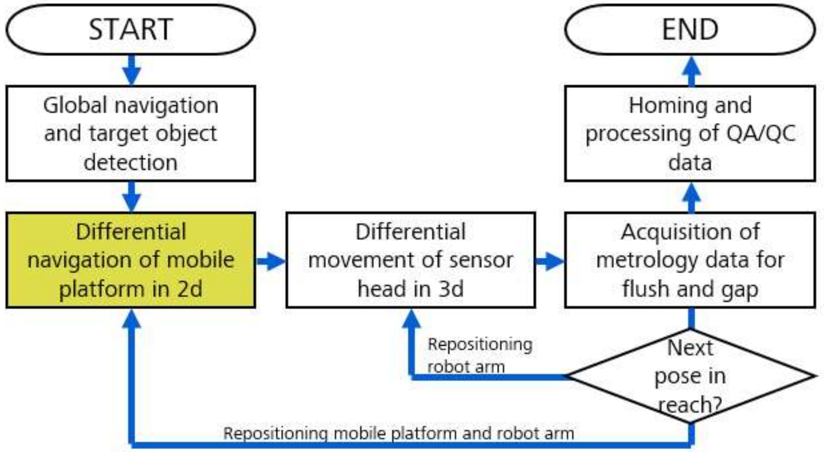
- static and dynamic obstacles
- 2d navigation stack (trajectory planning and execution)
- Safety zones implemented by lidar

Target detection and 2d navigation **goal refinement**

- Start of object detection (and verification) while approaching initial goal
  - Use of fisheye camera for large field of view
  - Below threshold distance (<5m)
  - Use confidence of detection
- Fuse object detection (direction) and depth information to update 2d navigation goal (accuracy <0.3m)

Implementation and performance

Differential platform navigation controlled by object tracking



Object tracking until 2d parking position is reached

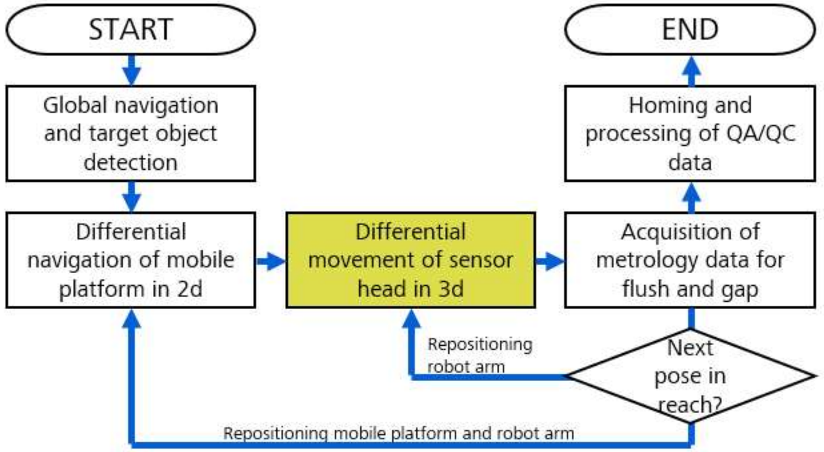
- 3d object pose tracking
  - Using 3d model of target object (CAD)
  - Fast vision-based update (~10fps)
  - Pose detection accuracy <30mm

Differential navigation with local 2d map respecting obstacles

- Data fusion from vision and odometry
  - Robust performance also in case of uncertainty (vibration, temporal occlusion)
- Safety distance zones
  - Normal velocity
  - Reduced velocity
  - Stop (before collision)

Implementation and performance

Differential robot arm positioning with optional refinement of pose estimation



Differential robot arm movement with local 3d map respecting obstacles

Like mobile platform navigation in 2d, now with robot arm movement in 3d

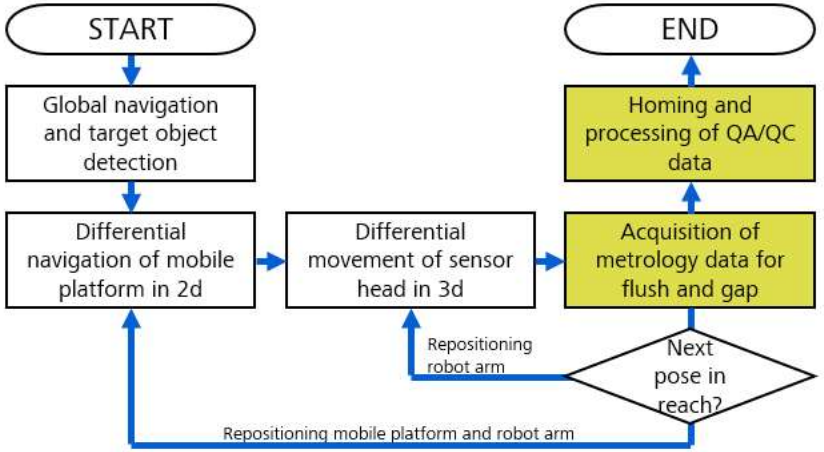
- Changed view: using RGB camera attached to robot arm
  - Surpassing inaccuracy of (collaborative) robot kinematics
  - Same tracking module as used from platform view
- Data fusion from vision module and robot joints
  - High robustness and good pose accuracy (<5mm)
    - Reference experiments with commercial tracker (ZEISS T-Track)
    - Evaluation of average distance deviation (ADD)

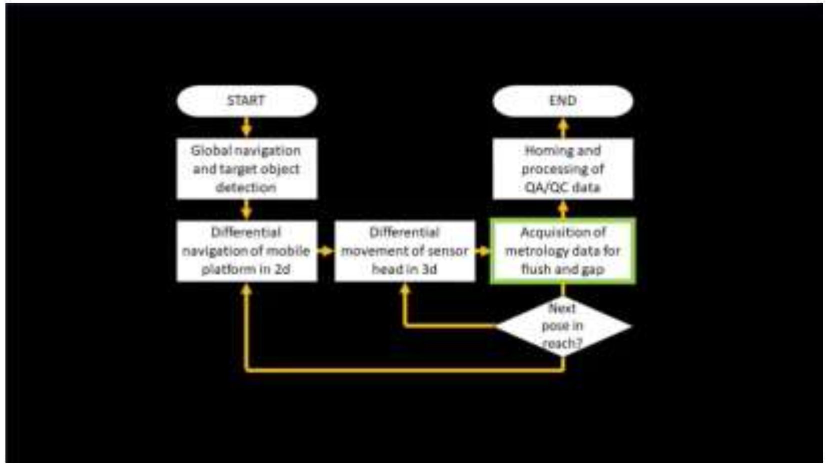
Pose refinement (optional) with multi-perspective adjustment

- High-resolution camera (12MP) available
- Pose evaluation from different 3d perspectives
  - Taking more detailed image features into account
- Data fusion from one or two vision module and robot joints
  - High pose accuracy (<2mm)

Implementation and performance

Inspection data acquisition and homing of mobile system



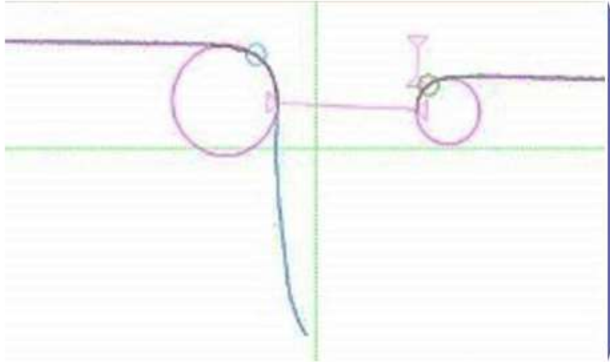


Predefined inspection poses reached by sensor head

- Trigger acquisition of inspection/ metrology sensor data
  - Here: demonstrated with flush & gap measurement sensor (ZEISS AImax Twin)
  - Viable concept for other optical sensors
- Platform parking positions optimized offline according to inspection plan to reduce platform repositioning (reachability)

Homing of mobile platform after mission accomplishment

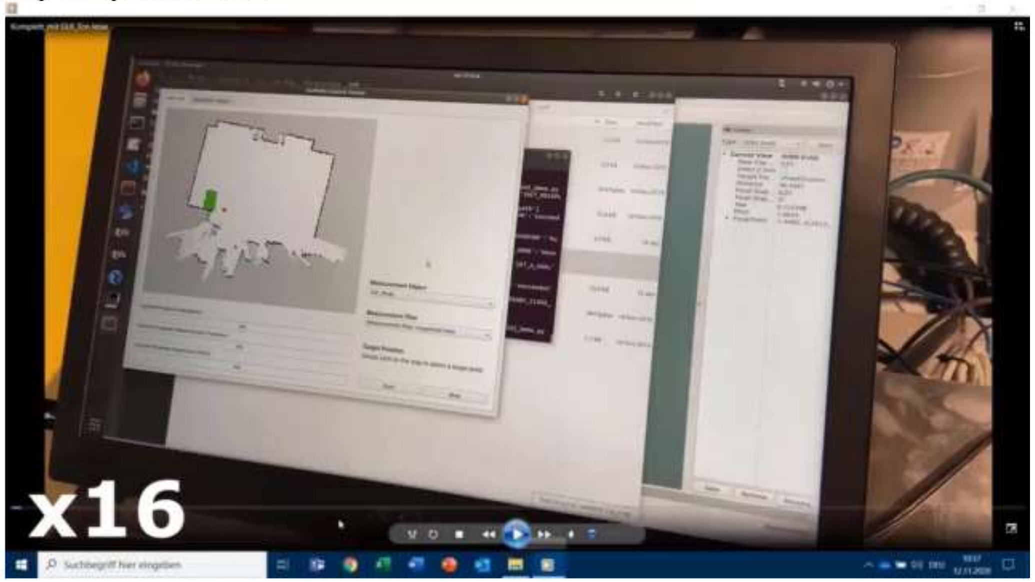
- Navigation time to home position can be used
  - for data evaluation (here: <2s)
  - for data transfer to superior system (MES)



Summary and Conclusion

- **Successful demonstration** of autonomous mobile robot for inspection of flush and gap
  - Workflow demonstrated for painted and unpainted car body door (shiny, textureless surface)
  - Cascaded target object approach with improving accuracy levels
    - accuracy <5mm or <2mm (optional refinement) achieved for sensor head

- **Flexible implementation** and **scalable application** in industry crucially depend on:
  - Use of digital twin of target object:
    1. For target object recognition
    2. For object pose estimation
    - without need for real images
    - for reliable and robust approaching procedure
  - Architecture for exchangeable metrology sensor
    - metrology sensor not part of target approach



Seeing beyond