3-D ENVIRONMENT RECONSTRUCTION USING TIME-OF-FLIGHT CAMERAS ON MOBILE SERVICE ROBOTS

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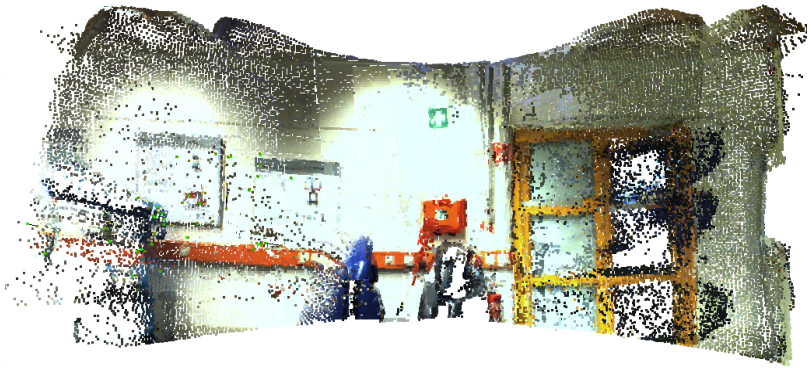

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Outline

- Motivation for 3-D Environment Reconstruction
- Service Robot Applications
- Process for Environment Reconstruction
- Applications for 3-D Environment Maps
  - Real-time Path Planning for Manipulation
  - Navigation with Low-Cost Sensors
- Further Research using Visual Sensors
  - Object Detection and Learning
  - Human Face Detection
- Conclusion

Motivation for Environment Reconstruction

- Robots should be able to act and interact autonomously in
  - Dynamic environments
  - Unknown environments
- Hardware has improved greatly in recent time
  - 3-D sensors: Time-of-flight cameras
  - PCs: computation power vs. size
- 3-D environment perception enhances
  - Navigation: Augmentation of 2-D maps with 3-D obstacles
  - Manipulation: Tracking of dynamic obstacles, collision avoidance, identification of relevant objects (table surfaces, shelves, cupboards)
  - Visualization: Tele-Operation of mobile robots
  - ➔ Need for dense 3-D representation of the environment

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Robotic Home Assistant Care-O-bot® 3

- Product vision, realized in 2008
- Functional design
- Two-side interaction concept
- Industrial grade components
- Reliable, robust and capable
- Compact integration
- Flexible system layout
- Easily extensible

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Industrial grade hardware components

Light-Weight-Arm
(7 DOF)

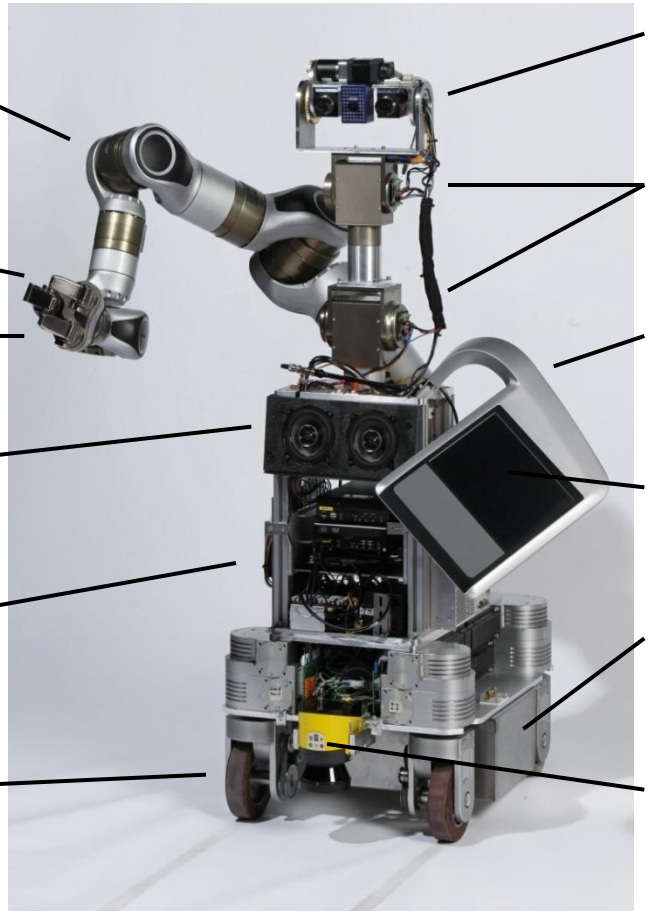
Gripper
(7 DOF)

Tactile sensors

Speakers

Computer Bay
(3-5 PCs)

Omnidirectional platform
(4 x 2 DOF)



Sensor head
(1 DOF, stereo and 3D-ToF)

2 PT-Units
(2 x 2 DOF)

Tray
(1 DOF)

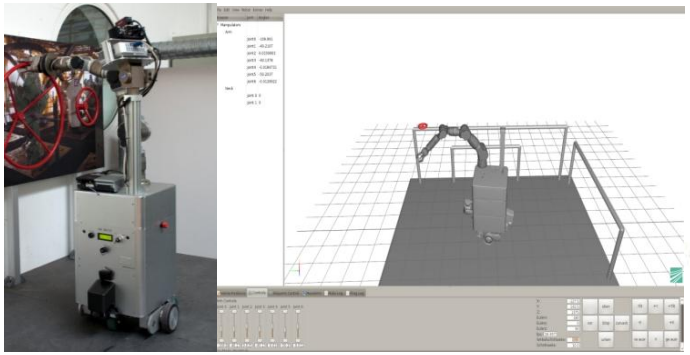
Touch screen

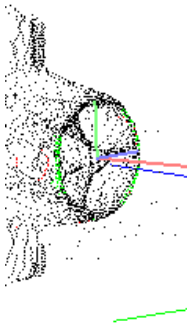
Battery

3 Laser scanners
(front, back, top of mobile base)

Industrial Inspection and Maintenance

- Built in 2010
- GUI for Tele-Operation
- Haptic input device
- Wheel detection
- Augmented Reality





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Components

Light-Weight-Arm
(7 DOF)

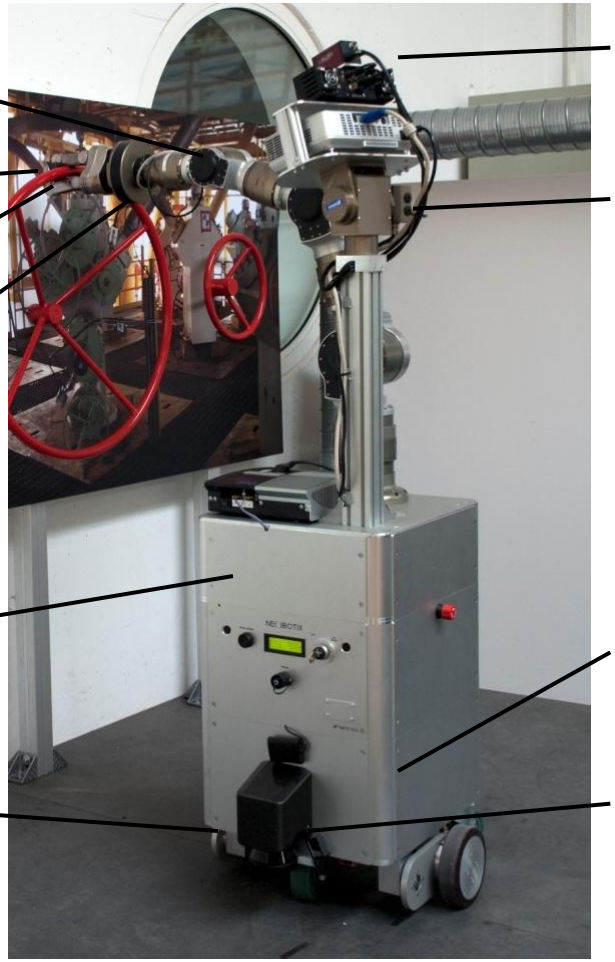
Gripper
(7 DOF)

Tactile sensors

Force-torque sensor

Computer Bay
(1-2 PCs)

Differential drive
(2 DOF)



Sensor head
(Color and 3D-ToF camera)

PT-Unit
(2 DOF)

Battery

2 Laser scanners
(front, back)

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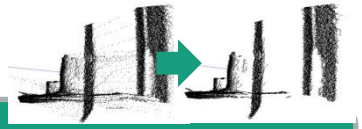
Environment Reconstruction - Overview

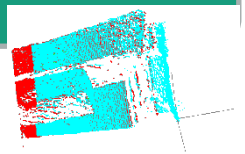
Cameras



Sensor data processing

Feature extraction and association

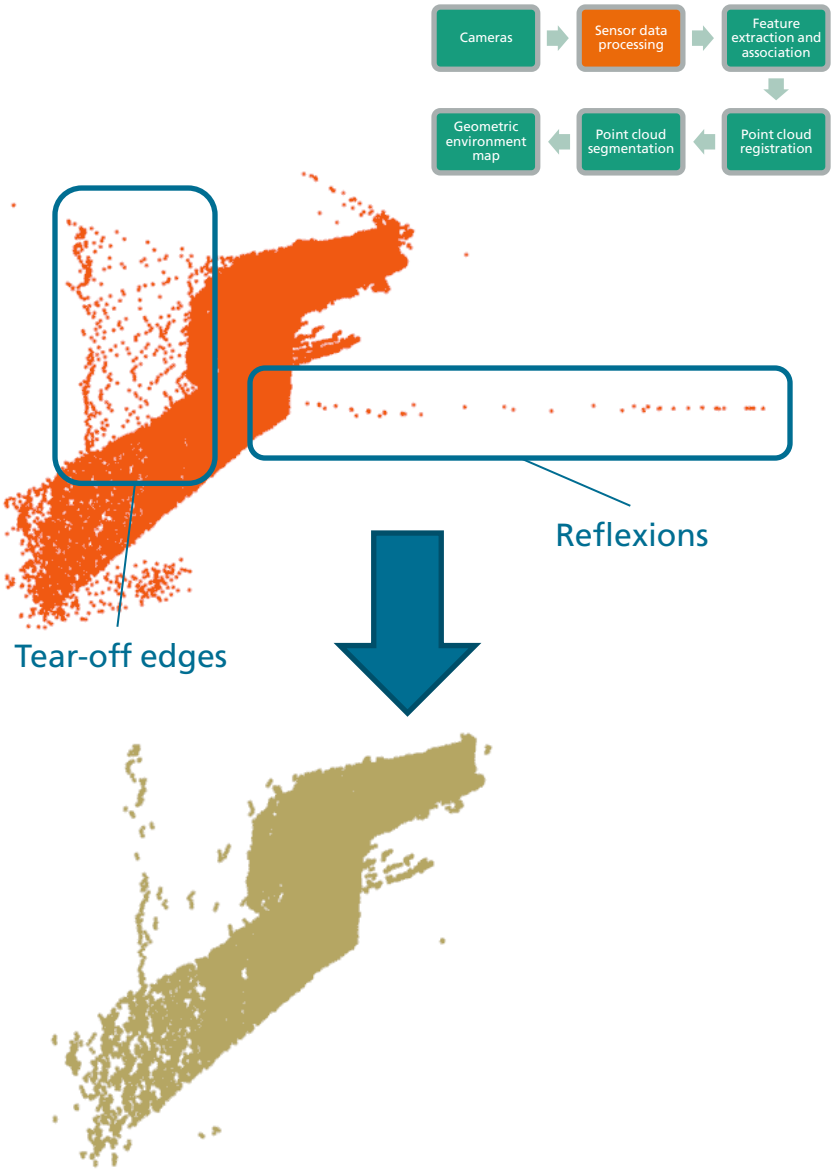
Point cloud registration



Point cloud segmentation

Geometric environment map

Sensor Data Processing



- ToF measurement uncertainty
  - Highly reflective objects
  - Non-Ambiguity range
  - Tear-off edges
- Filtering of noisy ToF data
  - Amplitude filtering
  - Filtering of tear-off edges
  - Speckle filter

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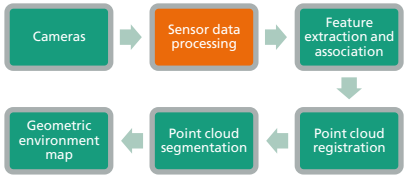
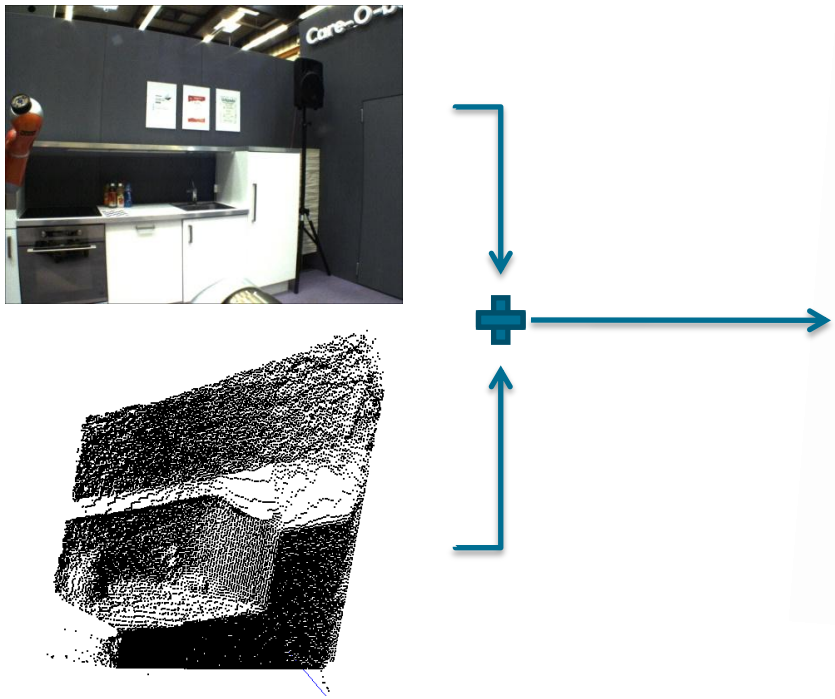
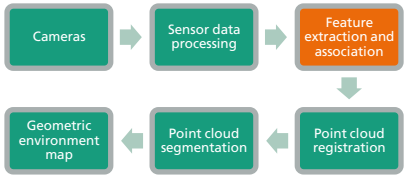
Generation of Colored Point Clouds



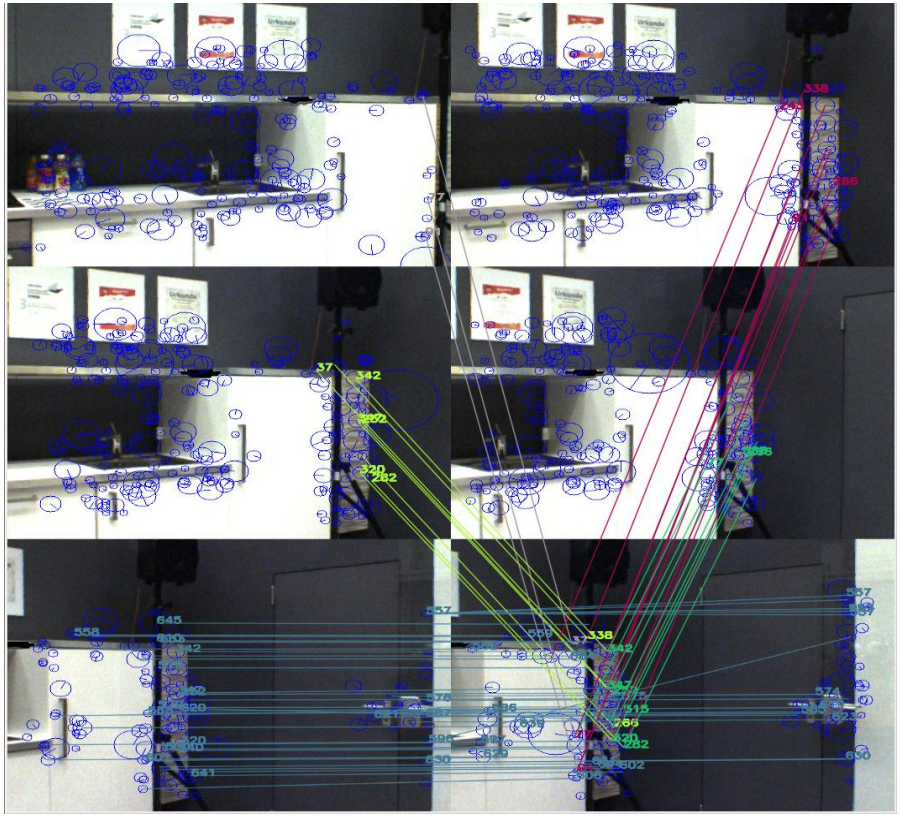
- Calculation of a colored point cloud
  - Calibration of cameras
  - Transformation of ToF data into color image



Feature Extraction and Association



- Extraction of SURF features from color image
  - Robust to light changes
  - Scale and rotation invariant
- Assignment of 3-D coordinates by colored point cloud
- Association of features between sensor views by
  - Descriptor
  - Distance
- Data reduction for point cloud registration



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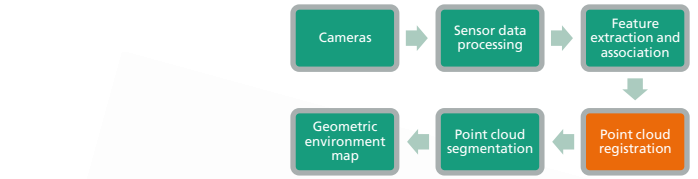
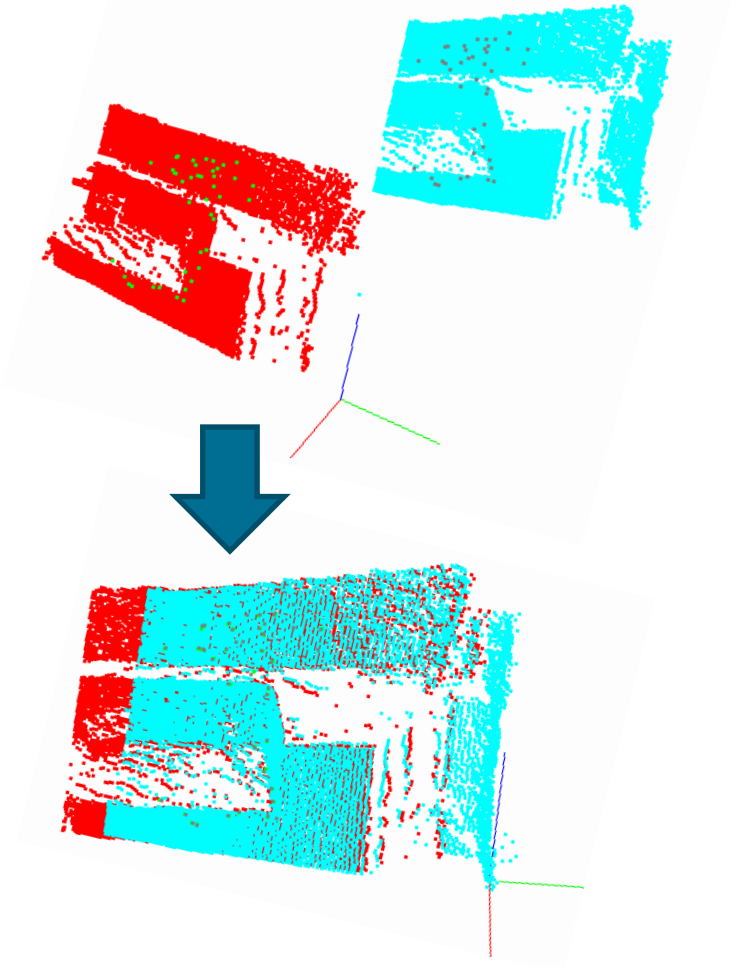
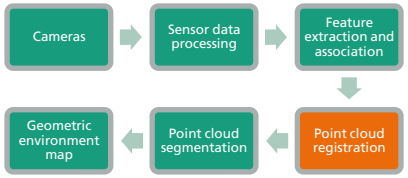
Point Cloud Registration

- Construction of a consistent point map during robot movement
- Challenges
  - Inaccurate sensor data
  - Uncertain robot position
- Iterative Closest Point (ICP) algorithm
  - Iterative algorithm
  - Error Function $E(R,t) = \sum_{i=1}^{N} \left\| R \cdot p_i + t - q_i \right\|$
  - Estimation of ego-motion R,t that minimizes error function
  - Transformation of point clouds

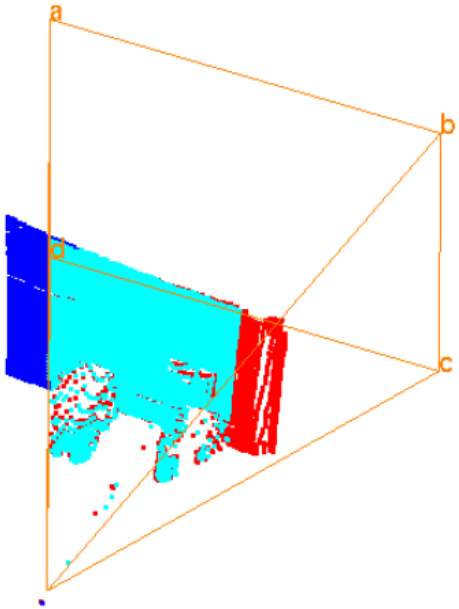


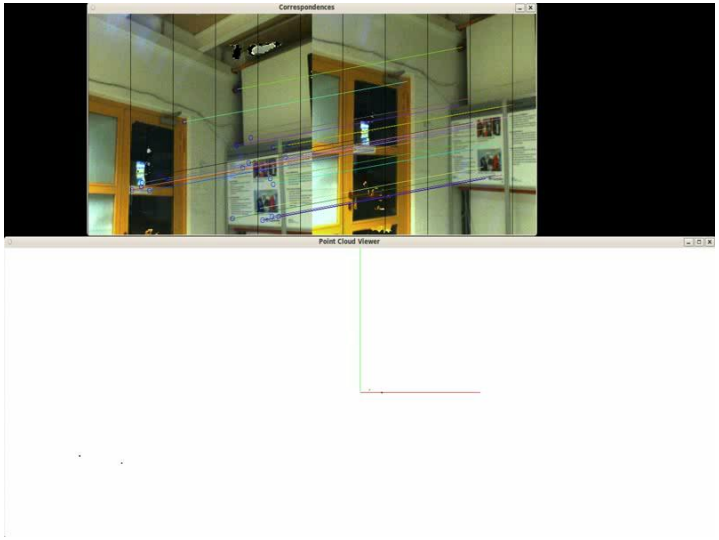


Point Cloud Registration



- Find overlapping region by field of view
  - Compute frustum
  - Only register overlapping part
- Use of features or raw data for registration
  - Accuracy vs. speed
- Example: Mapping of our robot lab





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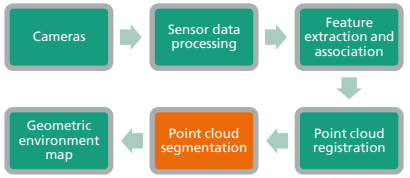
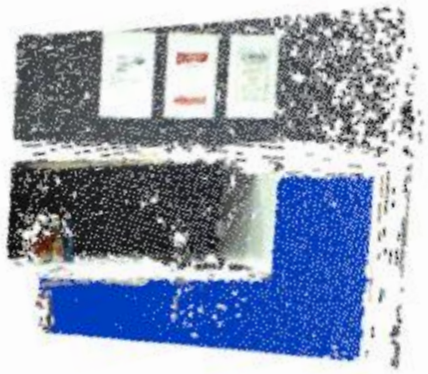
Segmentation of Point Clouds



- Segmentation of planes
- Base for Identification of
  - Table-tops
  - Doors
- RANSAC
  - Segmentation of the dominant plane
  - Labeling of Inliers
  - Further Processing
    - Move labeled points to new point cloud
    - Find next plane
- Segmentation of other shapes
  - Cylinders
  - Spheres



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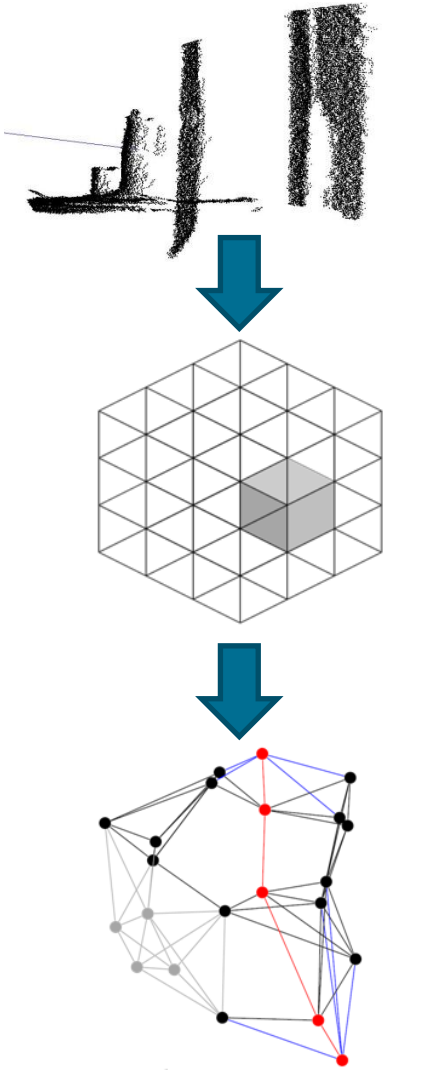
Real-time Path Planning for Manipulation

- Transformation of point cloud into a voxel grid
- Grid-based path planing algorithm
- Online collision-avoidance



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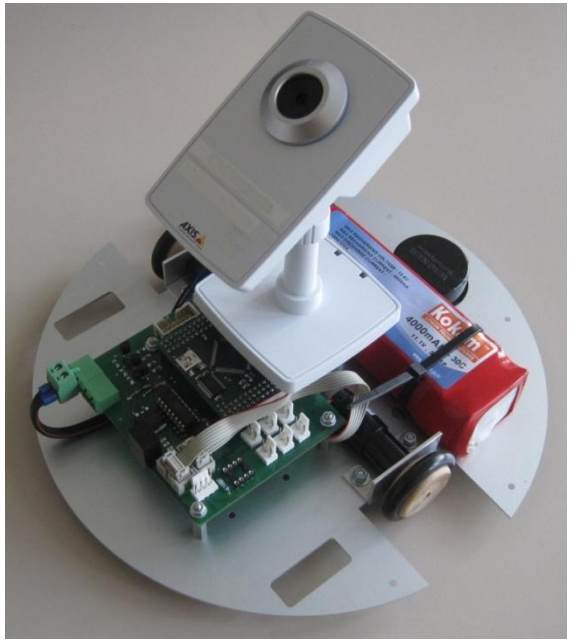
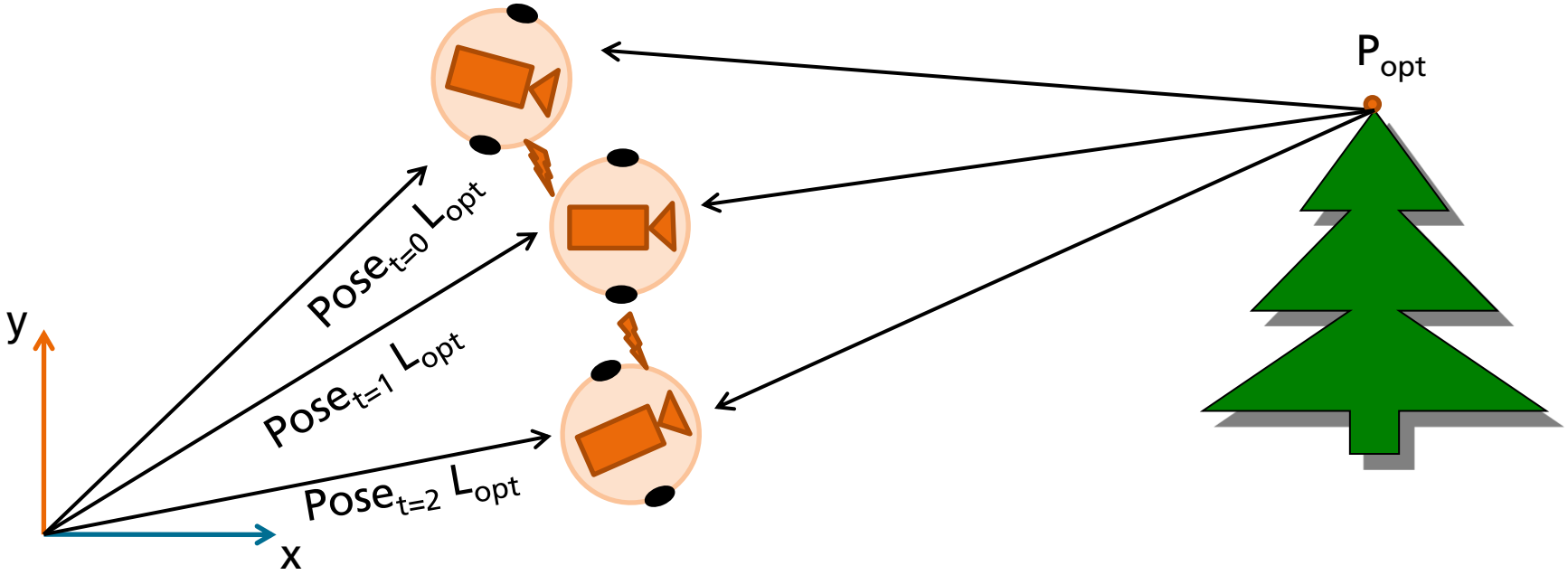
Navigation with Low-Cost Sensors

- State-of-the art robots for vacuum cleaning or lawn mowing move randomly
  - Limited coverage
  - High time and energy consumption
- Need for systematic navigation
  - Low-Cost Sensors
  - Embedded Hardware
- Prototype with
  - Color Camera
  - Differential Drive
  - Microcontroller
- Transfer of methods for environment reconstruction to low-cost sensors



Mapping with color camera

- Extraction of Feature Points
- Association between camera frames during movement
- Triangulation to obtain 3D features
- Optimization of feature and robot position over multiple frames



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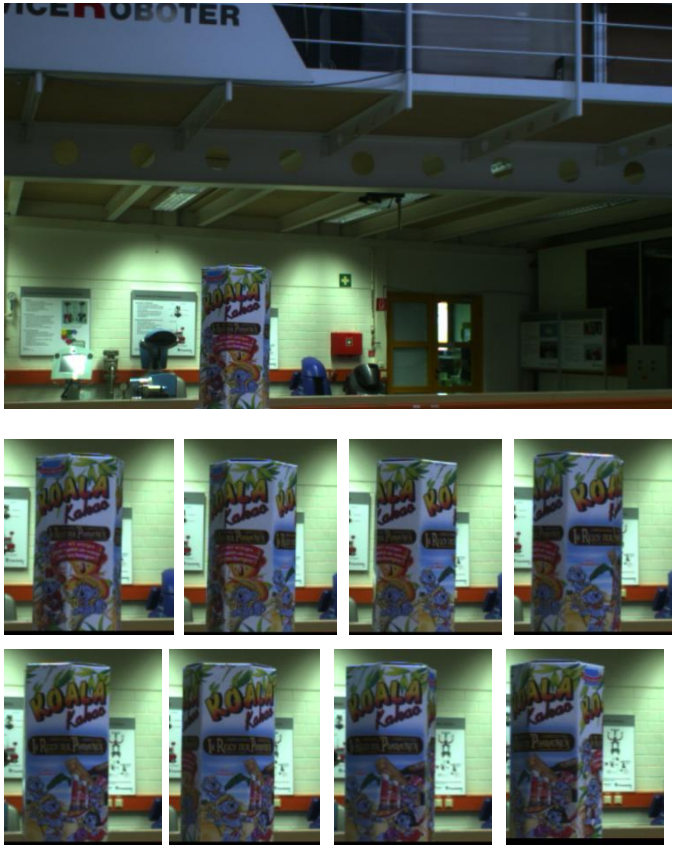
Object Learning

- Acquisition of different object views using stereo cameras

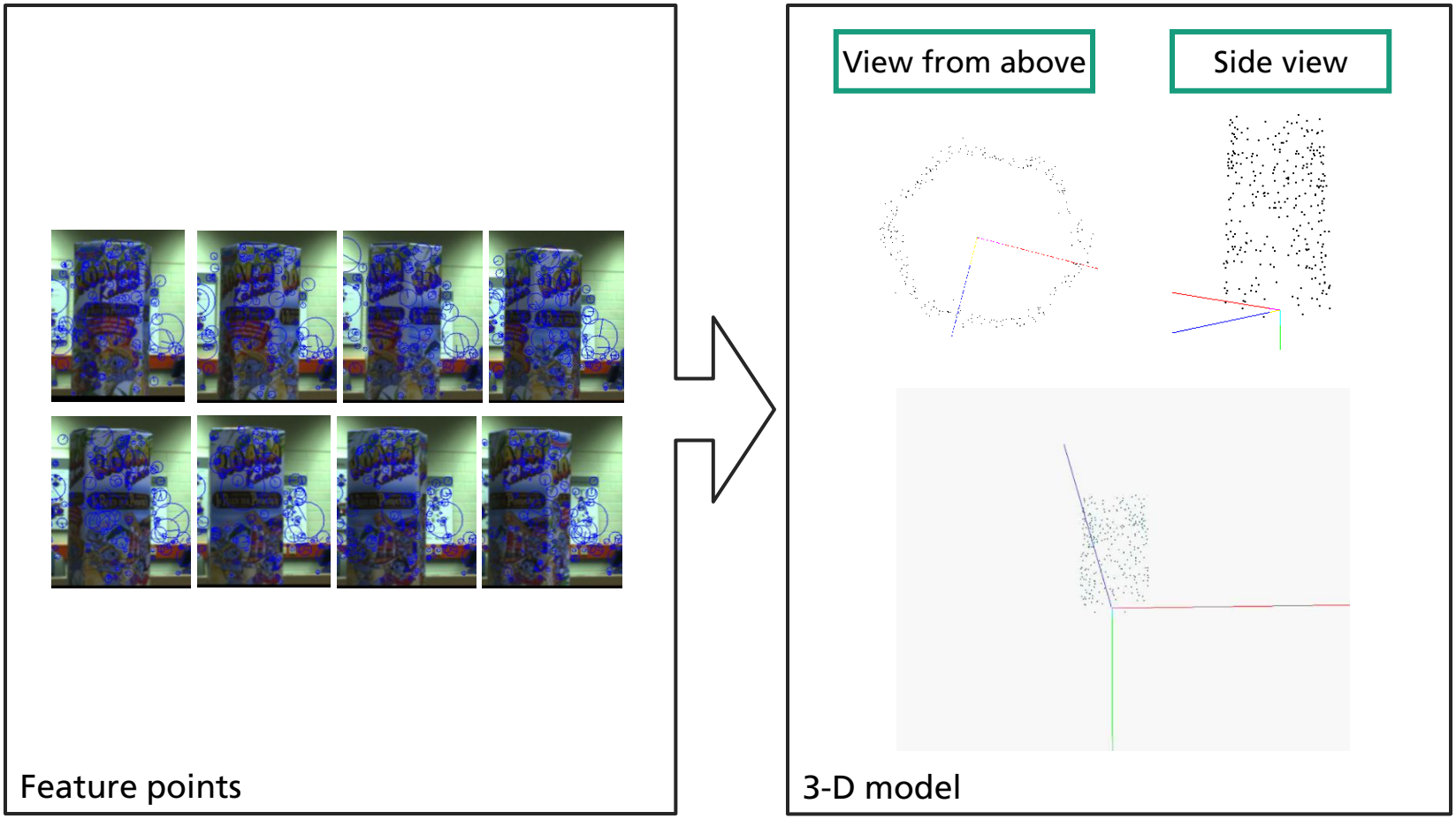
Setup



Training images

Object Learning

- Aggregation of a 3-D object model using a probabilistic filter



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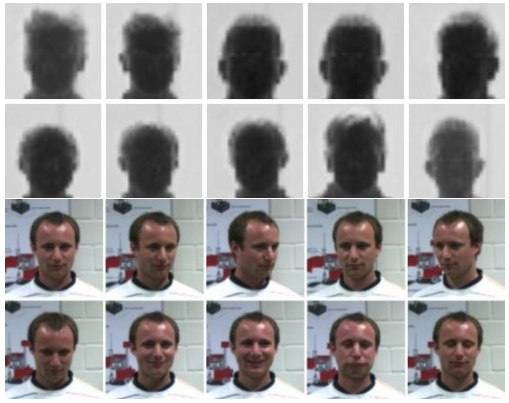
Object detection

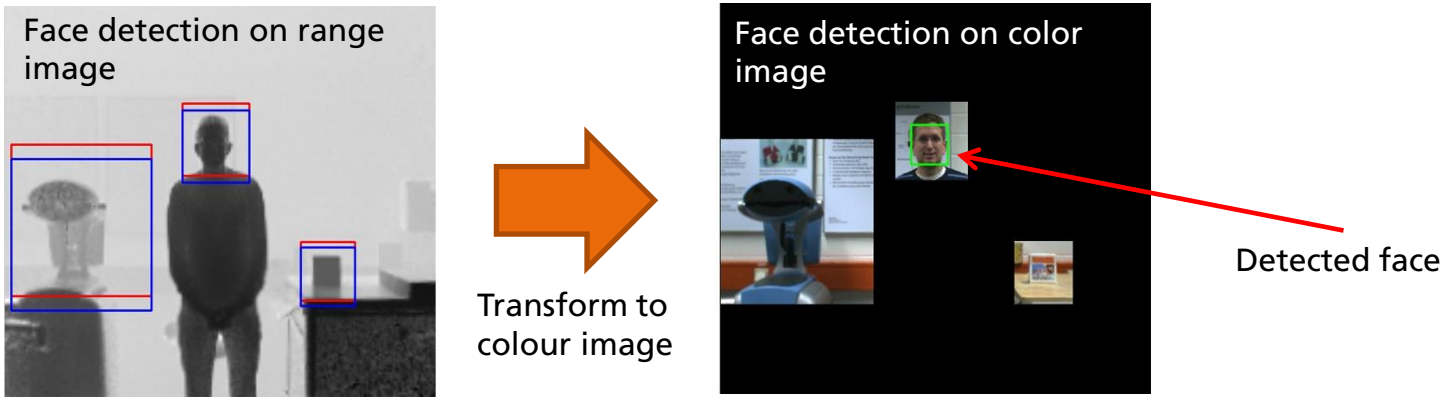
- Detection and localisation of objects based on the trained object models and feature point correspondences

Face detection

- Training of both color and range data
- Face detection initially performed on range images
- Detected Face-regions of the range image are further processed using the corresponding colour data
- Being labeled as a face region on range and color data, constitutes a detected face



Training data



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Conclusion

- 3-D environment construction extends capabilities of service robots
  - Navigation
  - Manipulation
  - Visualization
- Other applications for 3-D sensors
  - Object detection
  - Face detection
- Technology transfer to new products
  - Low-cost robotics: Vacuum cleaner, lawn mower
  - Collision avoidance during navigation: Commercial cleaning robots
  - Automotive applications: Driver assistance