School of Mechanical Engineering
FACULTY OF ENGINEERING

UNIVERSITY OF LEEDS

MECH5170M
Connected and Autonomous Vehicles Systems

Sensors Fusion

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Outline

- Sensors functionality
- Multiple inputs from environment
- Sensor Fusion
- Sensors noise and precision

Sensors Fusion

Sensors functionalities

ADAS and Autonomous Driving Sensor Modalities

Function	Imaging	Radar	LiDAR	Ultrasonic
Angular Resolution	Excellent/Good	Weak	Excellent/Good	No function / High cost
Depth Resolution	Weak	Excellent/Good	Excellent/Good	Excellent/Good
Velocity	No function / High cost	Excellent/Good	Weak	No function / High cost
Depth Range	Weak	Excellent/Good	Excellent/Good	Weak
Traffic Signs	Excellent/Good	No function / High cost	Weak	No function / High cost
Object Edge Precision	Excellent/Good	No function / High cost	Excellent/Good	Weak
Lane Detection	Excellent/Good	No function / High cost	Weak	No function / High cost
Color Recognition	Excellent/Good	No function / High cost	No function / High cost	No function / High cost
Adverse Weather	Weak	Excellent/Good	Weak	Excellent/Good
Low-Light Performance	Weak	Excellent/Good	Excellent/Good	Excellent/Good
Cost	Excellent/Good	Weak	No function / High cost	Excellent/Good

Excellent/Good Weak No function / High cost

Sensor Fusion - Multi-sensor Integration

Sensor Fusion = How to combine data from different sources?

- **Why is it necessary?**

– A single source of sensory information can only provide partial information of the environment, usually unable to solve ambiguities.

– The information from a single sensor is:

  - uncertain (has noise)
  - usually partial (e.g., occlusions)
  - occasionally spurious or incorrect (e.g., specular reflections in ultrasound)
  - often geographically or geometrically incomparable with other sensors

Sensor Fusion

Use diverse information from many different sources to overcome the limitations of a single source of information:

- coordinated constraint of partial interpretations,
- cooperative resolution of ambiguity.

Data fusion (in the context of automotive):

- Combine measurements from different sensors
- Combine measurements from different positions
- Combine measurements from different times (history)

Geometric description of sensor information

In a sensor team (sensor integration)

• **Each sensor** is a geometric extractor able to extract uncertain geometric information about the environment and communicate this information to the system

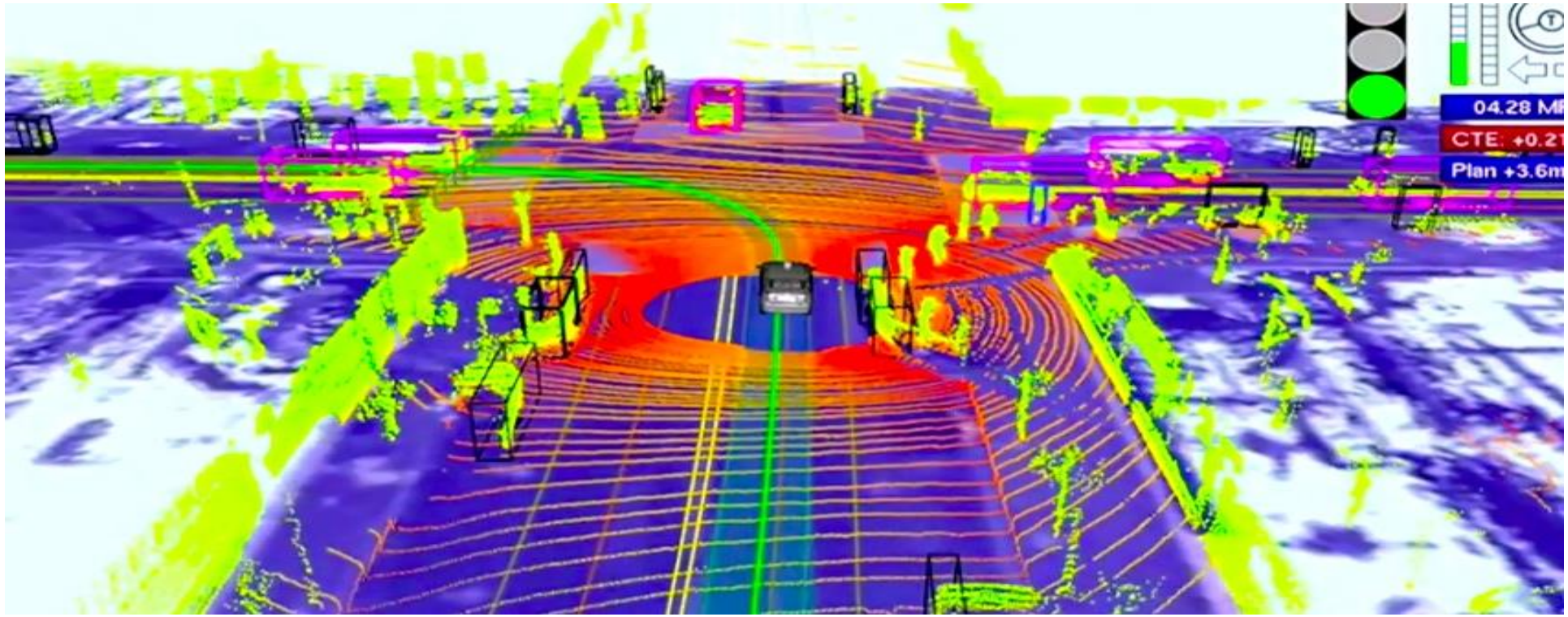
- Noise is naturally embedded
- The communication of information is reduced to the geometric functions.
- There is a common language of geometry.

Sensors as Team Members

Describe a multi-sensor system as a team:

- The sensors are considered members of the team
- Each sensor observes the environment and makes local decisions based on the information available to them.
- The observations made by a sensor are described by an information structure
- Each sensor can make a decision based on these observations, resulting in an action (e.g., estimation of characteristics of an object, size, distance)
- The opinions of each sensor are integrated to provide a team decision and action.

Environment model constructed from different sources of information



Sensors Limitations

- Distance
- Range
- Resolution
- Update Frequency
- Environmental conditions

Technology \ Environmental Extreme	Night	Day	Rain	Humidity	Snow	Fog	Smog	Hot	Cold	Wind
Ultrasonic										
Radar										
LIDAR										
Infrared										
Visible Systems										

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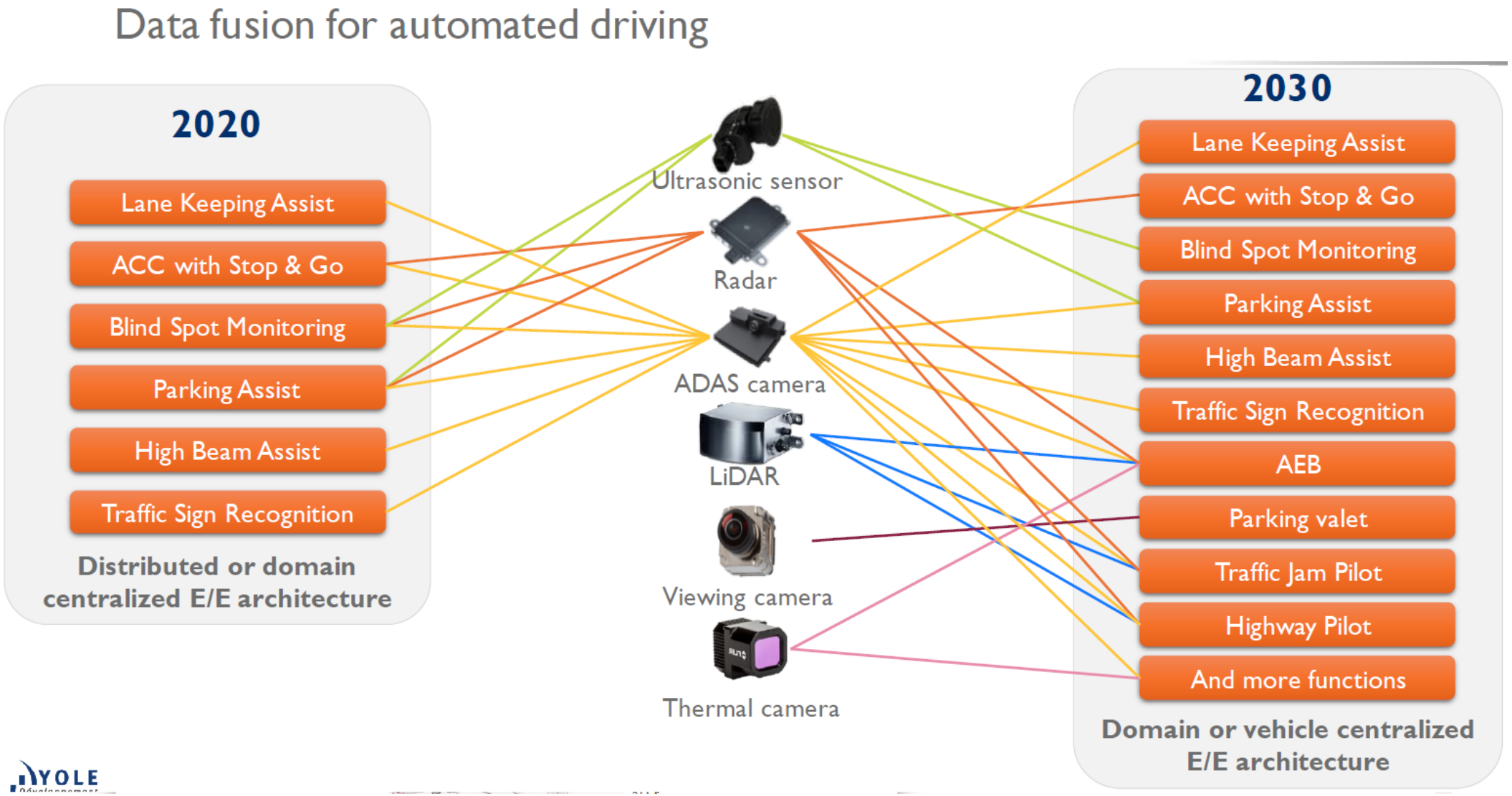
Data Fusion



Lidar signal with the noise

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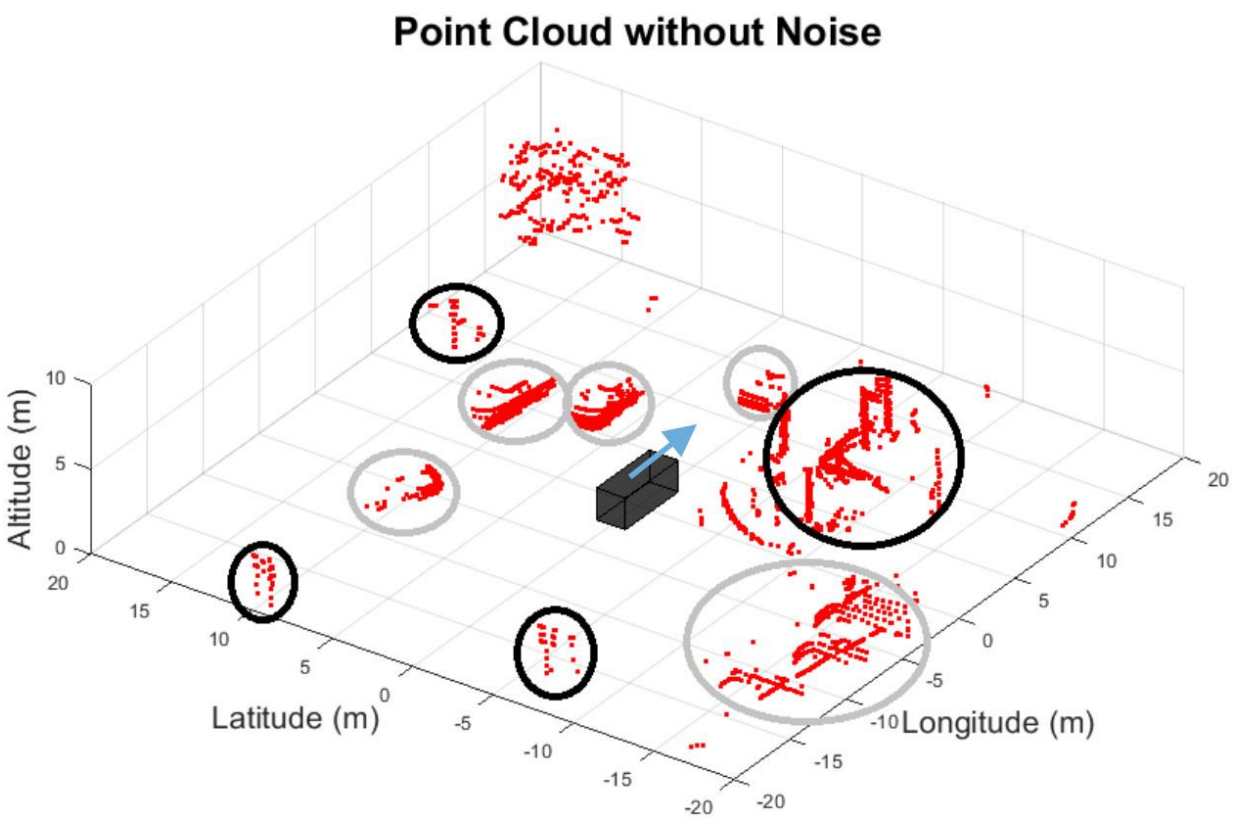

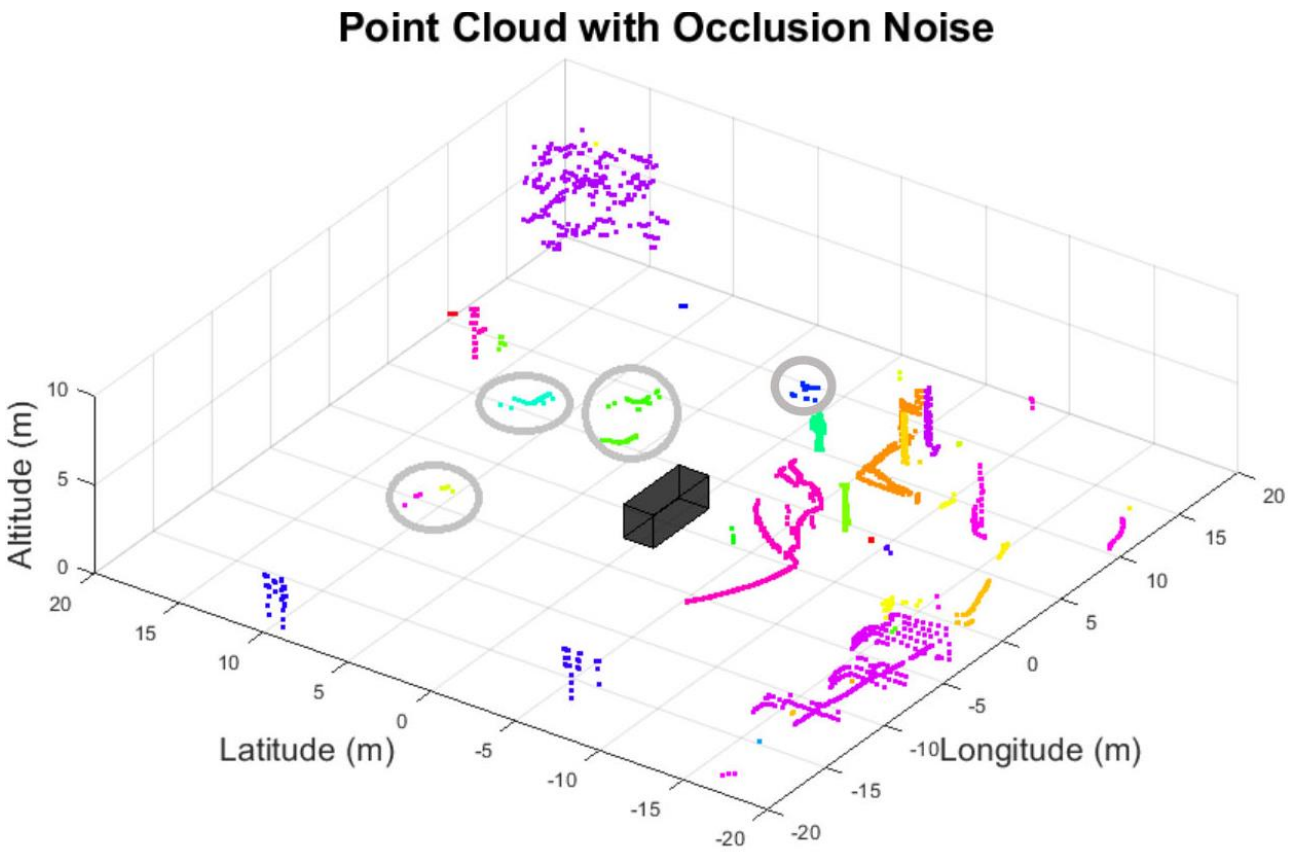

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Occlusion – for example pedestrian behind the bushes or tree

Lidar signal with the noise

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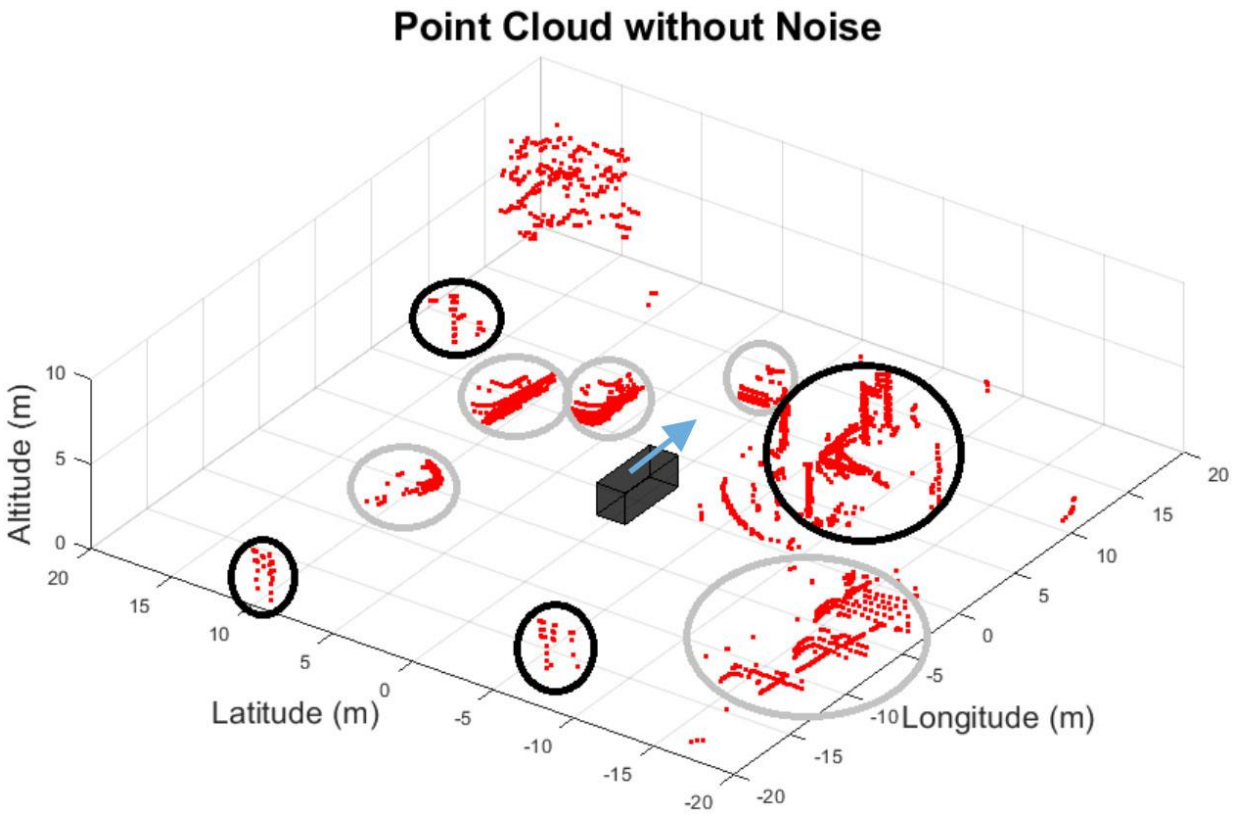

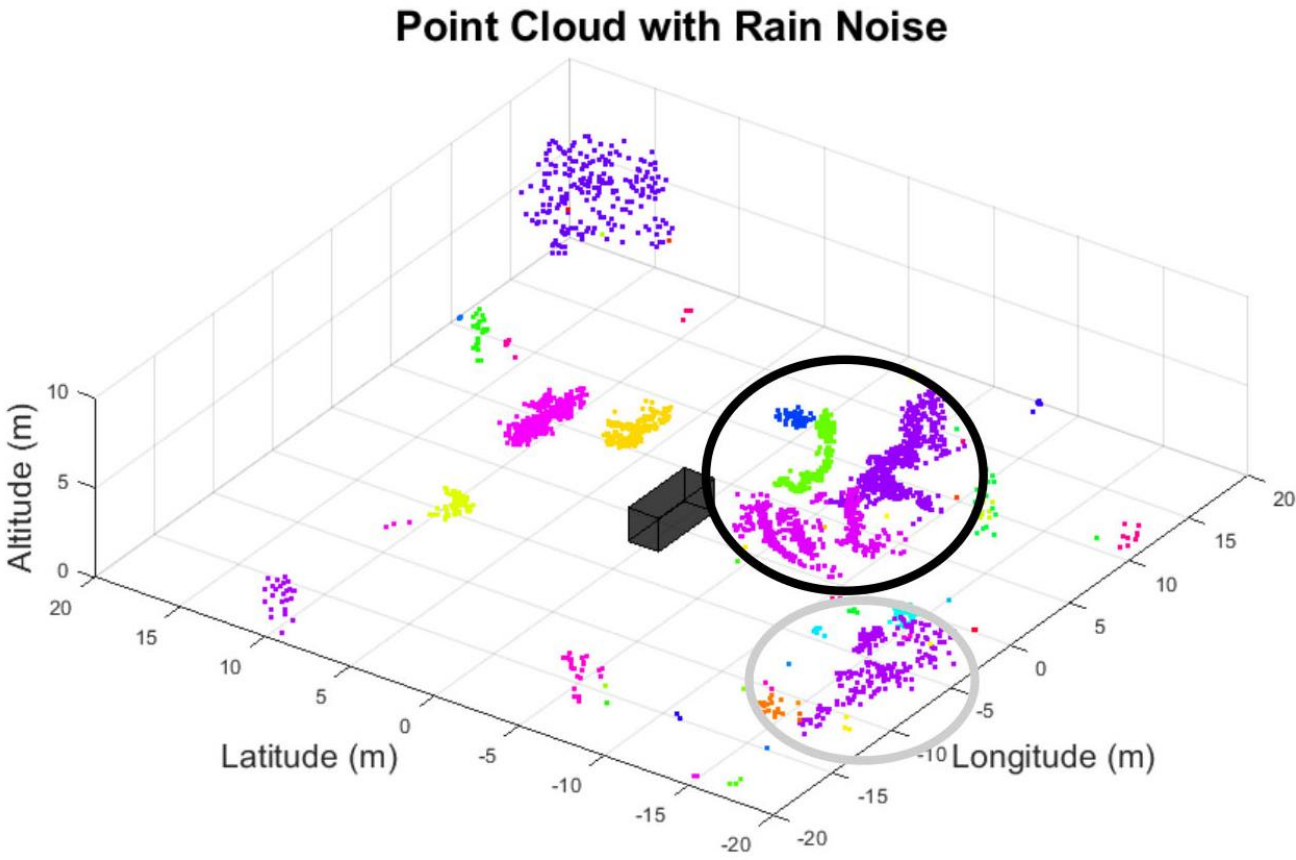

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Lidar signal with the noise

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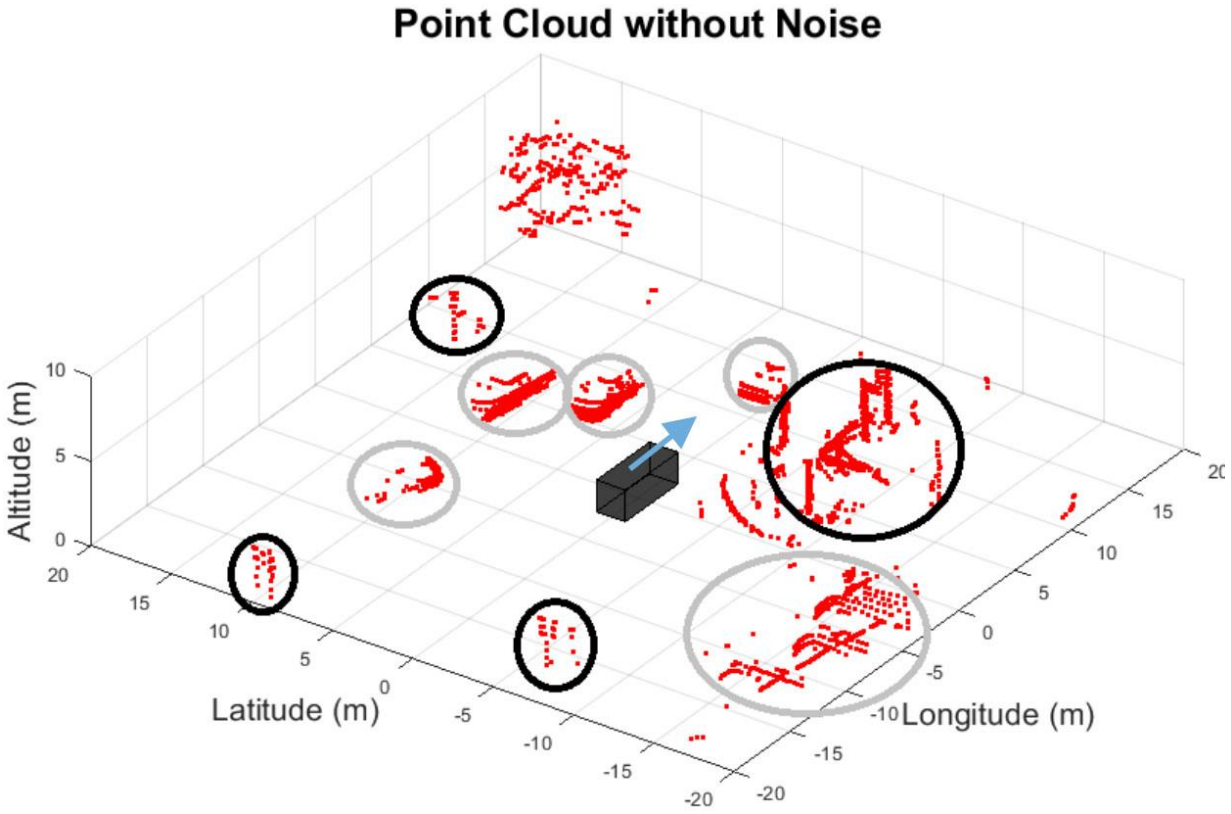

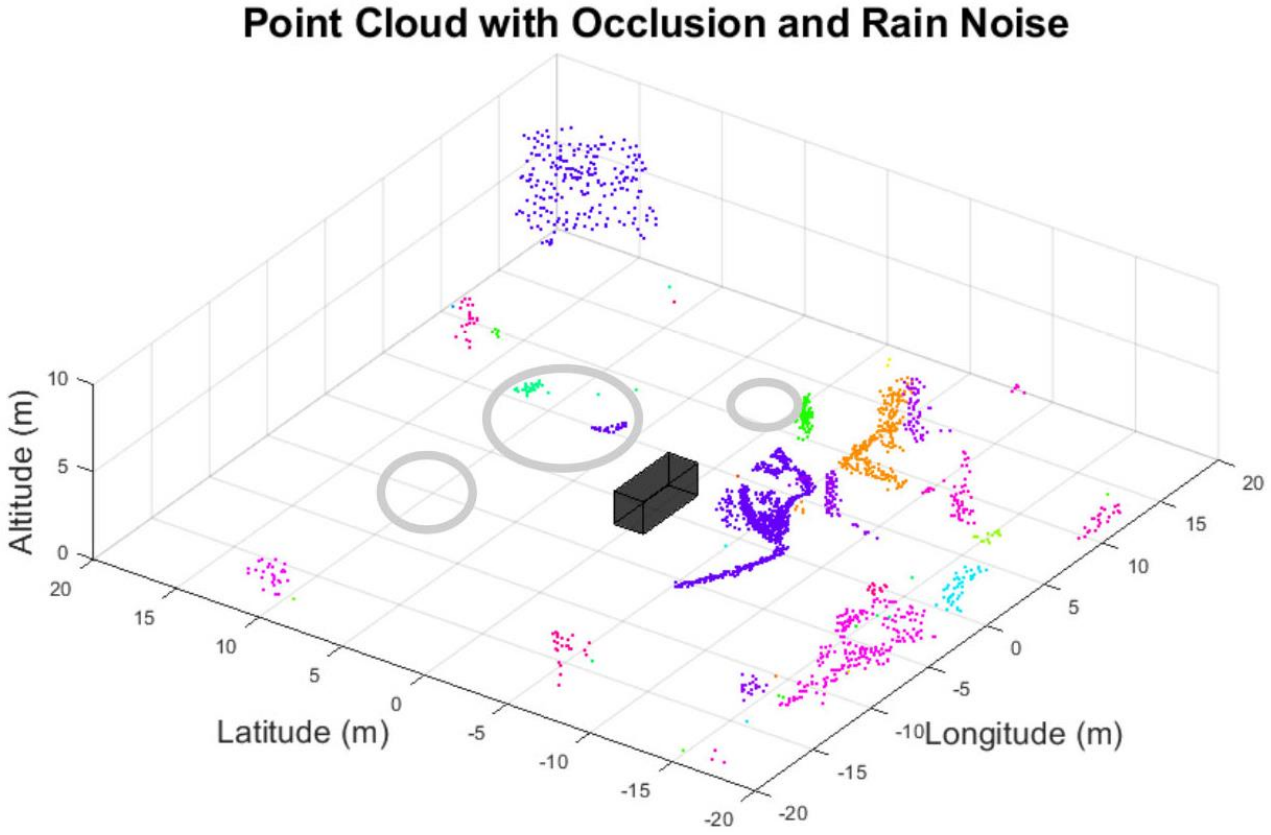

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LIDAR Noise Factors

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Intensity, (*I*), Time of Flight (ToF), Emission Angle (Ψ,Θ), and Point Coordinates (*x, y, z*)

Factor Type	ID/ Noise Factor	I	ToF	Ψ,Θ	x, y,z	Description
Piece to Piece	01. Laser Diode	✓	✓			Light emission is affected by the variability of fabrication parameters [14].
	02. Mounting			✓		Can affect the emission direction [12].
Change over Time	03. Emitter	✓	✓			Fluctuation/degradation of emitter power, bias, wavelength shift [15].
	04. Mechanics			✓		Wear in mechanical parts resulting in offsets and misplacement
	05. Receiver	✓	✓			Degradation could result in a responsivity wavelength shift and could result in lower or higher intensity recorded for a specific wavelength
	06. Circuits	✓	✓			Electronic circuit components degradation/aging over time
Usage	07. Multiple Returns	✓			✓	From multiple objects in beam path, ground, beam divergence [12]
	08. Motion			✓		Vehicle vibration, speed, acceleration, ground holes, etc.
	09. Clock Speed		✓			The clock is used as reference for the ToF (instability, errors) [16]
	10. Lens Damage	✓			✓	Dispersion effects reducing intensity and refraction may result in a return from a location that is not expected from the beam path
Envi-ronment	11. Weather	✓	✓			LiDAR is affected by weather conditions, such as rain, snow, fog, etc. [8, 10].
	12. Obstruction	✓			✓	Lens can be obstructed by objects, rain, mud, etc. Water drops can result in lensing effect, reduce intensity, etc. Mud can occlude the laser beam.
	13. Ambient Conditions	✓	✓			These conditions can affect light propagation. Temperature affects optical, electronic, mechanical components. Luminosity affects detector performance.
System Interac-tions	14. Malicious Attacks	✓			✓	External systems can disrupt the emissions and/or reception, e.g. by absorbing and reemitting at altered times or other methods [17].
	15. LiDARs				✓	Other LiDAR units can cause interference, false detection, etc.
	16. EMI	✓	✓		✓	Internal and external electrical components interactions

Sensor fusion framework

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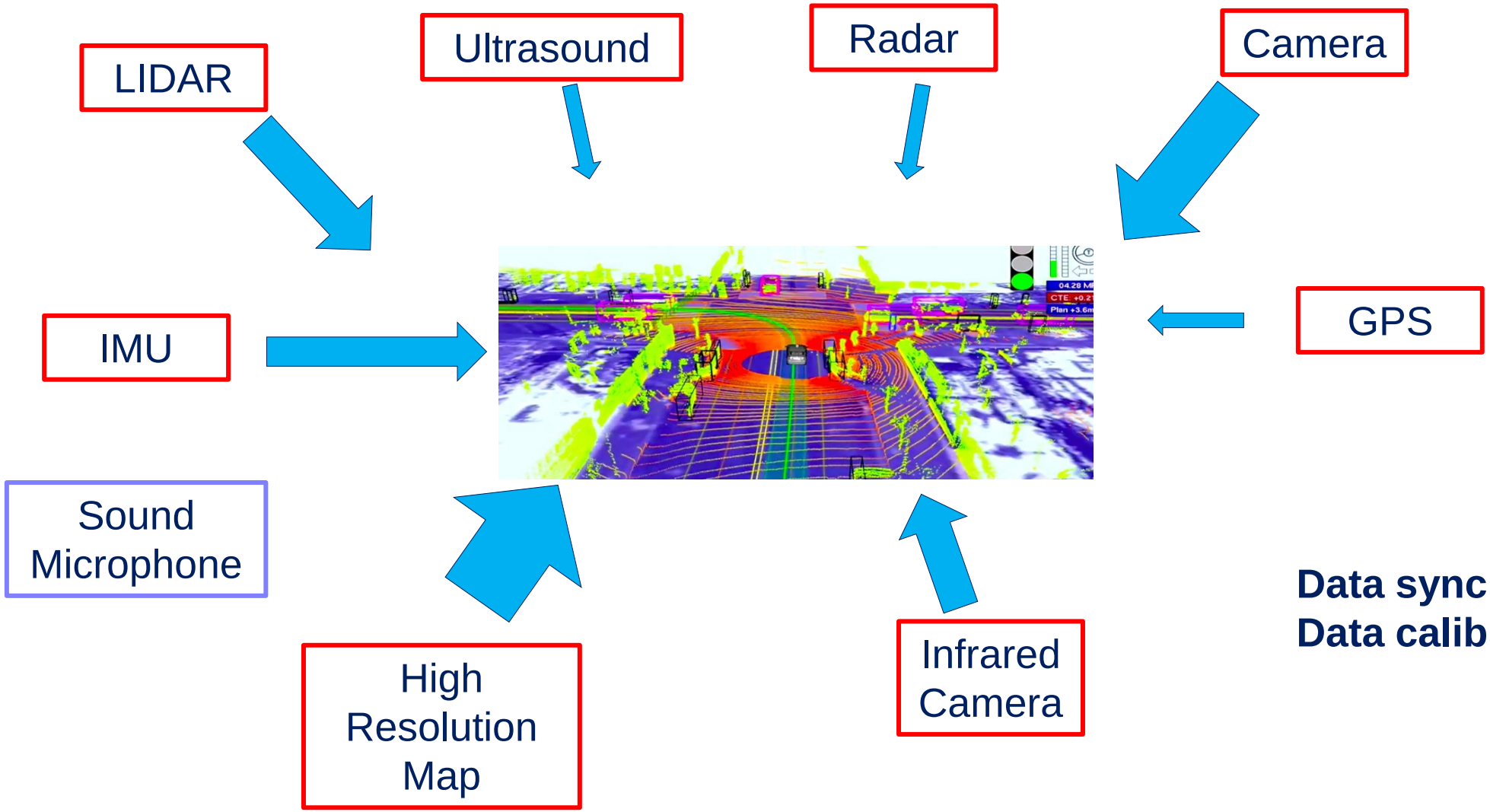

Data synchronisation
Data calibration

Conclusions

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- Need to combine signal from many sources to build robust map of the environment
- Quality and reliability of the data should be evaluated before fusion
- Environmental conditions influence signal quality
- Errors and noise can significantly affect sensors signal quality
- High processing power required to combine the data

ANY QUESTIONS ???