AUTOMATED VEHICLES SYMPOSIUM 2017

USERS. VEHICLES. INFRASTRUCTURE.

July 12, 2017

LiDAR and the Autonomous Vehicle Revolution for Truck and Ride Sharing Fleets

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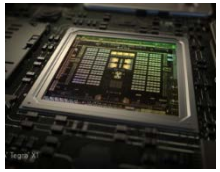
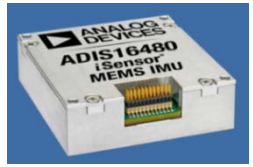
New Paradigm in 3D Sensing

- **Disruptive Technologies**:
  - Solid State 3D LiDAR sensors
  - Advanced embedded processors
  - Inertial Measurement Units (IMU)





- **Advanced Systems**:
  - ADAS, Autonomous Vehicles
  - Smart Homes, Smart Security
  - Robots, Drones, 3D-Aware Devices

- **Smart Solutions:**
  - Global daily-updated cm-accurate 3D HD Map
  - GPS-free Navigation through SLAM
  - Smart IoT

Our Mission

Social Impact

Save Lives

Save Energy

Save Space

Save Time

Save Money

Safety **Efficiency**

Our Position

- Quanergy is the leader in advanced sensing innovation
- Leadership position is in both hardware and software, enabling full system solutions

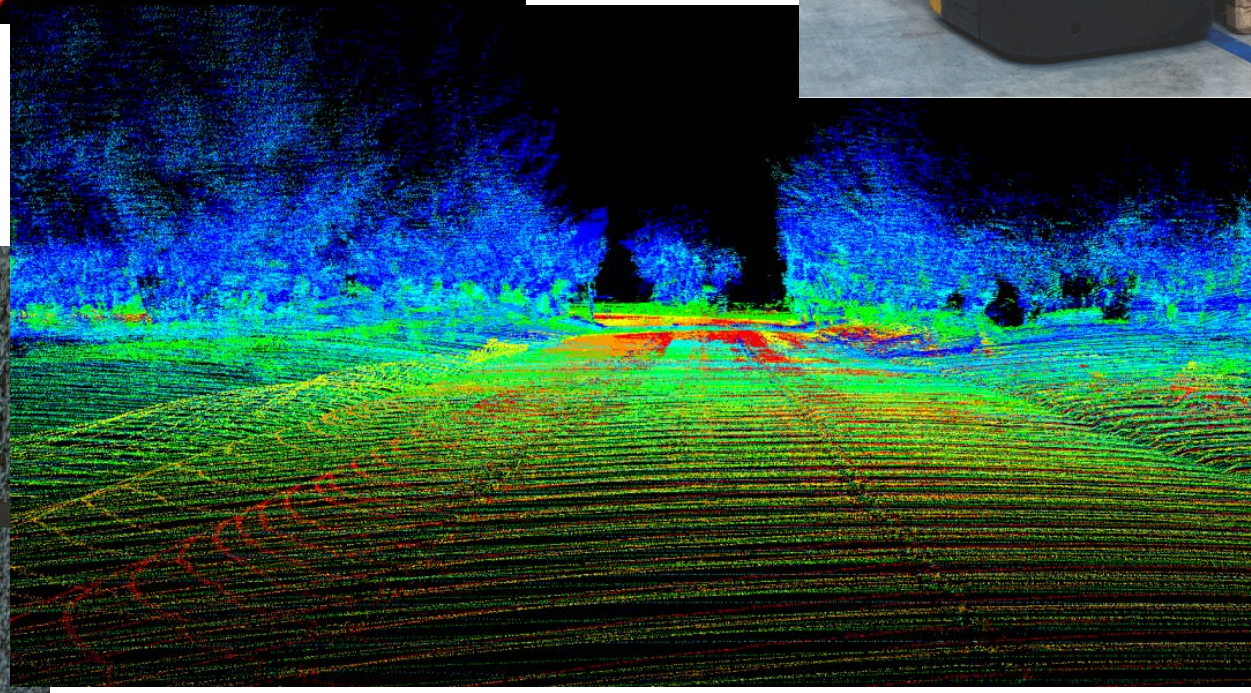
Awards & Recognition:

LiDAR Application Pillars

Transportation

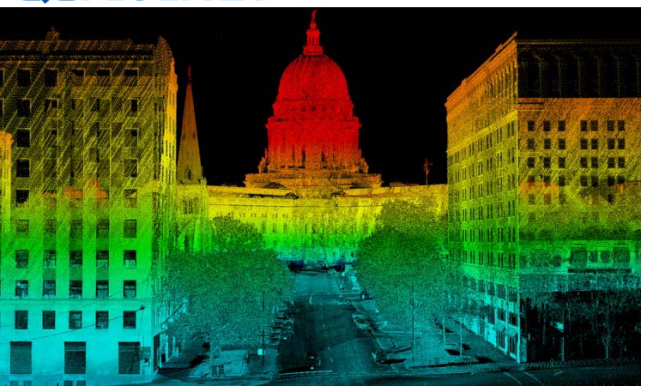
Industrial Automation

Mapping



Security

Some LiDAR Applications



3D Mapping & Navigation

Safe & Autonomous Vehicles

Fleets

Terrestrial & Aerial Robotics

3D LiDAR sensors enable safety and efficiency in areas unserved due to:

(1) COST (2) PERFORMANCE

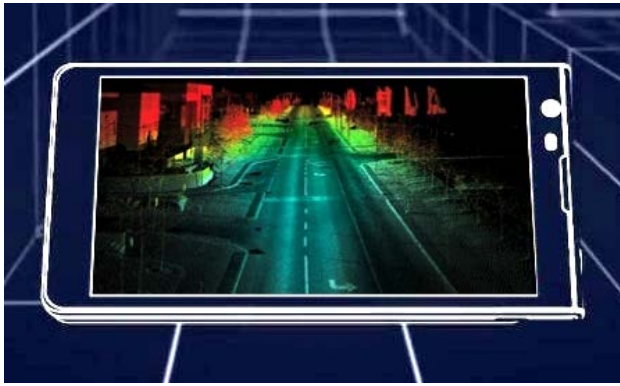
(3) RELIABILITY (4) SIZE

(5) WEIGHT (6) POWER

Smart Cities

Industrial (Mining, Logistics, etc.)

Smart Homes

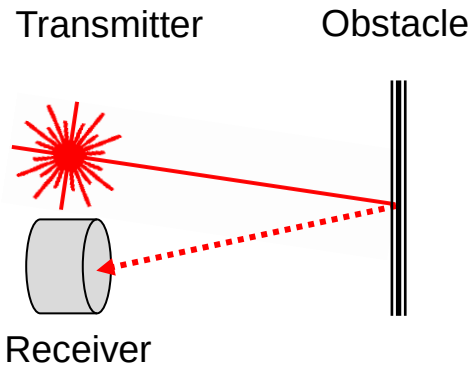


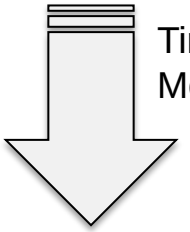
3D-Aware Smart Devices

Why LiDAR

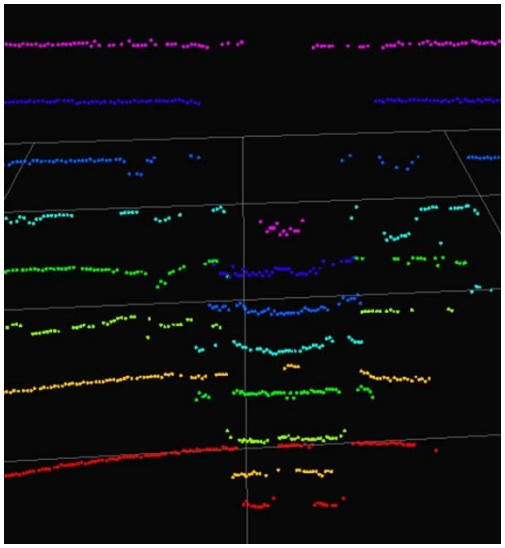
LiDAR is the most accurate perception sensor:

- 3D shape with high resolution up to max range
- Distance with high accuracy
- Orientation
- Intensity





	LiDAR	Radar	Video
Sensing Dimensions	3D	1D	2D
Range	+++	+++	×
Range Rate	++	+++	×
Field of View	+++	++	+
Width & Height	+++	×	+
3D Shape	+++	×	×
Object Rec @ Long Range	+++	×	×
Accuracy	+++	×	+
Rain, Snow, Dust	++	+++	×
Fog	+	+++	×
Pitch Darkness	+++	+++	×
Bright Sunlight	+++	+++	×
Ambient Light Independence	+++	+++	×
Read Signs & See Color	+	×	+++

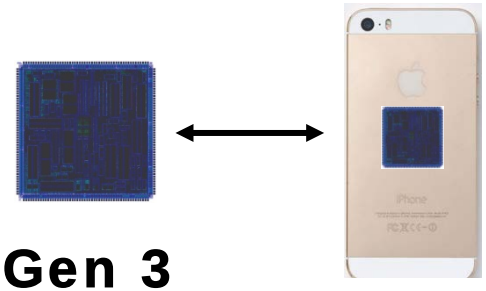


Solid State vs. Mechanical LiDAR

Mechanical LiDAR
Expensive, Large, Heavy, High Power,
Low Performance, Low Reliability

Solid State LiDAR (Quanergy S3)
Low Cost, Compact, Lightweight,
Low Power, High Performance,
High Reliability

Product Roadmap



Gen 3
Solid State
(S3 ASIC)

Gen 2
Solid State
(S3, S3-Qi)

Gen 1
Mechanical
(M8)

- 1 Patent Granted
- 9 Patents Pending
- 15 Patent Apps in Prep

MCM: Multi Chip Module
ASIC: Application Specific Integrated Circuit

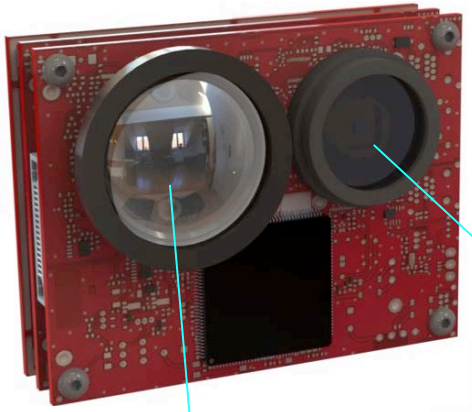
S3 ICs

S3 LiDAR

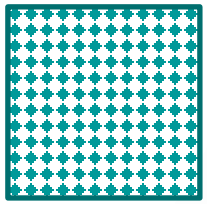
Main S3 ICs, all based on **Si CMOS**:

- **Transmitter:**
  - OPA (Optical Phased Array) Photonic IC
  - OPA Control ASIC for beam forming/steering
- **Receiver:**
  - SPAD (Single Photon Avalanche Diode) Array IC
  - ROIC (Read Out IC) with TDC (time-to-digital converter) circuitry
- **Processor:**
  - FPGA for processing raw data into point cloud
  - ARM-based processor for data fusion, perception and object list generation

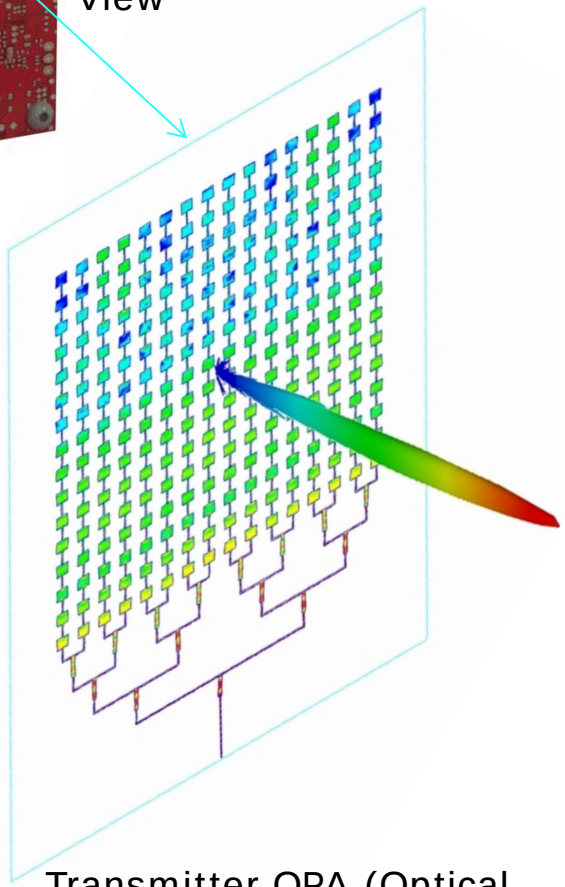
S3 Operation Principle



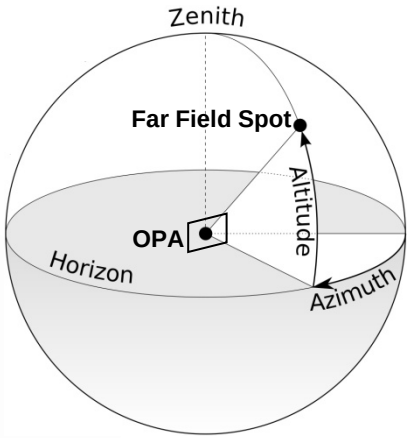
S3 Inside View

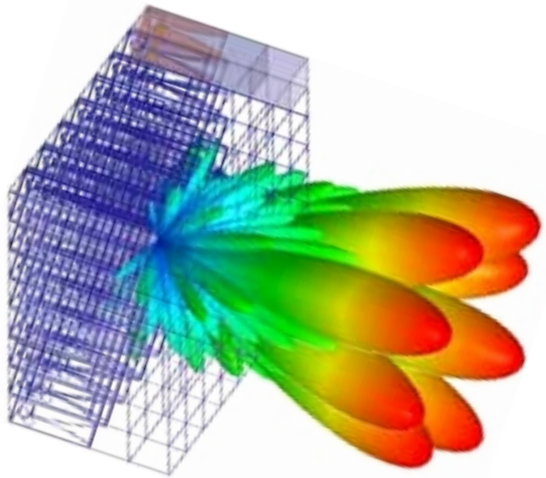


SPAD (Single Photon Avalanche Diode – Geiger mode APD) Array IC



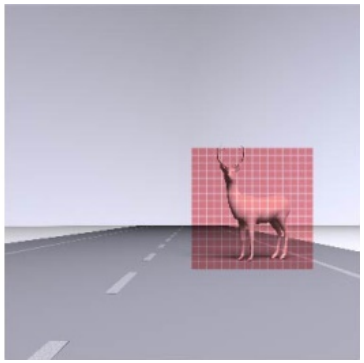
Transmitter OPA (Optical Phased Array) Photonic IC with far field radiation pattern (laser spot)





Overlaid far-field patterns for various steering angles

S3 Performance & Unique Capabilities



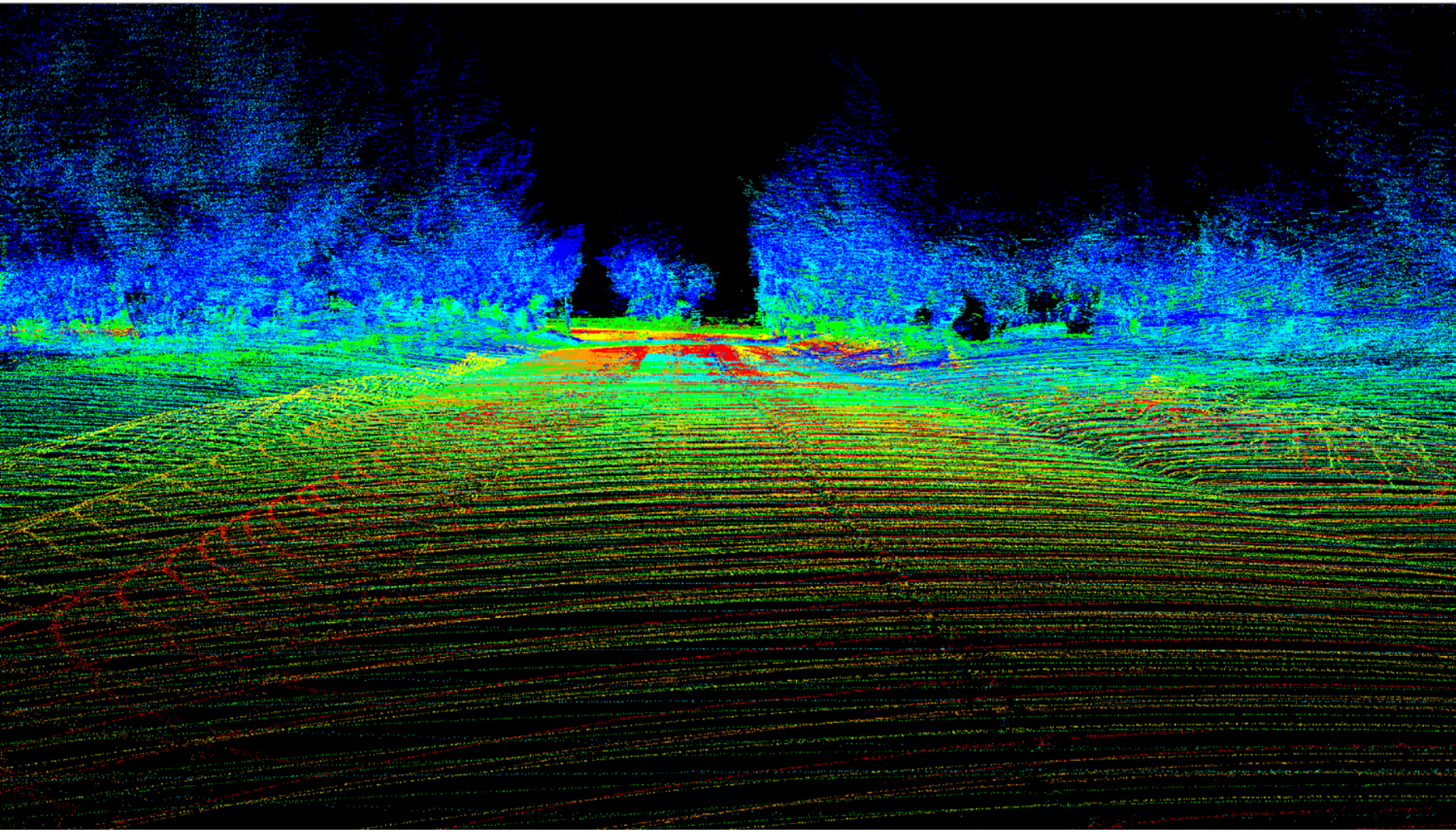
- No mechanical moving part – no wear, no misalignment, no recalibration, no eye safety issue, MTBF > 100,000hrs operation
- Large FOV (120°), long range (150m)
- High resolution, high accuracy (at 100m spot size < 5cm, accuracy < 5mm)
- Software defined beam forming
  - Zoom in/zoom out for coarse & fine view
  - Random access in entire FOV, no sequential scanning required
  - Adjustable window within field of view
  - Arbitrary point density within each frame
  - Software defined frame rate

Headlight-Integrated S3

- Developed with Koito, largest global maker of automotive headlights, first automotive headlight with built-in LiDAR sensors
- Each headlight, located on a corner of a vehicle, incorporates two S3 solid state LiDARs that sense forward and to the side
- The headlight protects the sensors from dust, dirt and water, and lens washers ensure an unobstructed view for the sensors
- World Premiered at CES 2017

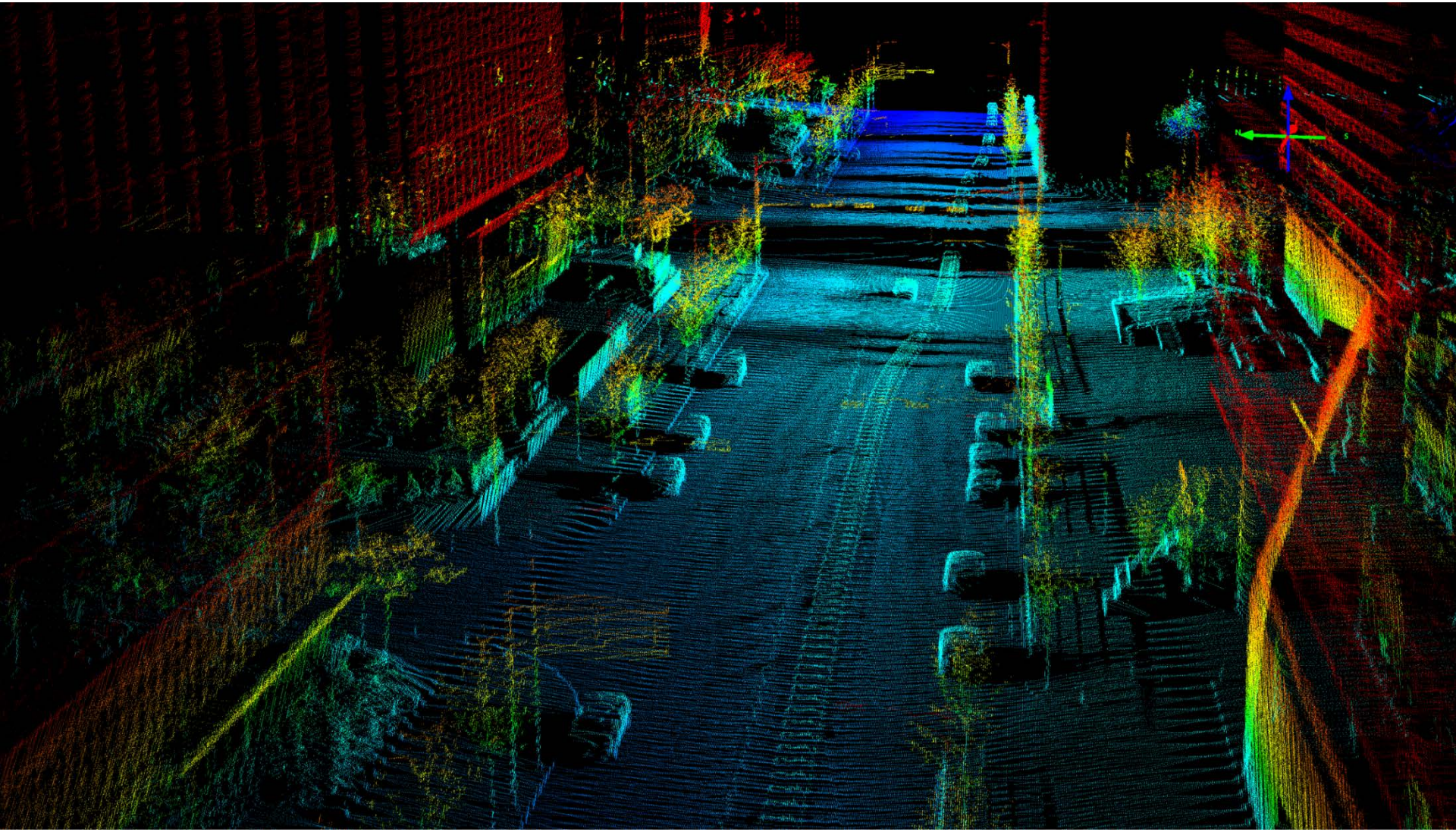
3D Composite Point Cloud

Terrestrial Mapping



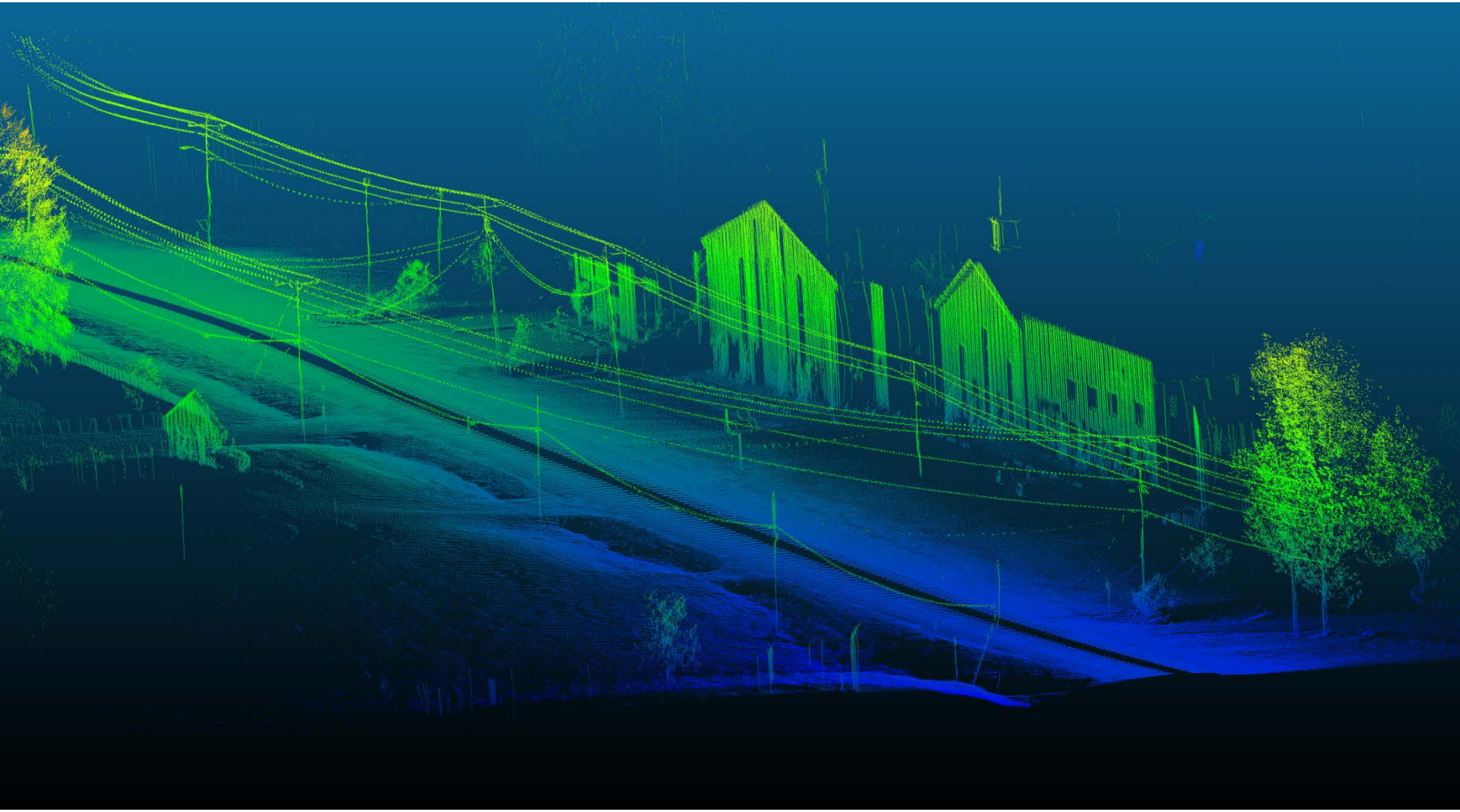
3D Composite Point Cloud

Aerial Mapping



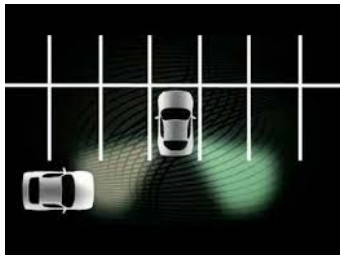
3D Composite Point Cloud

Aerial Mapping

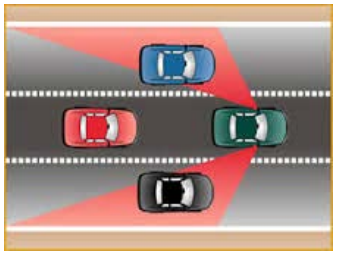


Advanced Driver Assist Systems (ADAS)

Lane Keeping



Parking Assist

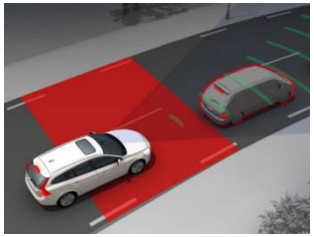


Blind Spot Detection

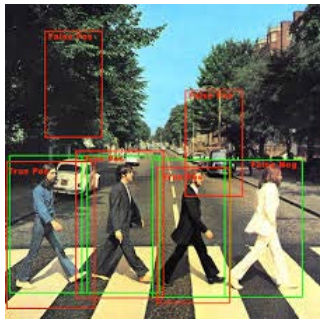
Adaptive Cruise Control
& Traffic Jam Assist

Front/Rear Collision Avoidance

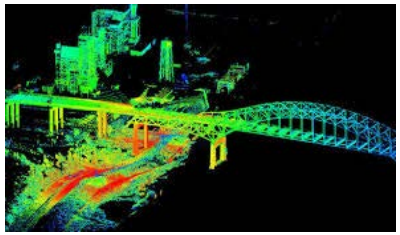
Cross Traffic Alert &
Intersection Collision Avoidance



Autonomous Emergency Braking
& Emergency Steer Assist



Object Detection,
Tracking, Classification



Scene Capture &
Accident Reconstruction

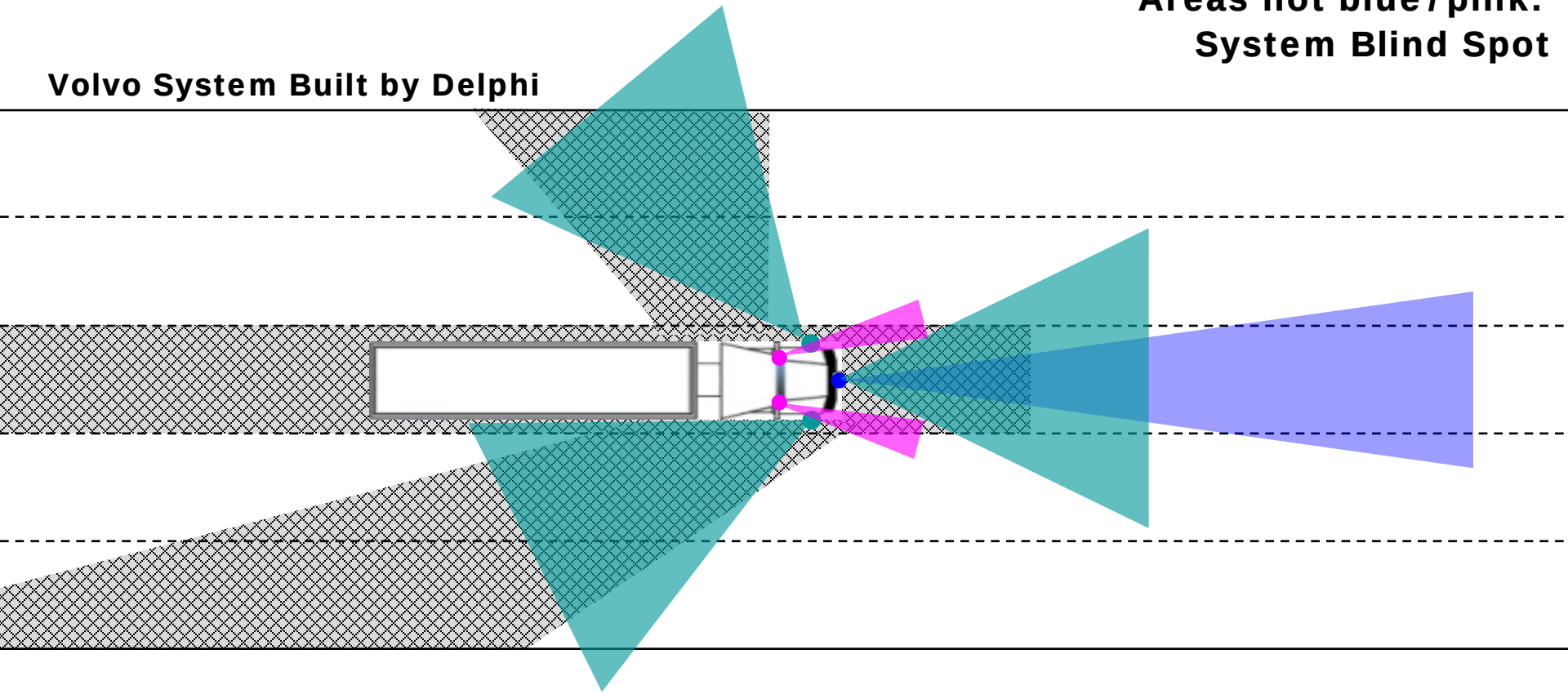
QUANERGY™

Typical Commercial ADAS

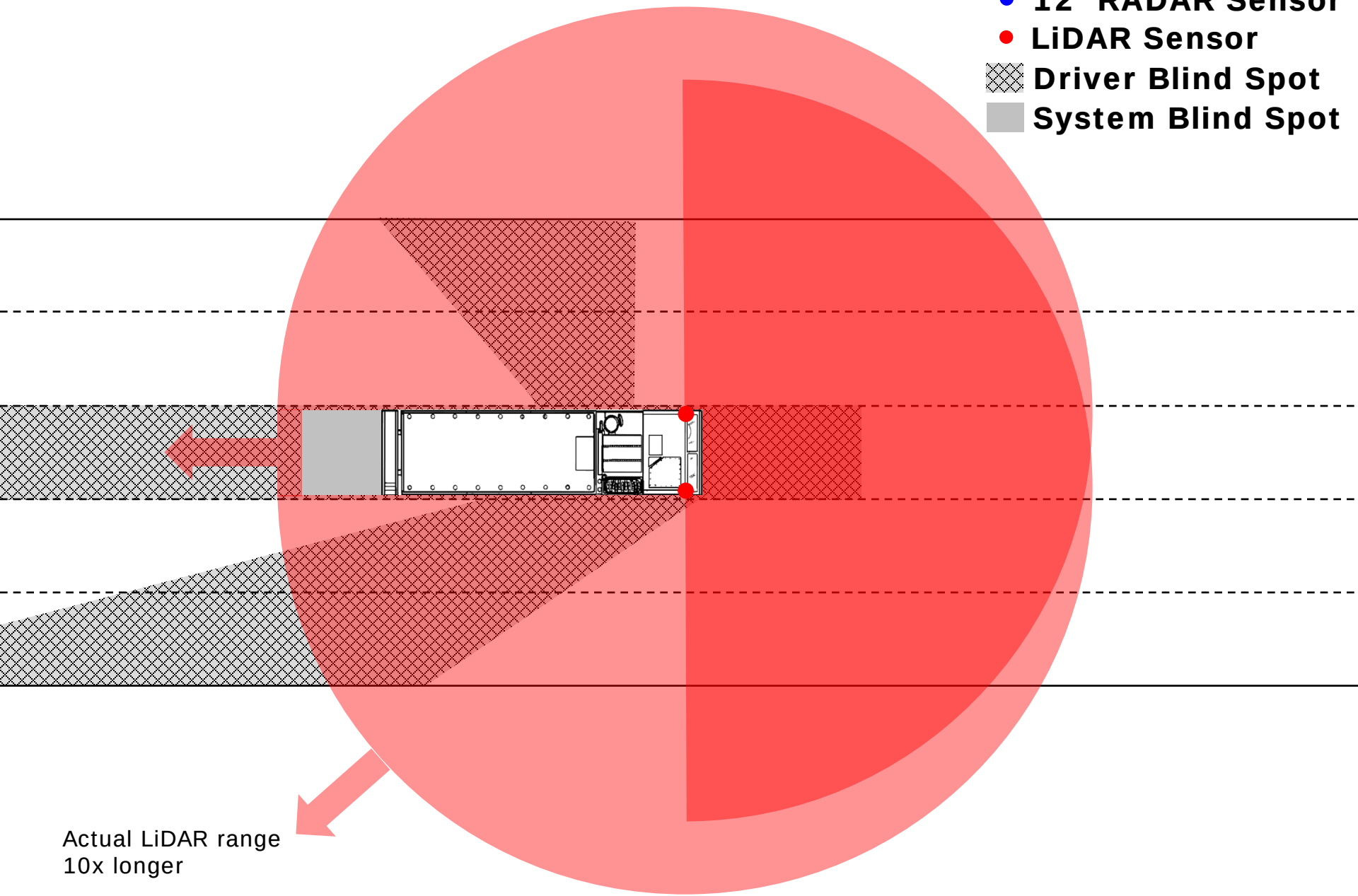
- Video camera
- 50° RADAR Sensor
- 12° RADAR Sensor
- LiDAR Sensor
- Driver Blind Spot

Areas not blue/pink:
System Blind Spot

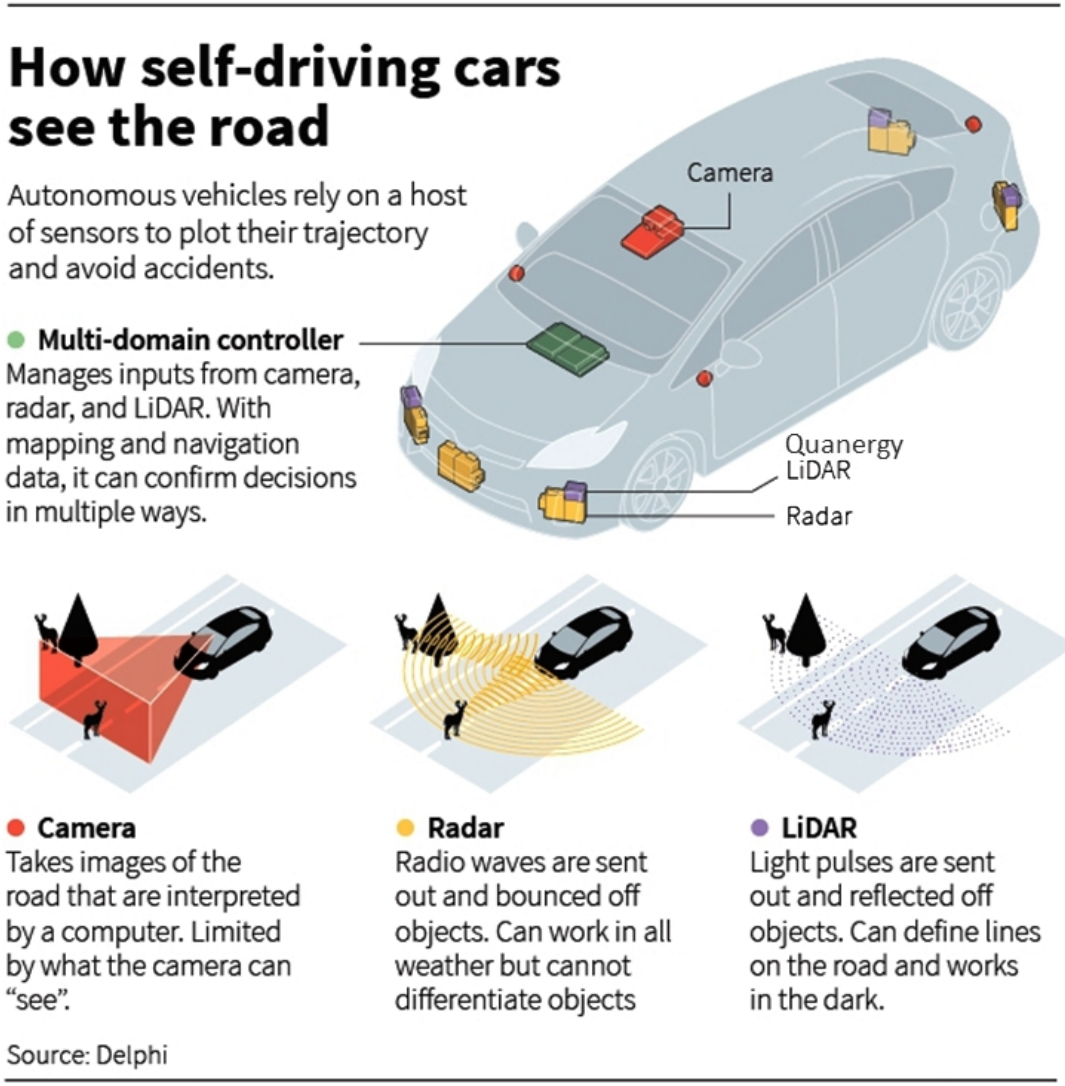
Volvo System Built by Delphi



Quanergy ADAS



Autonomous Vehicle Sensors



LiDAR is the primary sensor. As such, it is used for:

1. Perception
2. Localization
3. Navigation

Autonomous Driving Based on Deep Learning

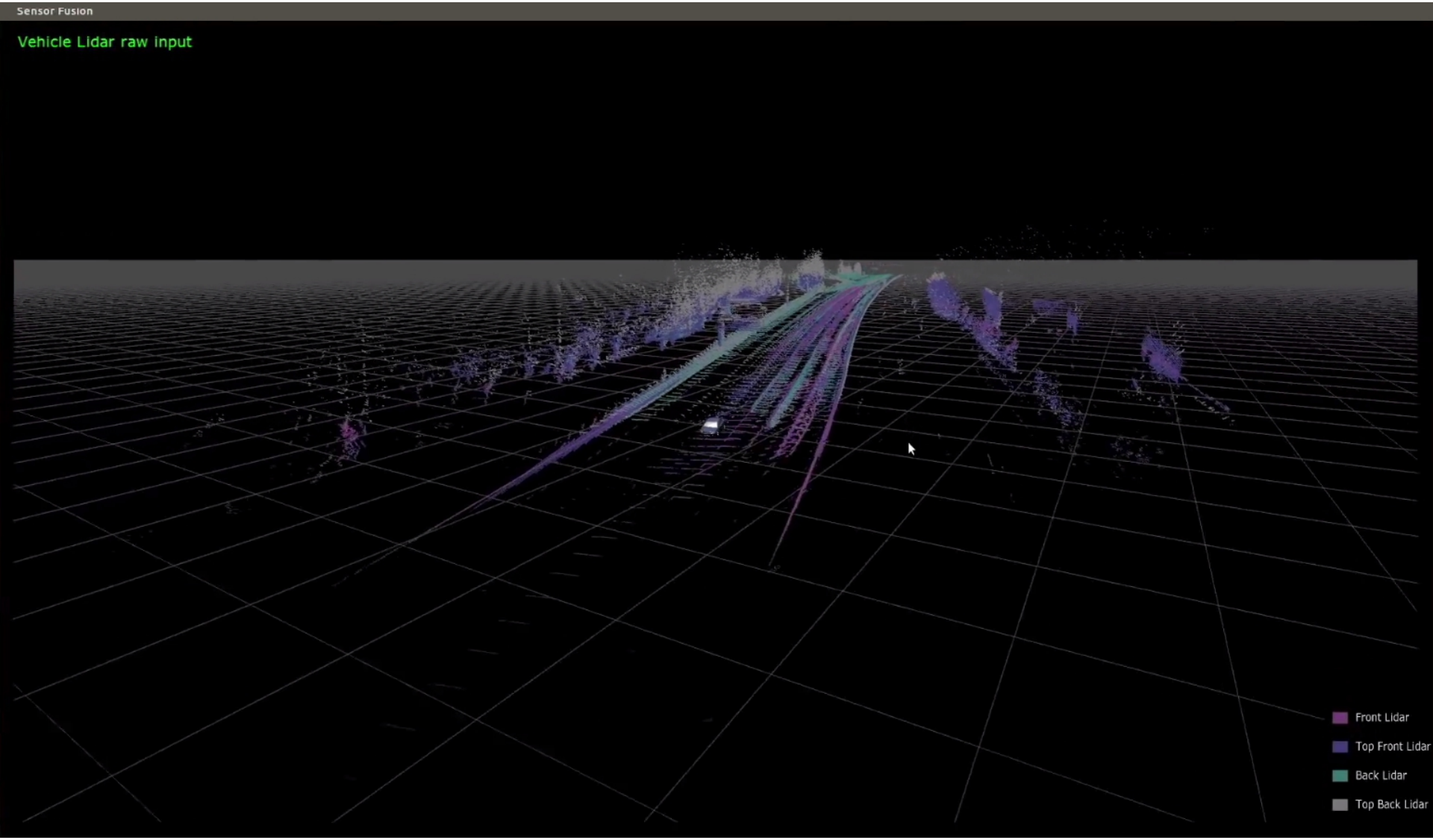
Perception Pipeline

Partner NVIDIA

1. **Vehicle LiDAR Raw Input**
   Corrected point cloud using IMU, and video frames
2. **Occupancy Map**
   Created using LiDAR-video sensor fusion, probabilistic map informs which voxels are likely occupied
3. **Object Detection & Tracking**
   Run LiDAR and video output into a neural network that was trained to recognize and classify objects (cars, bikes, pedestrians, etc.)
4. **Localization**
   Determine position by registering within a pre-existing HD map, localize in a lane: use GPS, place car in lane, compensate for errors of GPS
   (GPS accuracy: several meters, accuracy needed: several cm)
5. **Path Planning**
   Run algorithms to perform path/motion planning, taking into consideration car kinematics, decide whether to stay in lane or switch lanes
6. **Navigation**
   After intensive computation, if decision is to take action, actuation in near-real time of vehicle controls to ensure safety and comfort

Autonomous Driving Based on Deep Learning

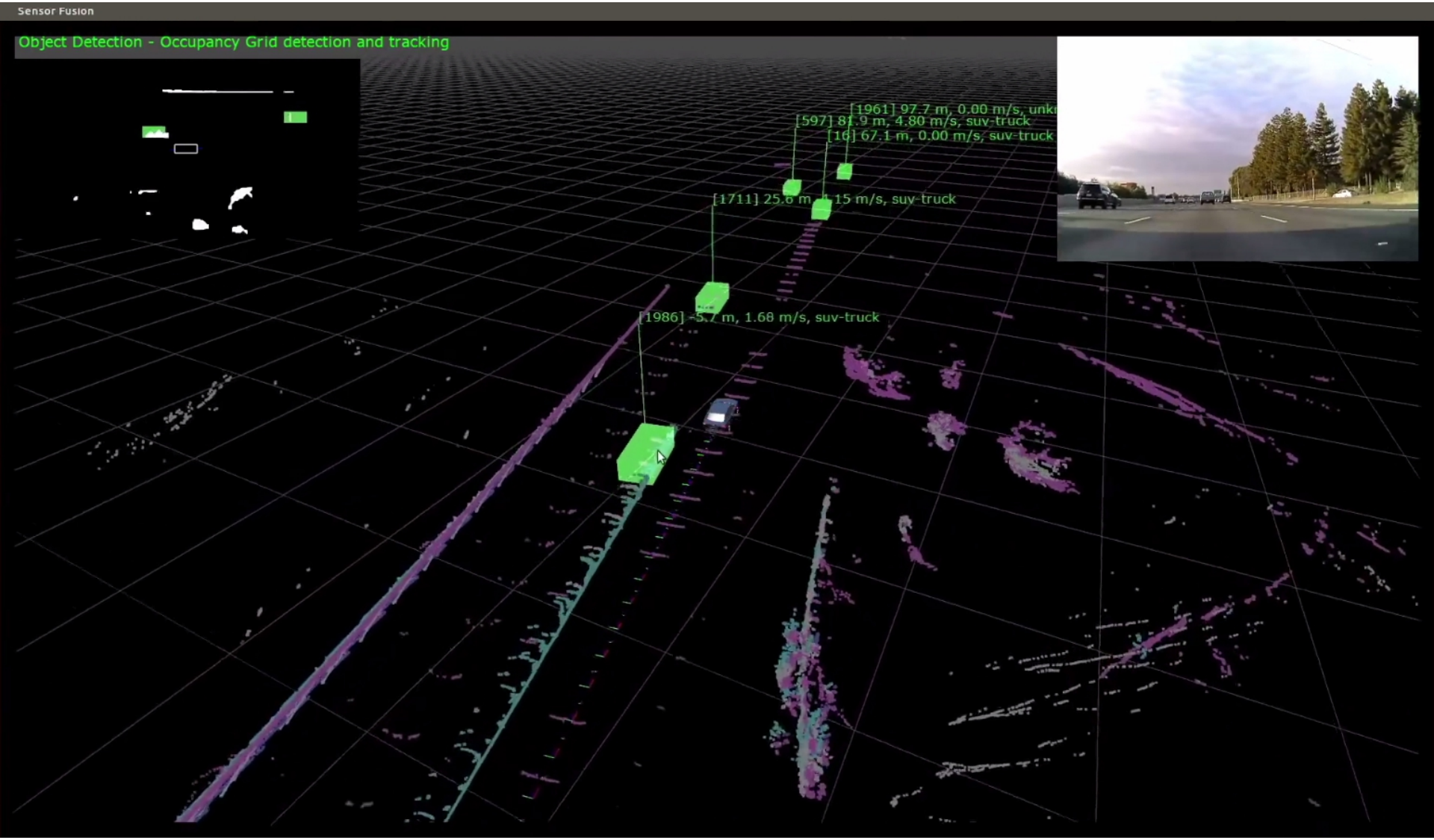
Vehicle LiDAR Raw Data



Nvidia data collected with Quanergy LiDAR sensors

QUANERGY™ Autonomous Driving Based on Deep Learning

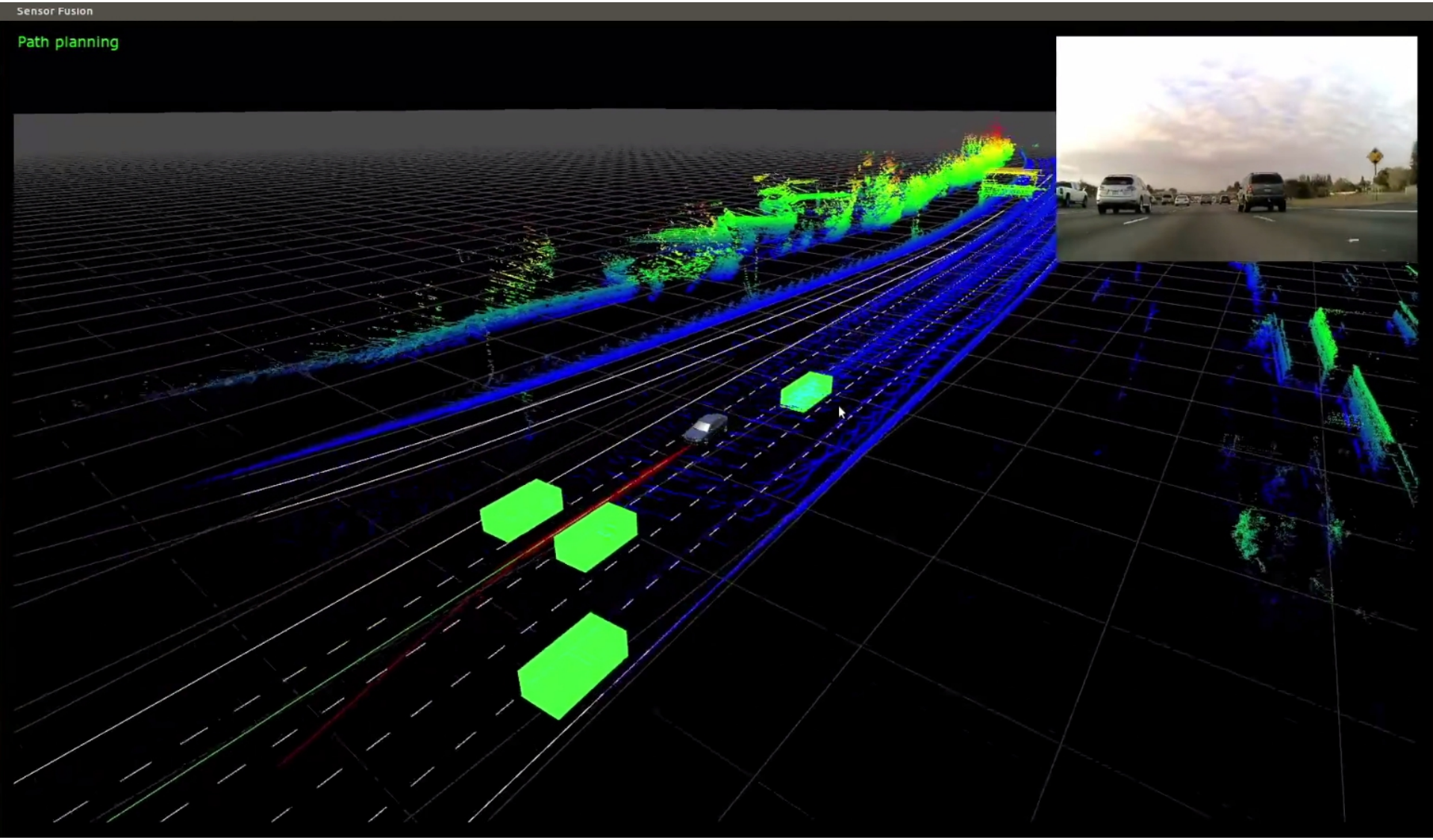
Occupancy Map, Object Detection & Tracking



Nvidia data collected with Quanergy LiDAR sensors

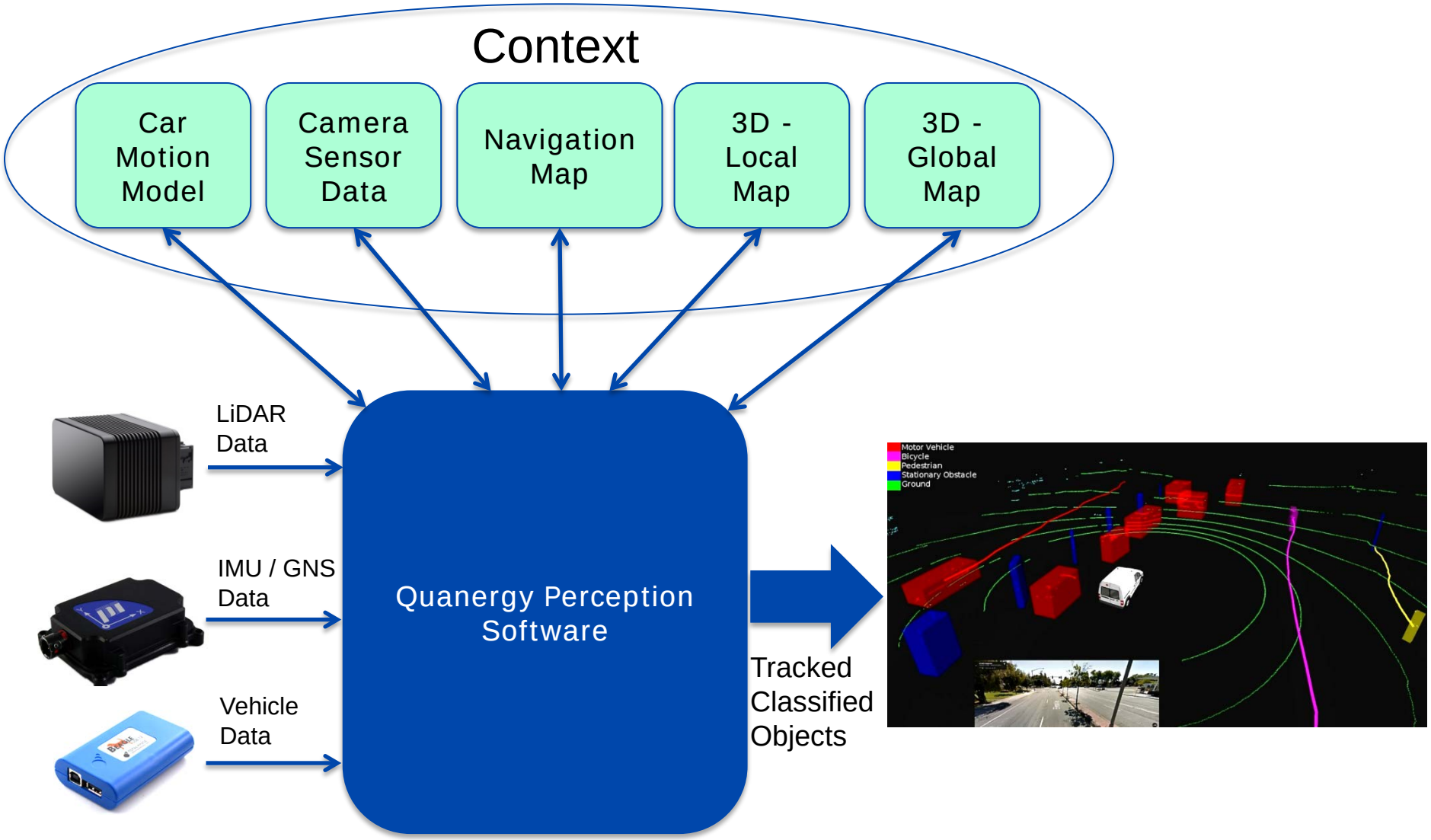
QUANERGY™ Autonomous Driving Based on Deep Learning

Localization, Path Planning & Navigation



Nvidia data collected with Quanergy LiDAR sensors

Automotive Sensing and Perception



Levels of Automation for Vehicles

NHTSA Level	SAE Level	SAE Name	SAE Narrative Definition	Execution of Steering and Acceleration/ Deceleration	Monitoring of Driving Environment	Backup Performance of Dynamic Driving Task	System Capability (Driving Modes)
	Human driver monitors the driving environment			Human driver	Human driver	Human driver	n/a
0	**0**	**Non-Automated**	The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems				
1	**1**	**Assisted**	The driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	Human driver and system	Human driver	Human driver	Some Driving modes
2	**2**	**Partial Automation**	The driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task	System	Human driver	Human driver	Some Driving modes
	Automated driving system ("system") monitors the driving environment			System	System	Human driver	Some Driving modes
3	**3**	**Conditional Automation**	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene				
4	**4**	**High Automation**	The driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene	System	System	System	Some Driving modes
	5	**Full Automation**	The full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver	System	System	System	All driving modes

Source: Summary of SAE International's Draft Levels of Automation for On-Road Vehicles (July 2013)
NHTSA - National Highway Traffic Safety Administration
SAE - Society of Automotive Engineers

Automation Deployment

- L1 platooning launches this year – fuel efficiency
- Automation up to L2 helps in all vehicles – accident reduction
- Skipping L3 for all vehicles could be wise – convenience in traffic jam assist; re-engaging the driver risky; does not improve productivity
- Passenger vehicles owned by consumers: jump from L2 to L4 (productivity), then L5 (cost savings); if L3 is used, auto-pilot naming should be avoided (Audi, BMW, Daimler, China)
- Trucks and Ride-sharing Fleets: skip from L2 to L5 – cost savings not realized until vehicles are driverless
- Starting L4/L5 applications are confined work sites
- Mining/Agriculture L5 vehicles used today (CAT)
- L5 for on-road 10+ years away; self-driving lanes could accelerate
- Benefits:
  - L1 – cost reduction (fuel)
  - L2 – safety
  - L3 – safety, convenience (not to be confused with comfort or productivity)
  - L4 – safety, comfort, productivity
  - L5 – safety, cost reduction (eliminate driver)
- Responsible and robust implemented of all automation levels have LiDAR as primary sensor

QUANERGY

Some Public Partners

Sensata Technologies

Sensata and Quanergy Strategic Partnership

In March 2016, Sensata and Quanergy announced strategic partnership:

- Exclusive partnership for the ground transportation market
- Companies to jointly develop, manufacture, and sell component level solid-state LiDAR sensors
- Quanergy to lead technology development including perception software
- Sensata to design for manufacture, make, and sell to ground transportation customers
- Sensata investment in Quanergy and on board of directors

Thank You

Quanergy Sites:
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London
Munich
Dubai
Shanghai
Tokyo

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