TAMPEREEN TEKNILLINEN YLIOPISTO

Sensor technologies for autonomous machines

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Development of autonomous machines / Challenges

- **Mapping of the environment**; detecting and classifying objects in surroundings reliably (and cost effectively)
  - Sensor technologies and sensor fusion
  - Deep neural networks
- **Decision making**; to make a right decision how to react in changing situations
  - Situational awareness assessment
  - Navigation, collision avoidance, route following and planning
- **Communication;** how to communicate with remote operator safely and securely
  - Mobile networks (4G, 5G), WLAN, satellite communication systems
  - Data link capacity
  - Cybersecurity

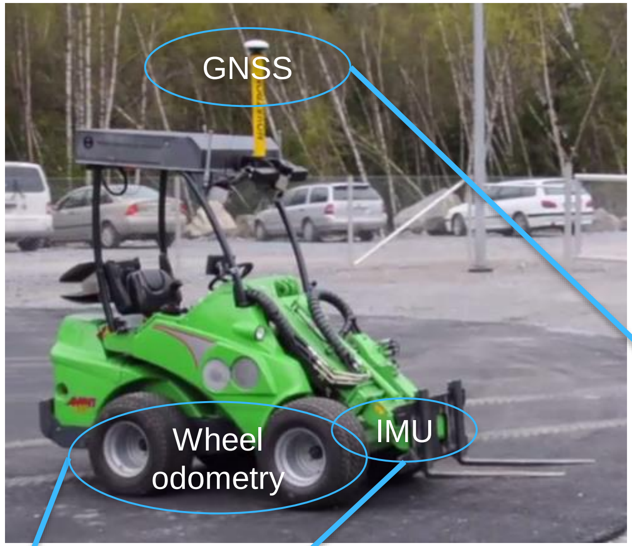
Sensor technologies

- Environment mapping and situational awareness
  - High resolution, Thermal and Night Vision cameras
    - Object detection and classification
    - Image analysis algorithms are demanding for computational power
    - Thermal cameras has quite narrow Field Of View and low resolution
  - Radars
    - Long range radars used long time in maritime applications; well known technology
    - Middle and short range (automotive) radars, 24/77 GHz
    - Better resolution, use in working machine applications possible
    - Robust against dust, snow, rain, fog
  - LiDARs; (*Light Detection and Ranging*)
    - Many different type of solutions from very cheap to very expensive;
    - New solid state LiDARs for more robust detection
    - Accurate mapping, 3D point clouds
    - More sensitive to dust, snow, rain, fog
- Sensor technology is developing very fast!

Sensor technologies

- Localization
  - Global Navigation Satellite System (GNSS)
    - GPS (USA), GLONASS (Russia), Galileo (EU), BeiDou-2 (China)
  - Inertial Measurement Unit (IMU)
    - Many different type of solutions from very cheap to very expensive
    - MEMS, Fiber Optical
  - Local beacon based localization
    - Ultra Wide Band (UWB) technologies, European Union ETSI EN 302 065 standard

Localization example



Dead reckoning (wheel odometry and inertial measurement unit)

Velocity,
Angular velocity,
Pitch and Roll

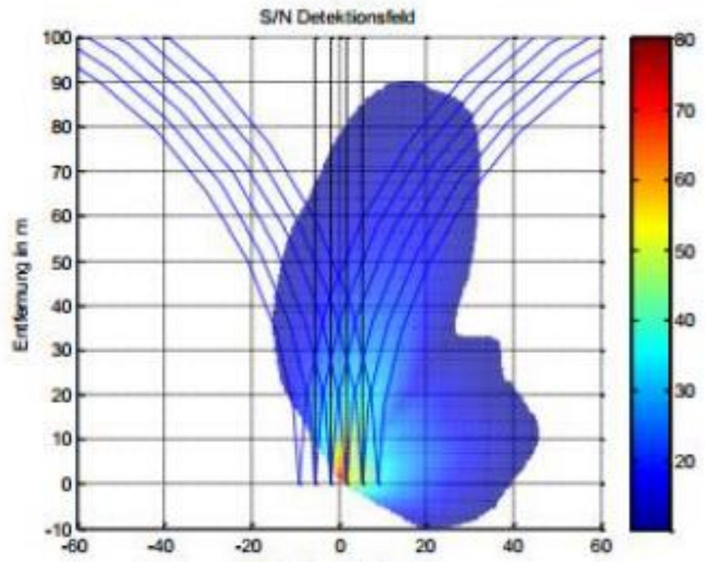
Global navigation (Kalman filter)

Position and Yaw angle in global frame

Short range 77 GHz (automotive) radar

- A list objects (32) are send via CAN every 40..70ms.

time (added at xPC Target)
id (added at xPC Target)
(1) vr
(2) dr
(3) wExist
(4) countAlive
(5) dpPower
(6) phiSdv
(7) phi
(8) flagHist
(9) flagMeas
(10) flagValid
(11) MessAconsistBit



Kuvien lähteet: Bosch

Radar test

-tracking a row boat

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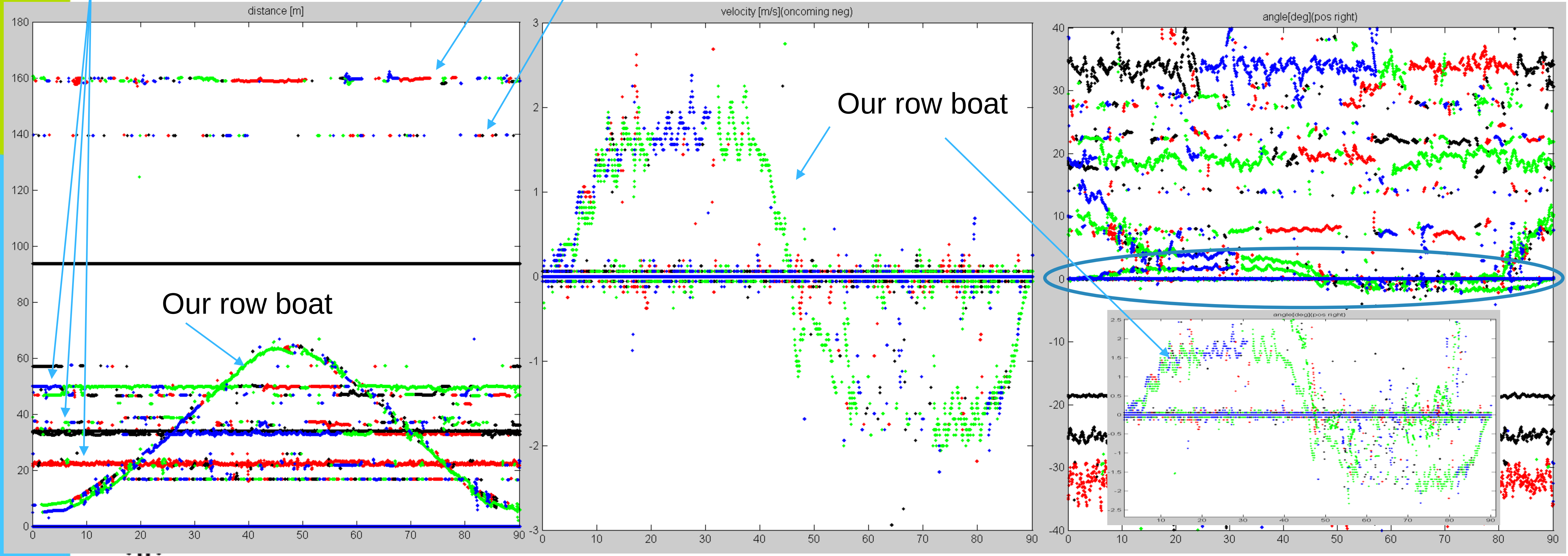
All 32 object data plotted together vs. time

Distance(left), Velocity(middle) and Angle(right)

(Note! Objects 1-8 red, 9-16 black, 17-24 green, 25-32 blue)

Other stationary row boats

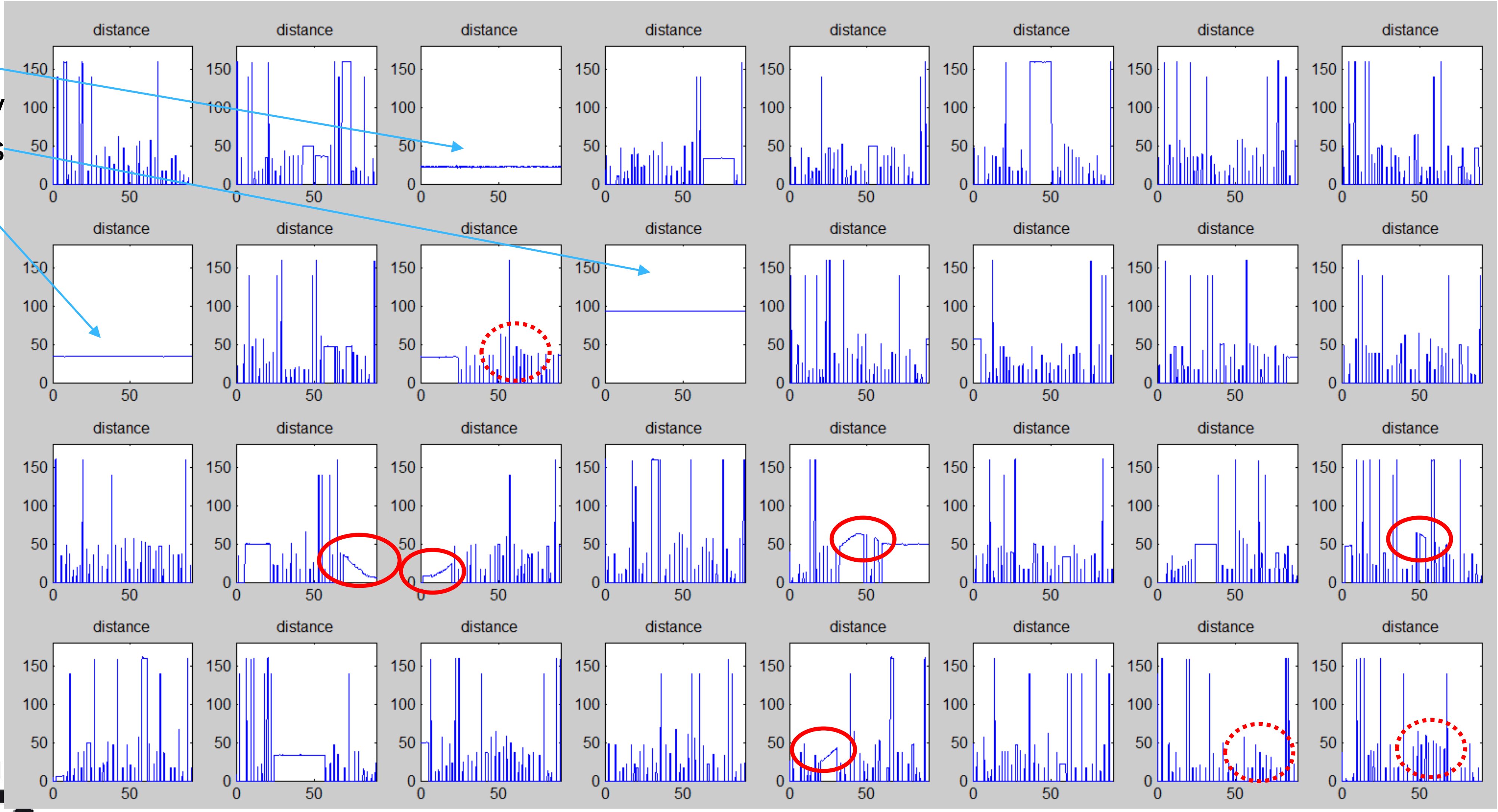
Shore, buildings



Object data (1-32), distance [m]

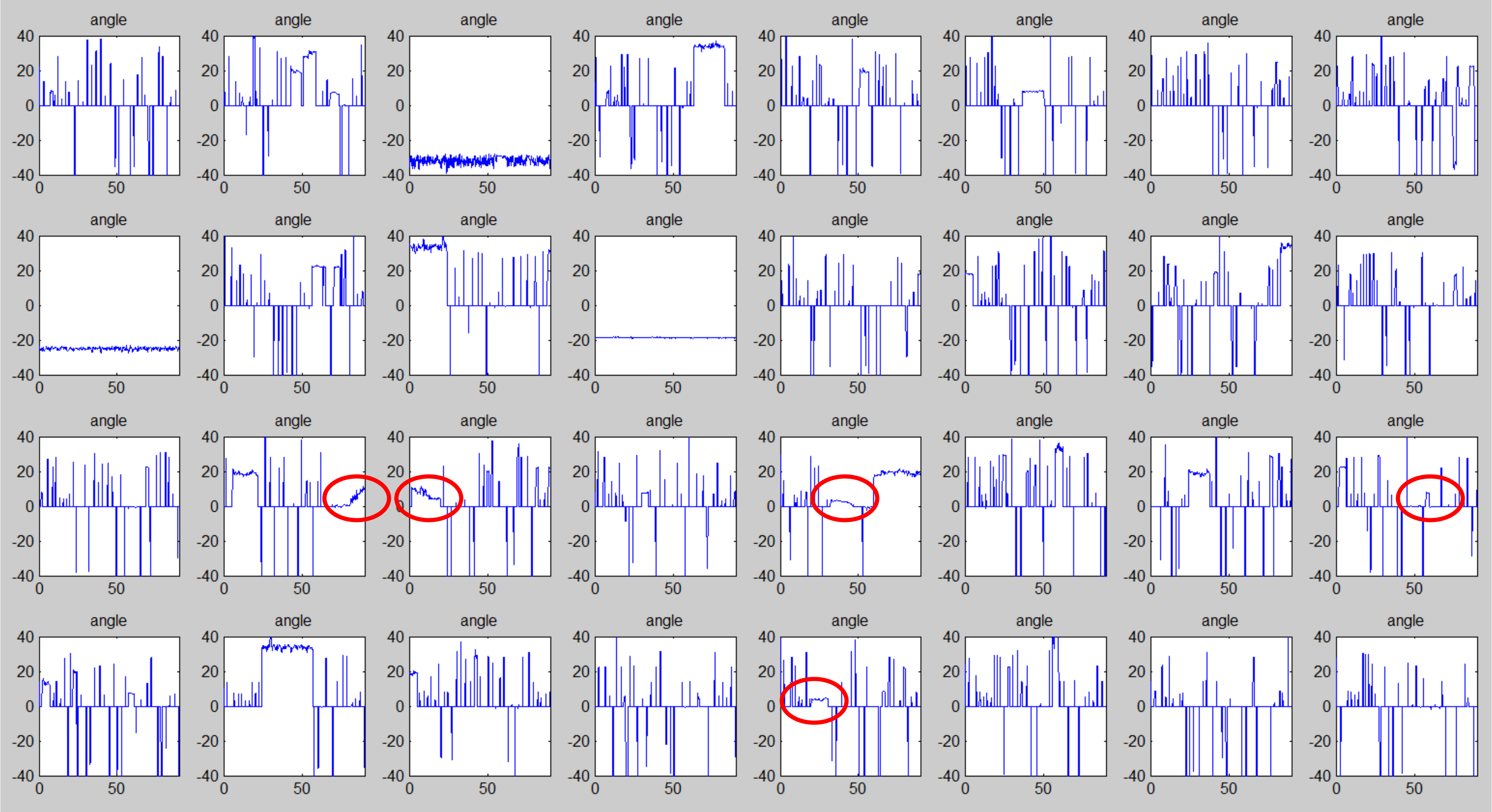
Our row boat

Other stationary row boats



Our row boat

Object data (1-32), angle [deg]



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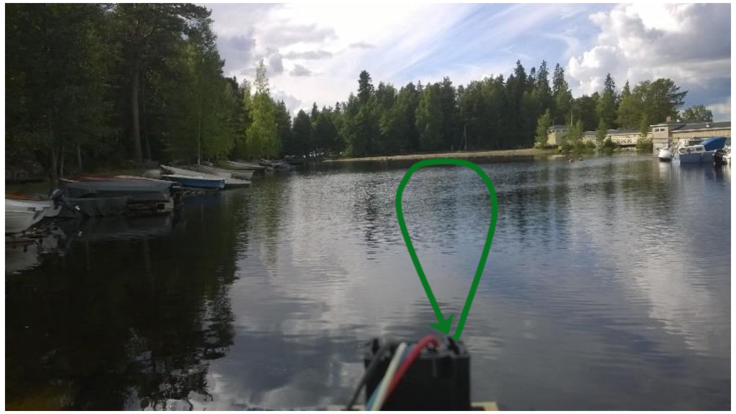
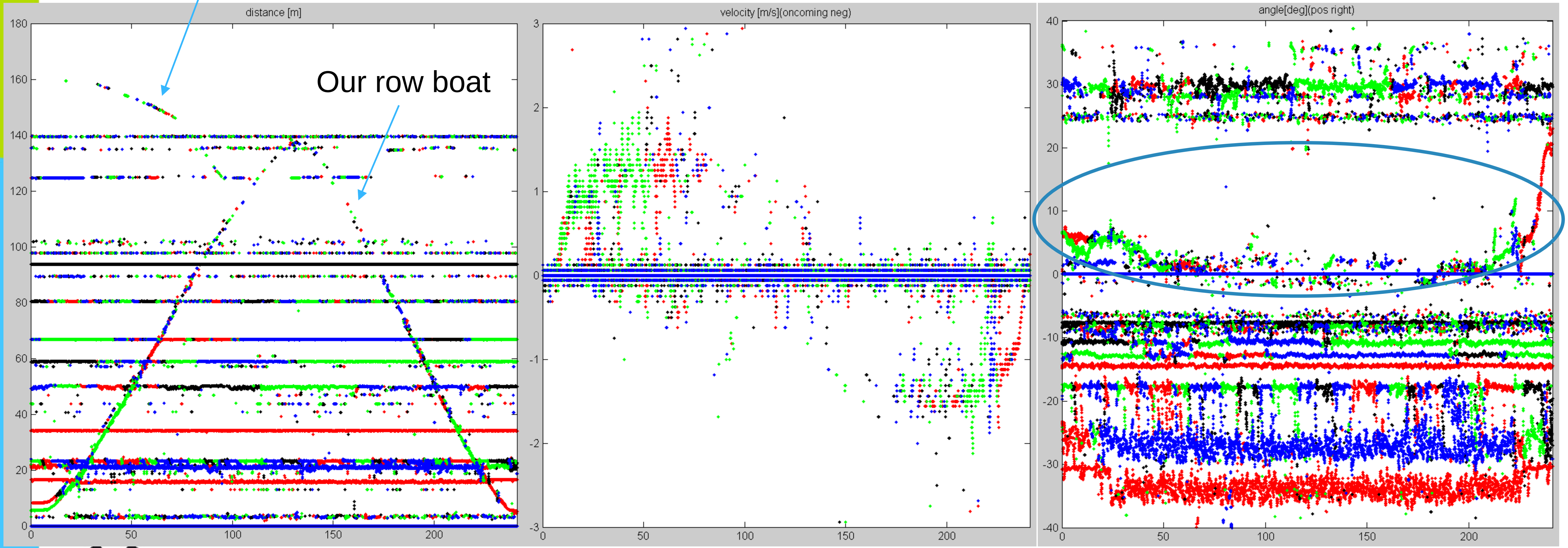
Radar test, tracking a row boat, case2

Distance(left), Velocity(middle) and Angle(right)

(Note! Objects 1-8 red, 9-16 black, 17-24 green, 25-32 blue)



Another boat leaving from shore to lake



Leddar sensor / Evaluation Kit test

Featured Application Notes

- Collision Avoidance Sensor for Large Vehicles
- Counting Objects on Multiple Conveyors
- Loading Dock Vehicle Position Sensor
- Security and Surveillance Optical Barrier for Secured Premises
- Street Parking Space Occupancy Sensor
- Truck Classification Sensor for Inspection Stations
- Vehicle Detector for Barrier Gate Control

- RS-485
- CAN bus
- DIP switches² (4)
- MicroSD card slot2
- Expansion connector2 (UART, CAN, SPI, GPIO, DAC)

The following is a description of the main components of the Leddar™ Evaluation Kit.

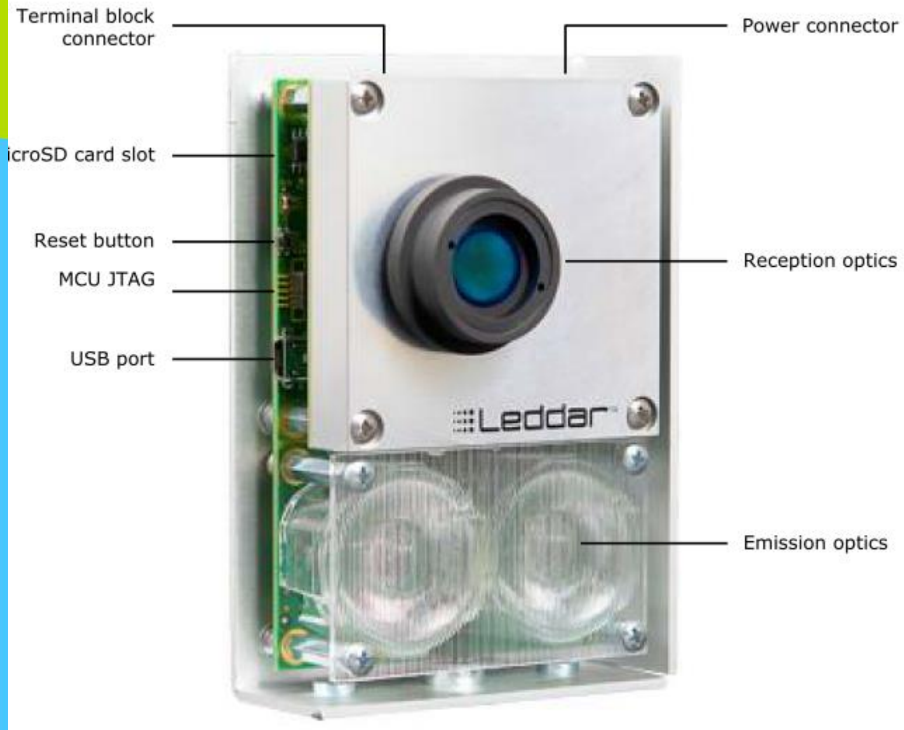
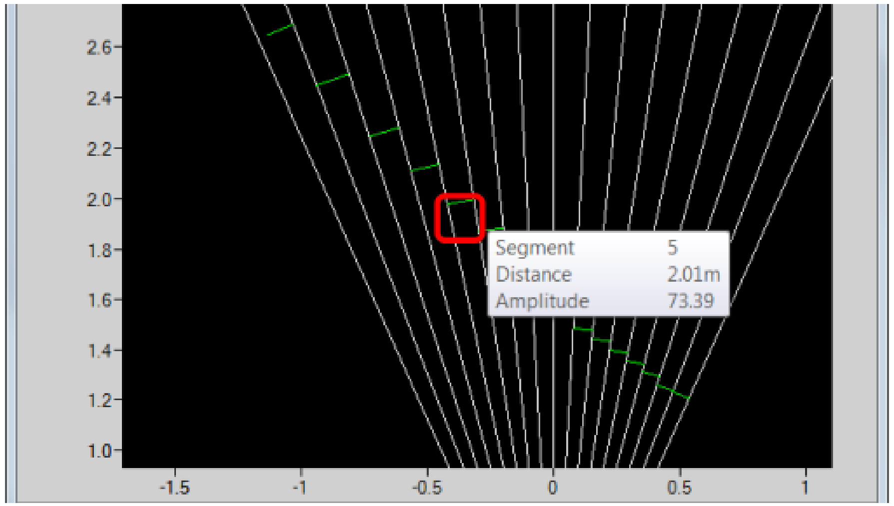


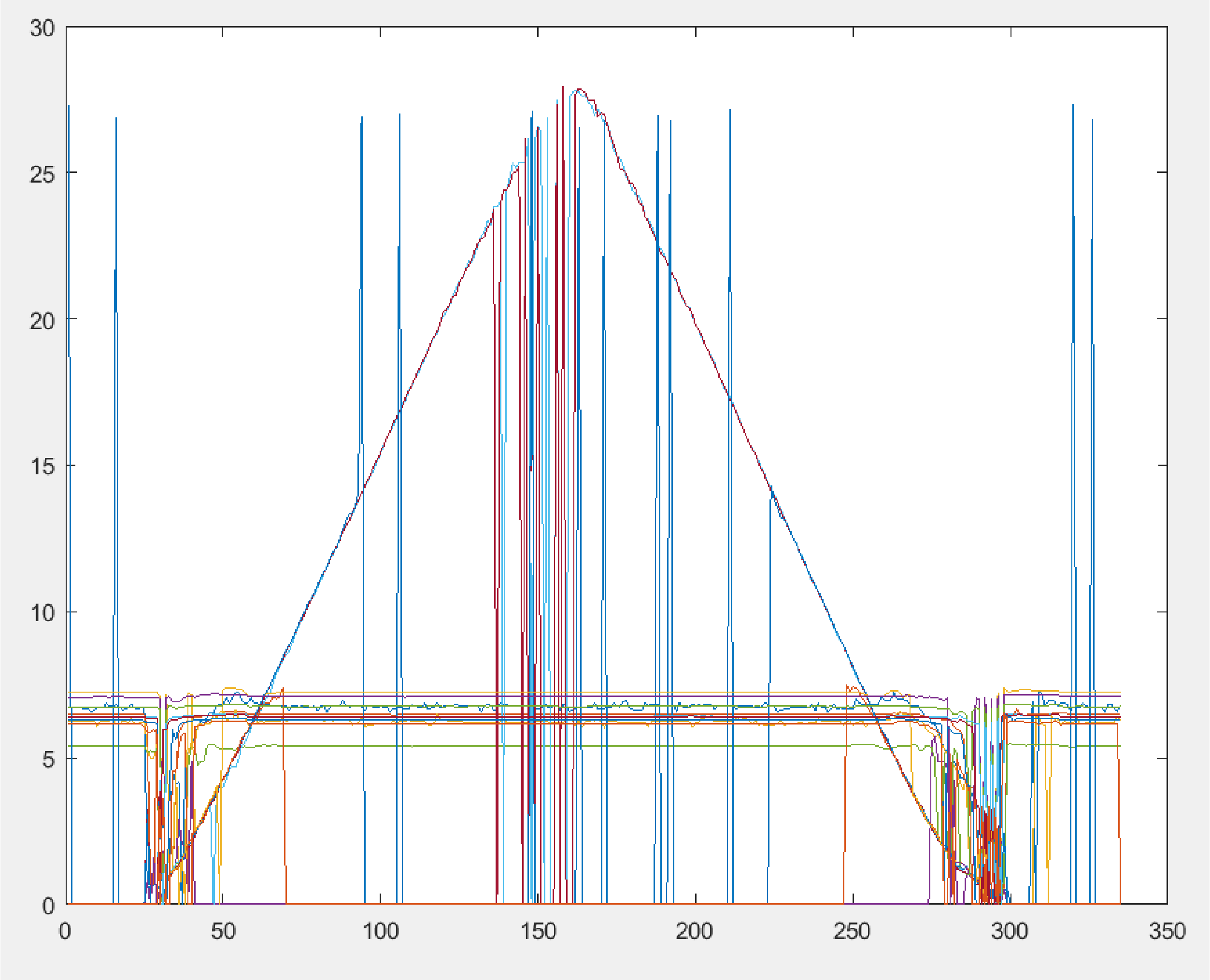
Figure 1: Evaluation Kit Sensor



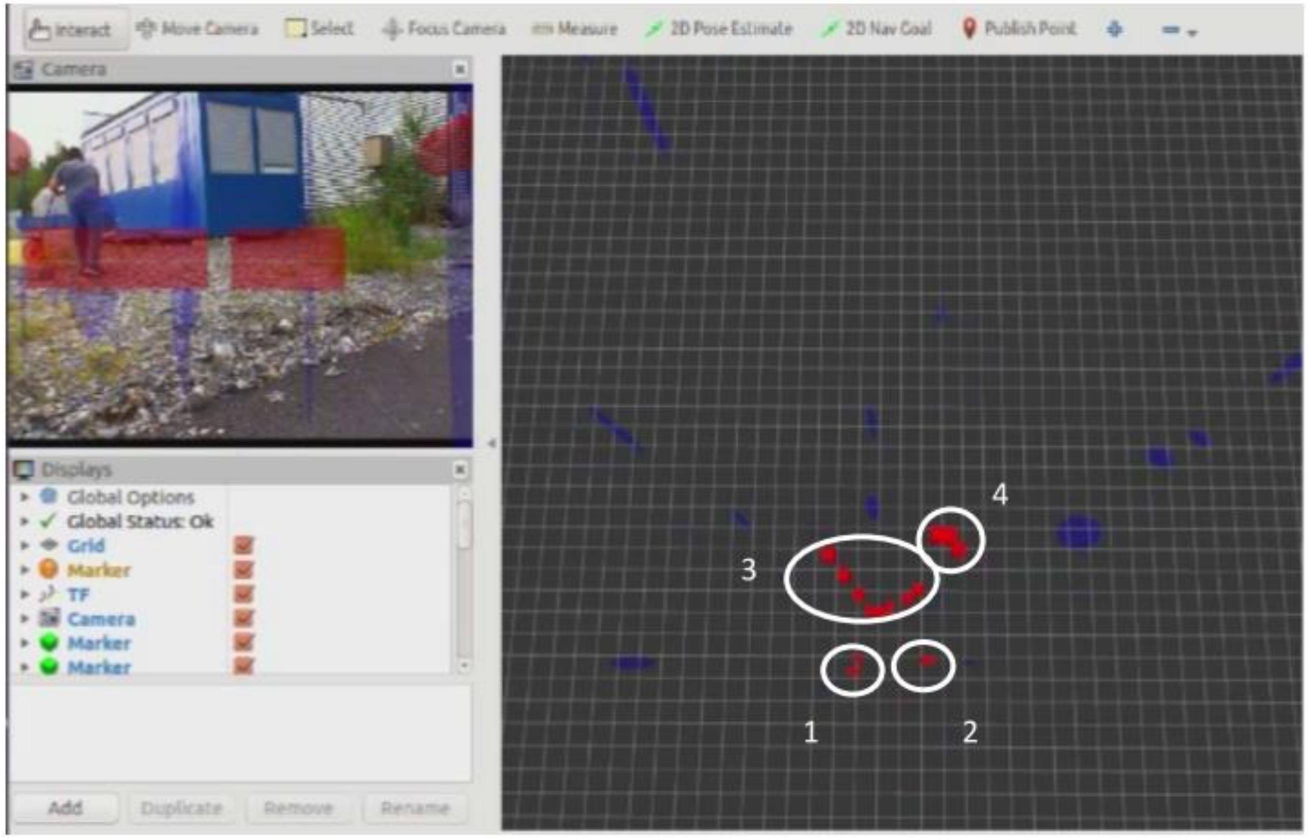
Kuvien lähteet: Leddar

Test at TUT mobile hall / raining sleet

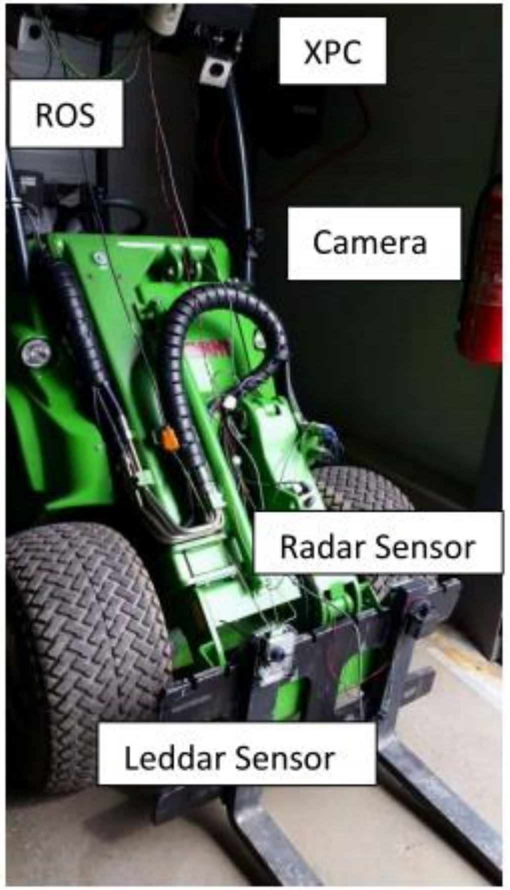
- Human walking to the car and back



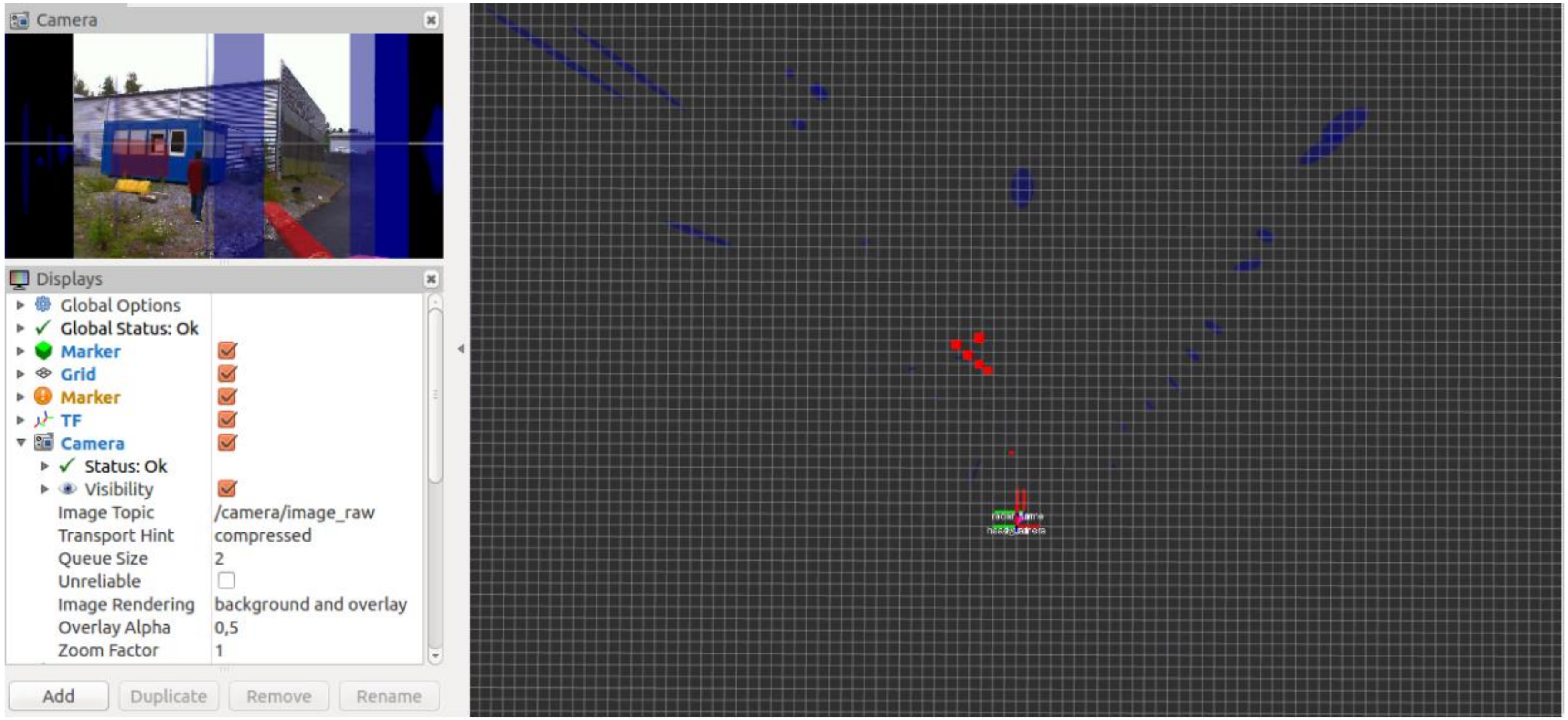
Leddar and 77 GHz radar at experimental work machine of TUT



The first test was to detect different stationary objects. as it can be seen in the image above. the 1st circle contains Leddar segments of detecting human. 2nd circle contains Leddar segments of some bushes whereas the 3rd and the 4th circles contains segments which are showing container and building respectively



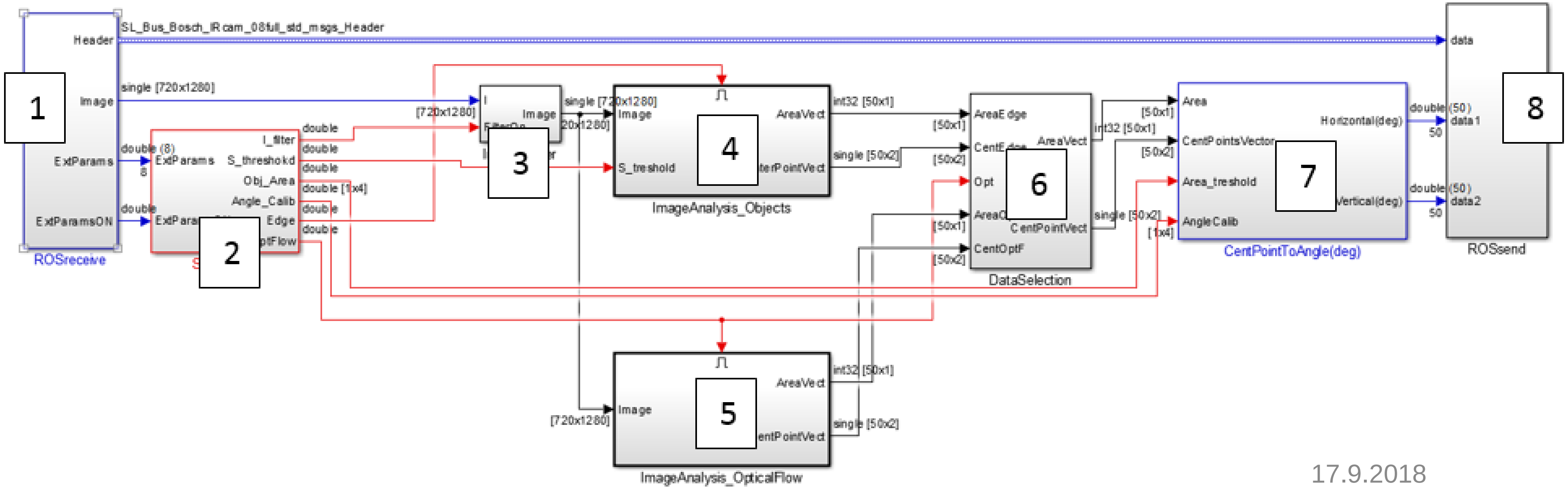
Leddar and 77 GHz radar at experimental work machine of TUT



Human detection is also possible while the sensor is in dynamic condition. In this image the human is detected by the sensor in addition to the building behind it.

Example of camera data analysis in Matlab/Simulink

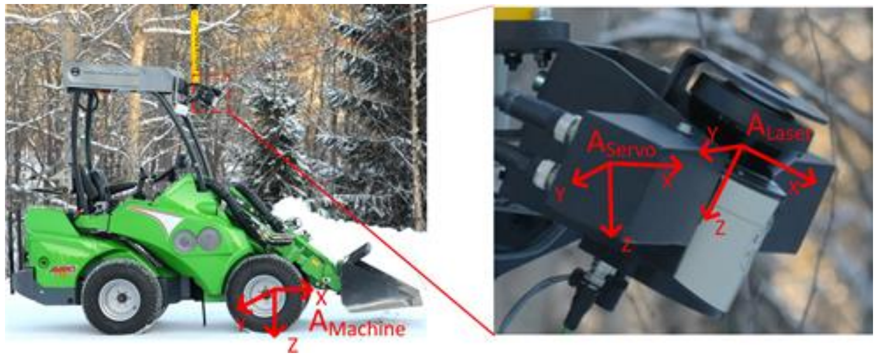
1. Raw data image receiving from ROS camera data stream
2. Filter parameters and used method selection
3. Image median filter, can be selected on/off
4. Sobel Edge detection and Blob analysis algorithms
5. Lucas-Canade Optical flow and Blob detection algorithms
6. Data selection and Blob filtering
7. Data conversion from image to horizontal and vertical angles for working machine display
8. Object data sending to ROS

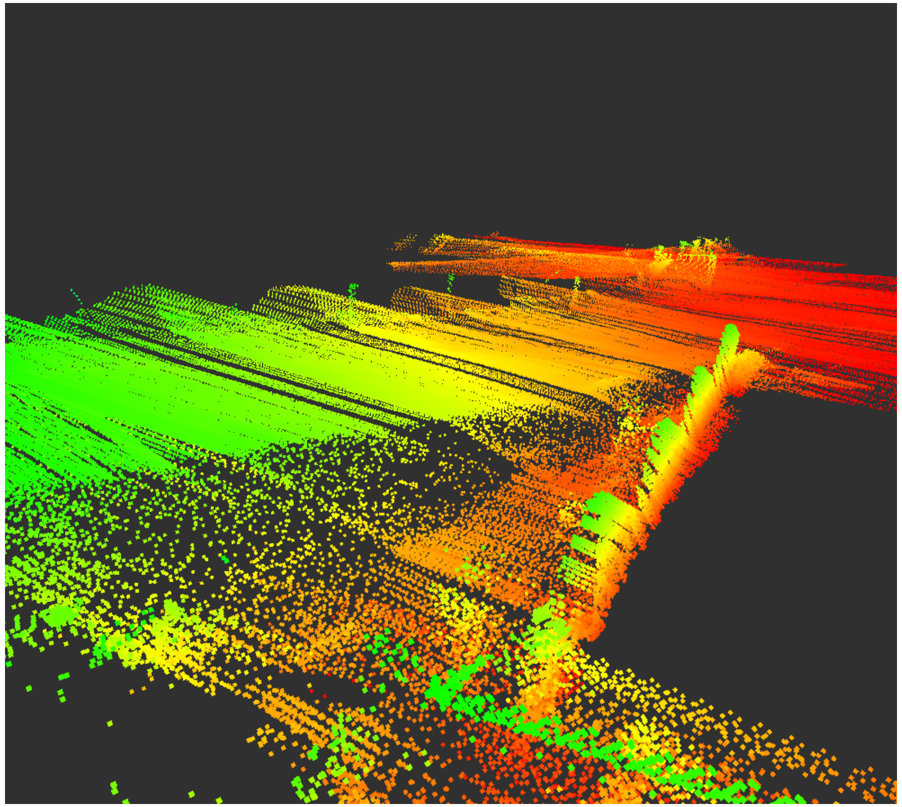


Thermal camera

LiDAR based mapping

- Sensing the world with LiDAR and creating a point cloud with variance information based on the location of AGV.
  - Tilting 2D laser scanner
  - Localization of the machine in 6DOF based on GNSS, IMU and wheel odometry.

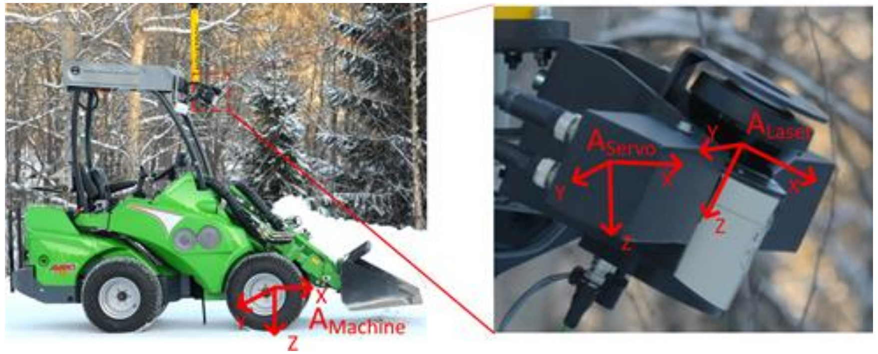


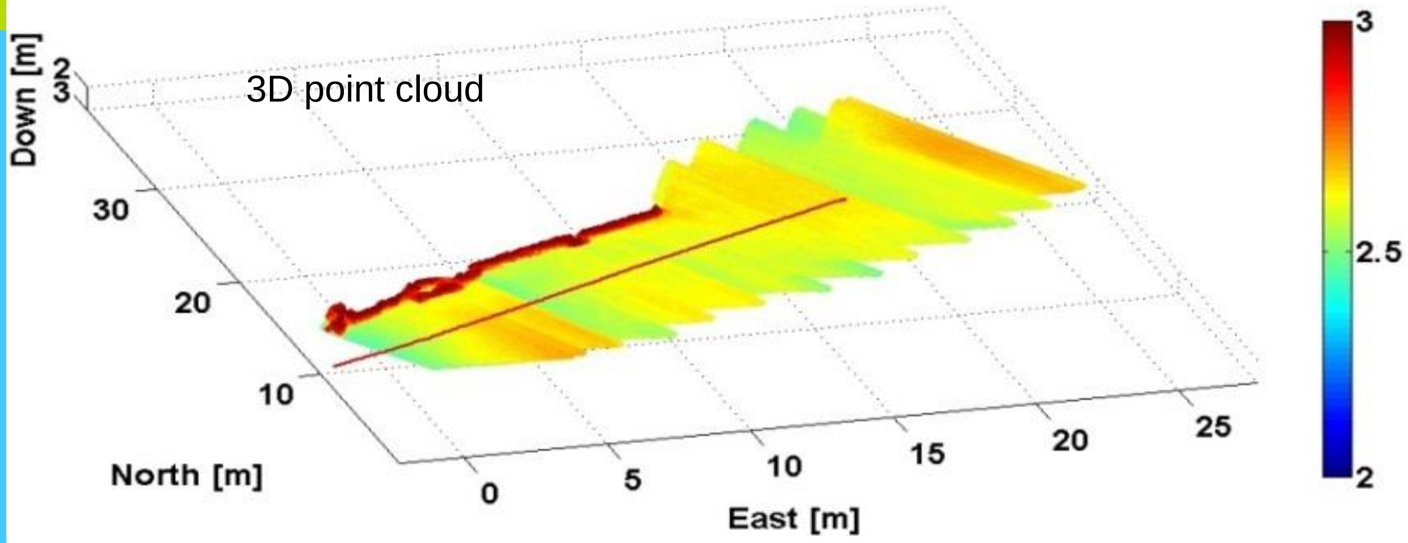


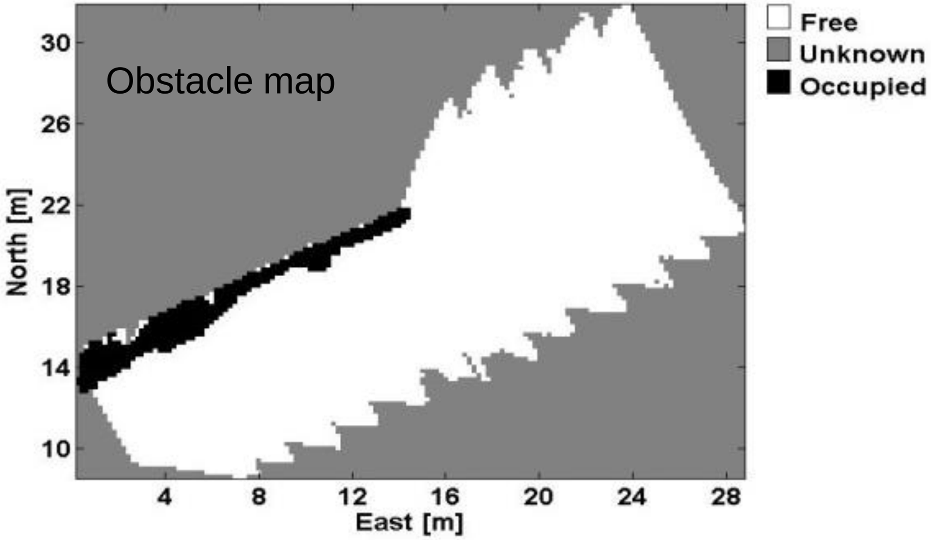
Challenges:
localization, time sync. & calibrations

Mapping and obstacle avoidance for AGV

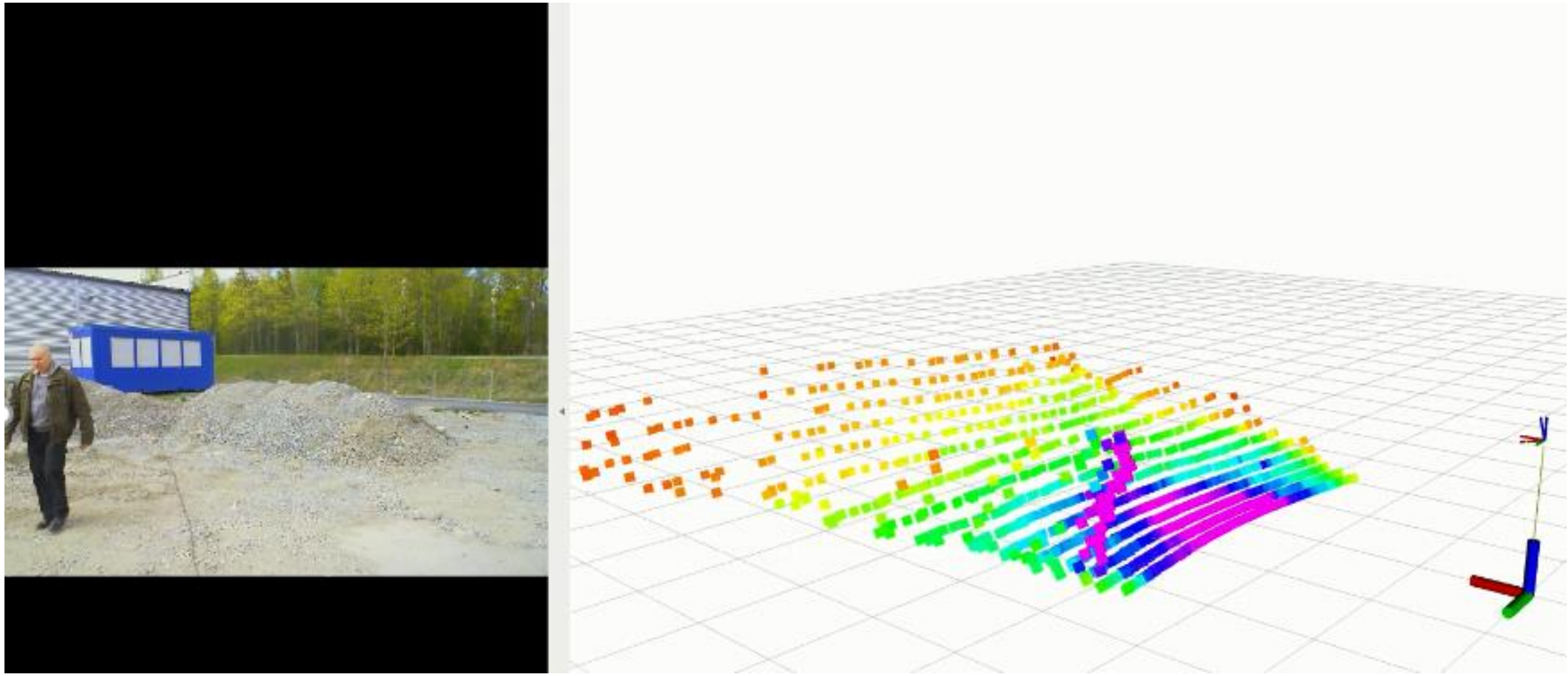
- Height map is calculated based on the 3D point cloud and gradient thresholding is used to create obstacle map that can be used for path planning and obstacle avoidance.



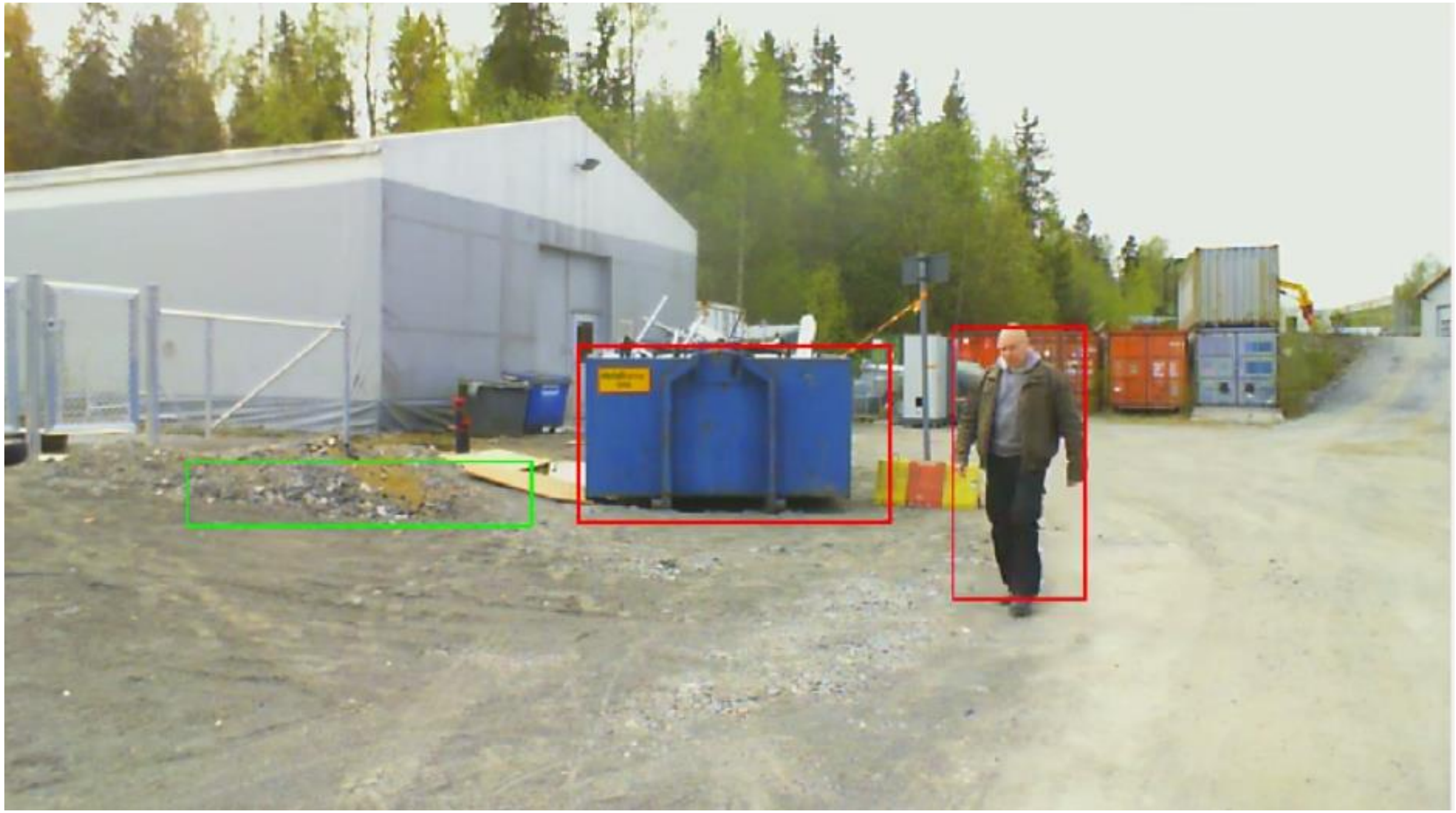




TOF camera / point cloud data

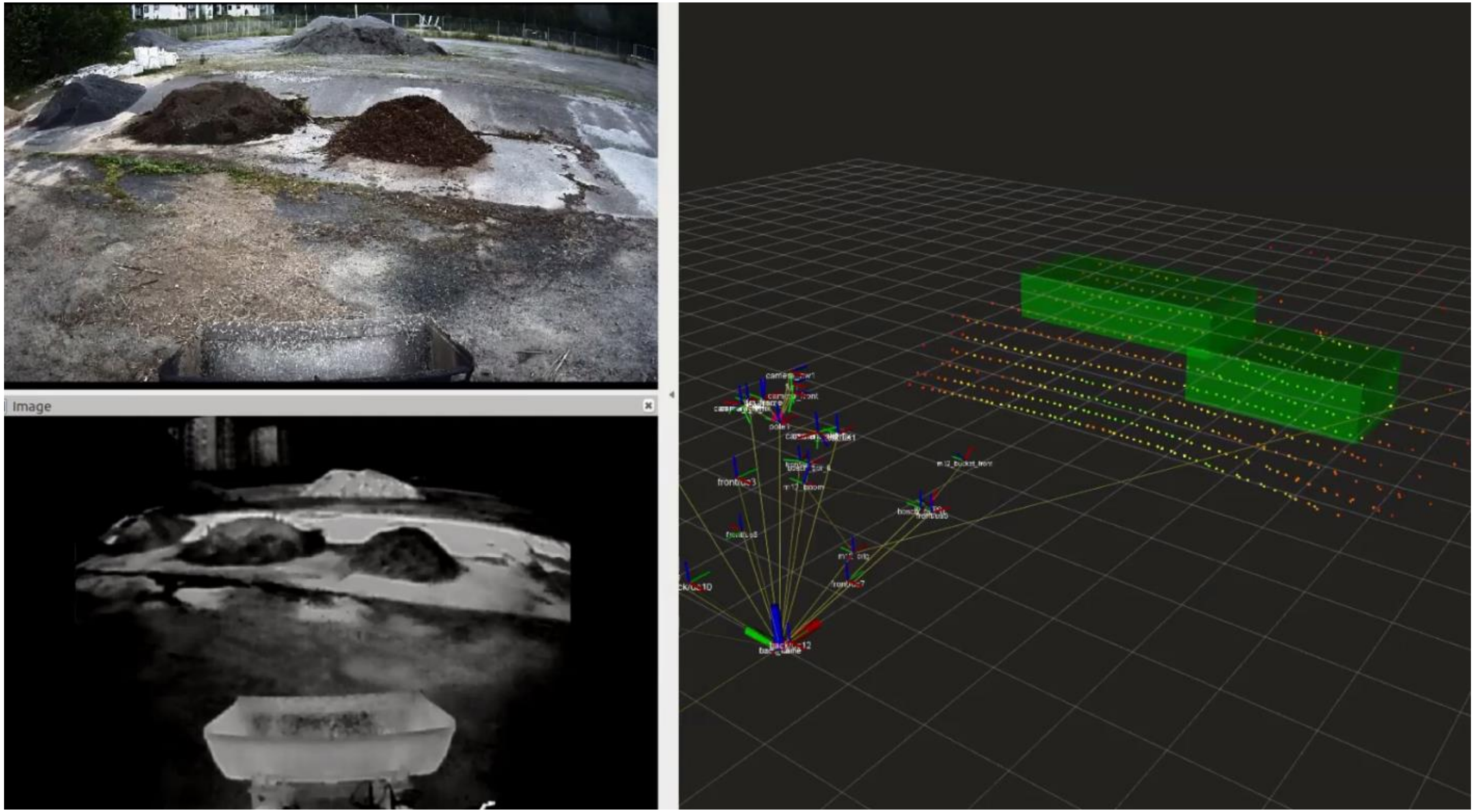


TOF camera / data analysis example / obstacle detection



Data fusion

HD camera

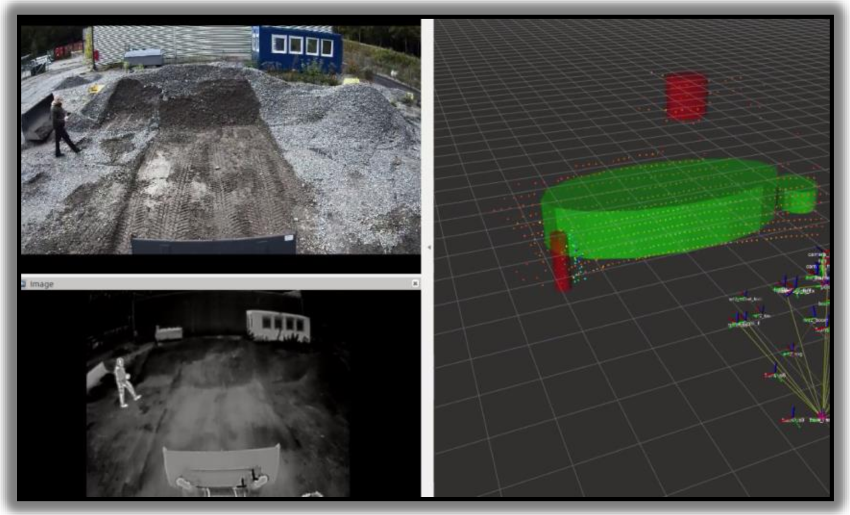


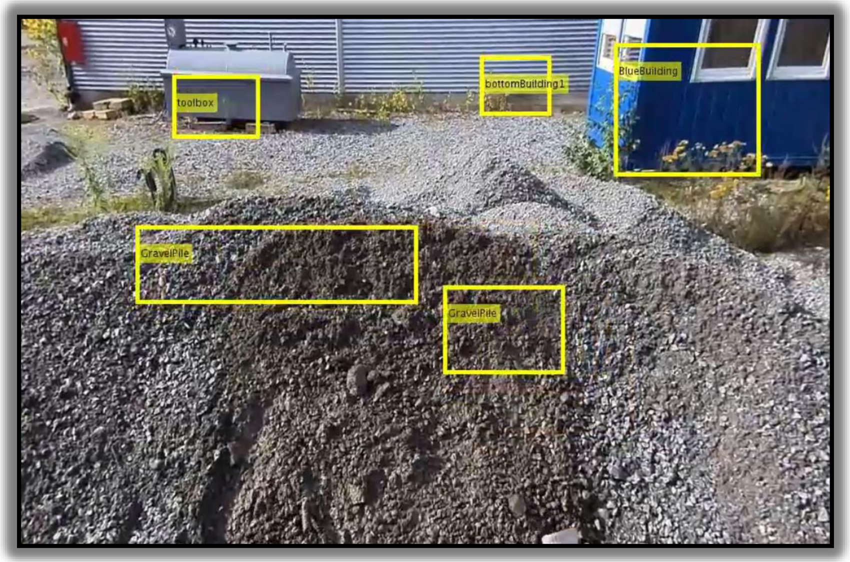
TOF -sensor

Therma camera

Data fusion / Autonomous working machines

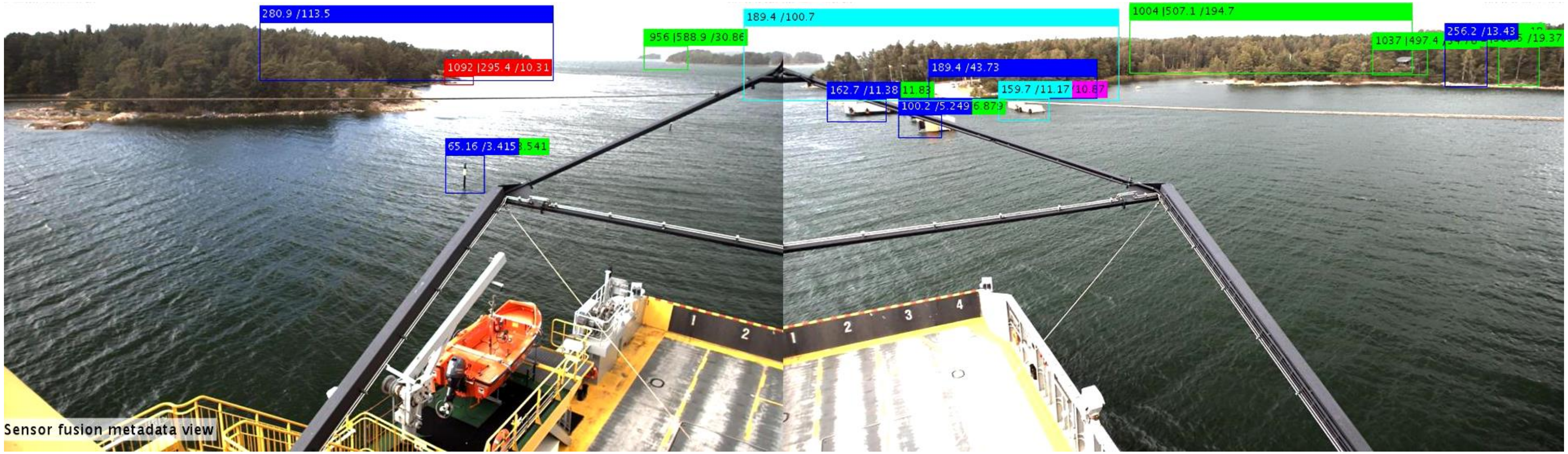
- Autonomous driving
  - Navigation, path planning, path following, collision avoidance
- **Autonomous manipulation**
  - ”Controlled collision” with manipulated objects
  - Demands for situational awareness system; robust and reliable object detection and classification important
    - Use of deep neural networks
      - Convolutional Neural Networks for real time object detection and classification





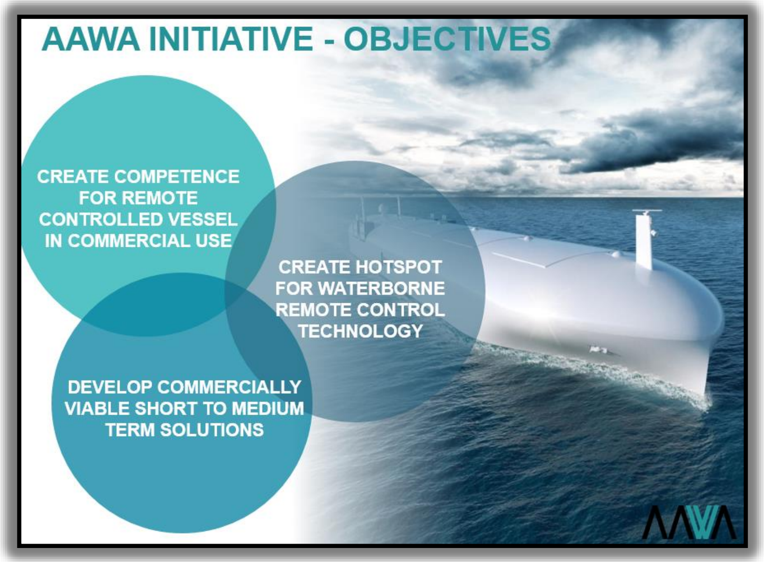
Data fusion / Autonomous ships

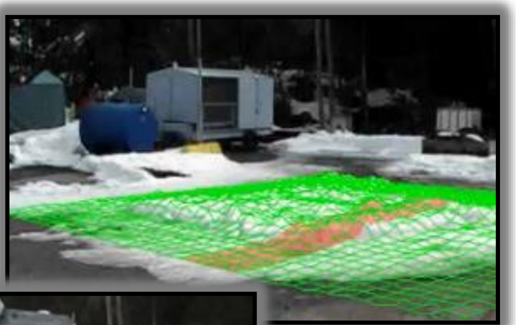
- Data of different sensors are fused (Kalman filter, Particle filter etc.) to create a map of the environment and localization of the machine in the map.
  - they can further be used in driver assistance systems or in collision avoidance systems of the autonomous machines.

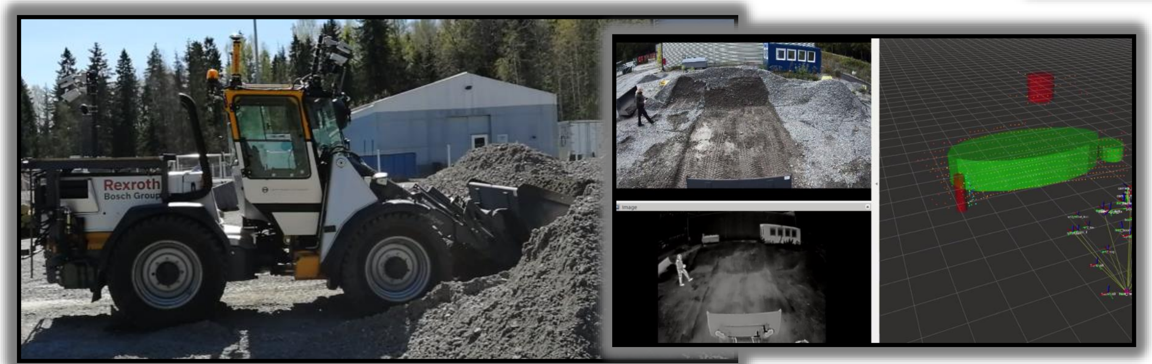


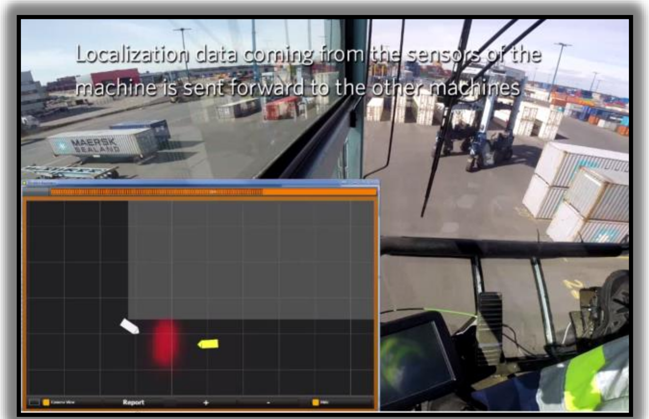
Research of unmanned mobile machines at TUT/AUT

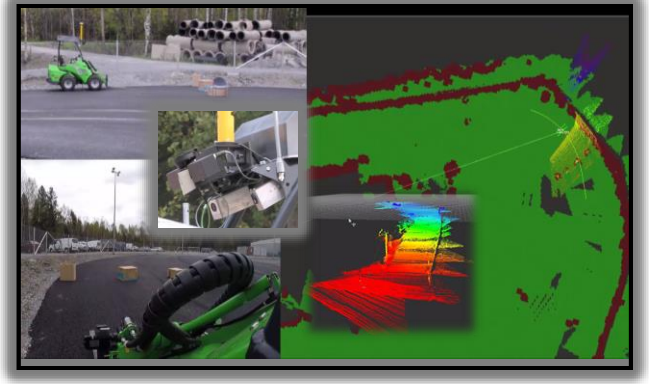
- Navigation using sensor fusion (IMU, GNSS, Radar, Lidar, Camera, Thermal cam., TOF sensor …)
- Dynamic mapping and obstacle avoidance
- Situation awareness systems
- Path planning and following for autonomous driving and manipulation
- Energy efficiency research of the mobile machines











Future trends in autonomous machines (in general)

- All functionalities of the mobile machines can’t be covered (cost effectively) with fully autonomous machines; human is still needed in many applications.
  - Sliding autonomy solves this problem; the same machine can be fully autonomous, fully manual or something in between.
- Environmental aspects
  - Different weather conditions; snow, rain, temperature etc.
    - The same algorithm won’t work everywhere, how to detect right one?
  - Unstructured and not restricted environment
    - First applications in places where environment easy to deal with autonomy; agriculture, ships, construction sites, rail roads…
- Autonomous manipulation of the mobile machines is challenging and expensive
  - Unsolved sensing and control problems still exists in many applications; snow ploughing, sand/gravel/rock removal etc.
- Artificial intelligence -> ethical problems
  - Who to save in accident? Decision making in different applications (civil engineering, automotive, military, nursing etc.) applications?
  - Who is responsible; manufacturer, coder,…?

Thank you!