GPU TECHNOLOGY CONFERENCE

April 6, 2016

QUANERGY

Solid State LiDAR for Ubiquitous 3D Sensing

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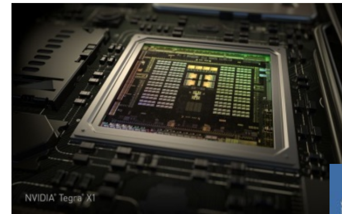
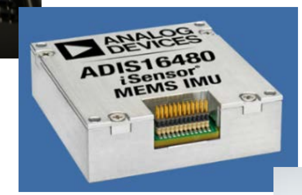
CEO, Co-founder
Quanergy Systems

New Paradigm in 3D Sensing





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

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

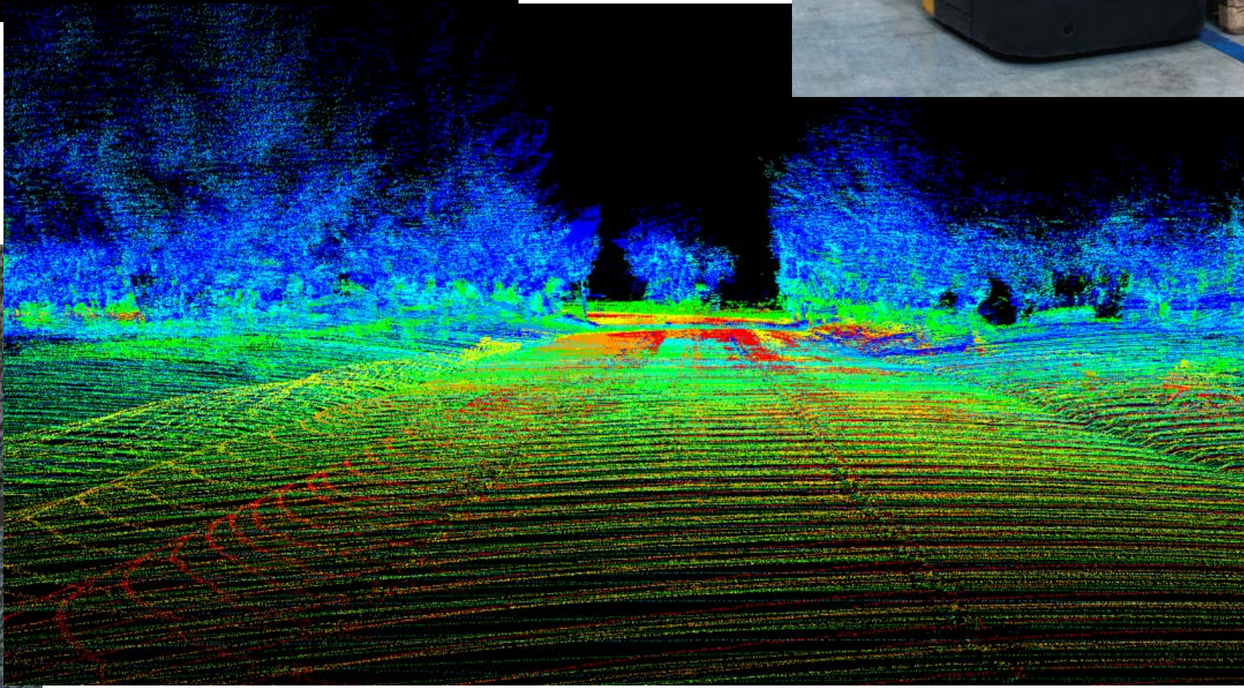
- **Smart Solutions:**
  - Daily-updated cm-accurate Global 3D Map
  - GPS-free Navigation through SLAM
  - Smart IoT

LiDAR Application Pillars

Transportation

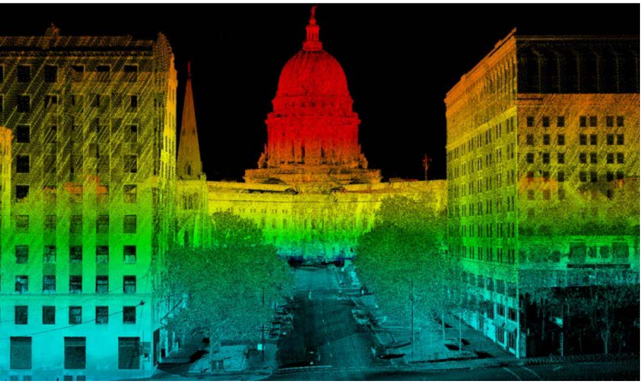
Industrial Automation

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

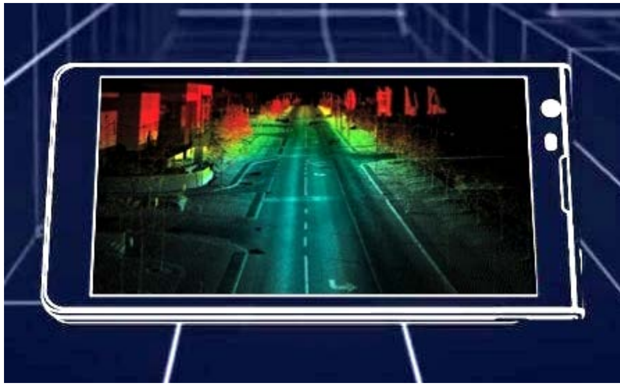
(3) RELIABILITY (4) SIZE

(5) WEIGHT (6) POWER

Smart Cities

Industrial (Mining, Logistics, etc.)

Smart Homes



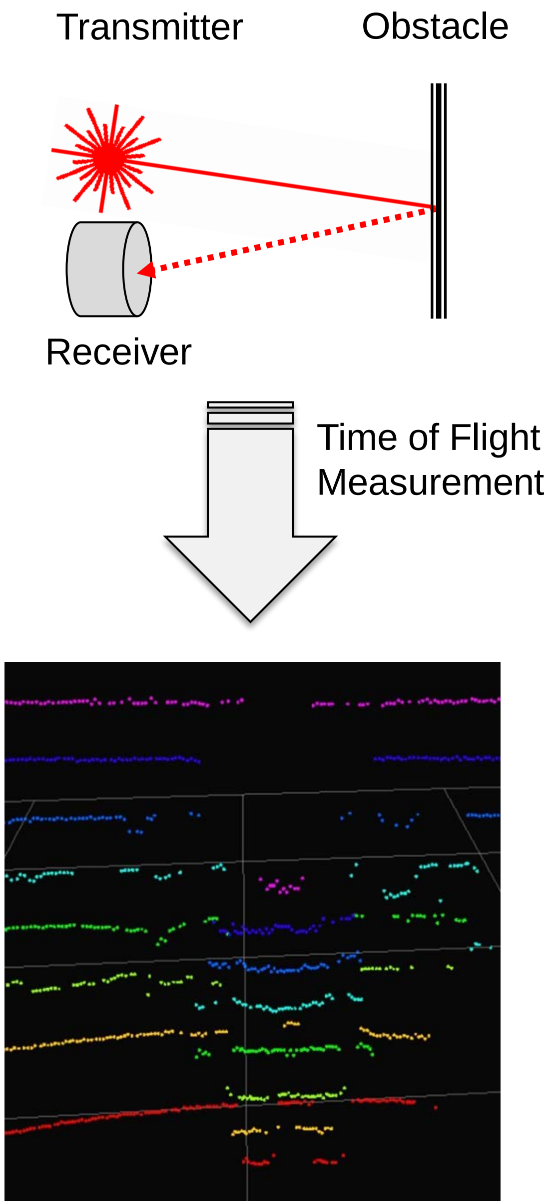
3D-Aware Smart Devices

Why LiDAR

LiDAR is most accurate perception sensor:

- 3D shape with width/height information
- Distance with high accuracy
- Orientation
- Intensity

	LiDAR	Radar	Video
Range	+++	+++	-
Range Rate	++	+++	-
Field of View	+++	++	+
Width & Height	+++	-	+
3D Shape	+++	-	-
Object Rec @ Long Range	+++	-	-
Accuracy	+++	-	+
Rain, Snow, Dust	++	+++	-
Fog	+	+++	-
Night time	+++	+++	-
Read Signs & See Color	+	-	+++



Historically, LiDARs have been expensive, bulky, unreliable (mechanical failure)

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Quanergy vs. Traditional LiDAR

Traditional Solution

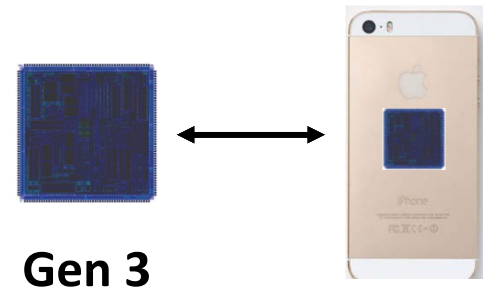
Expensive, Large, Heavy, High Power, Low Performance, Low Reliability, Mechanical LiDAR

Quanergy Solution

Low Cost, Compact, Lightweight, Low Power, High Performance, High Reliability, Solid State LiDAR

Quanergy LiDAR Roadmap

All Solid State



Gen 3
Solid State
(S3 ASIC**)**

Gen 2
Solid State
(S3 MCM**)**

Gen 1
Mechanical
(Mark VIII – **M8)**

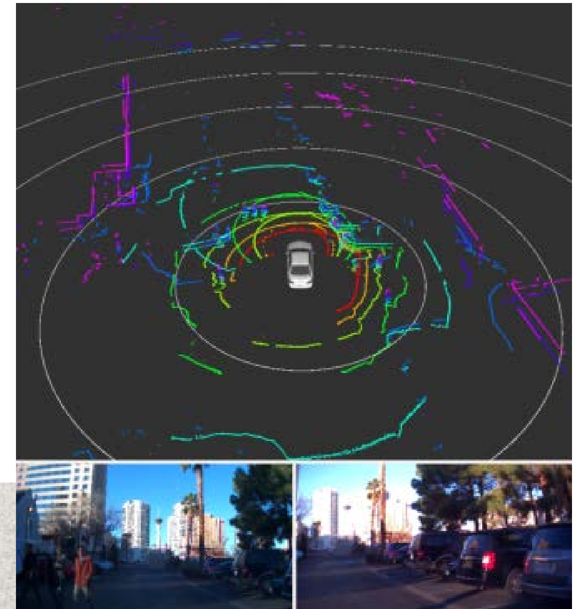
Volume Pricing:
Gen 1: <$1,000
Gen 2: <$250
Gen 3: <$100

Quanergy LiDARs

Designs focus simultaneously on **cost, performance, reliability, size, weight, power consumption**

Gen 1: Mechanical LiDAR (M8)

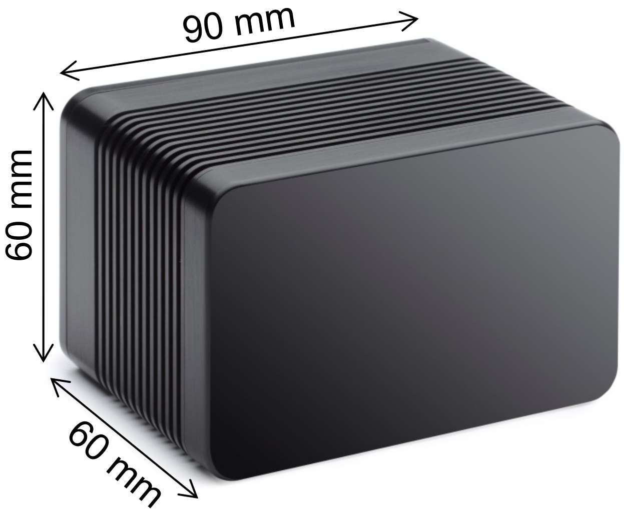
Gen 2 & 3: Solid State LiDAR (S3)



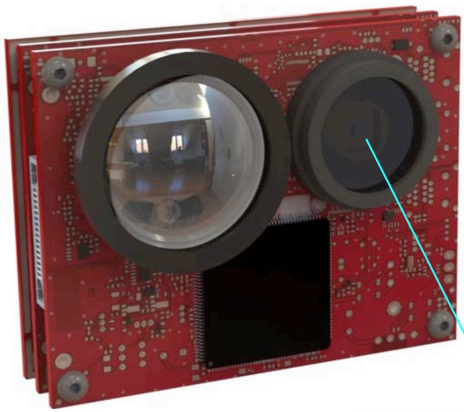
8 Patents Pending

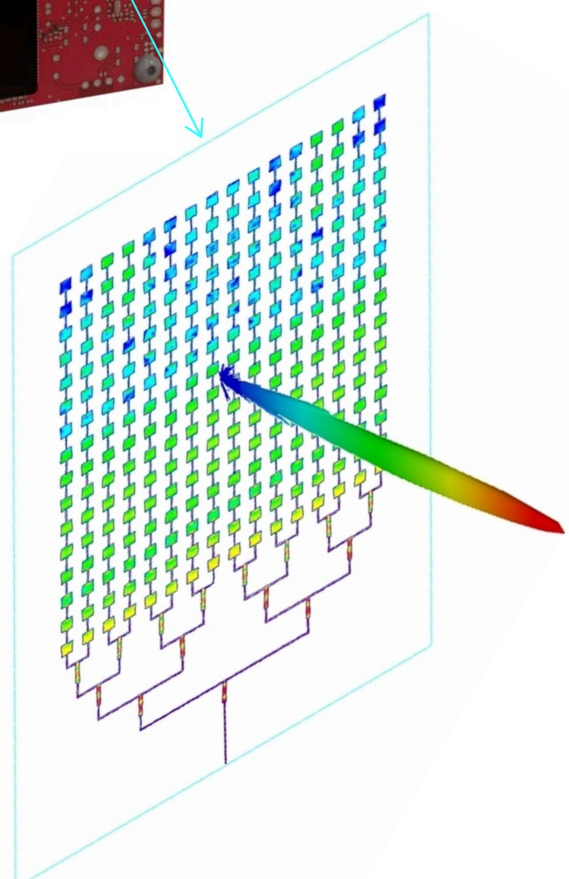
15 Patents in preparation covering **Gen 1, 2 & 3**

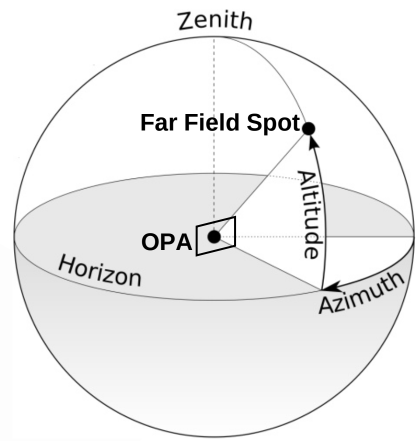
Quanergy S3 LiDAR

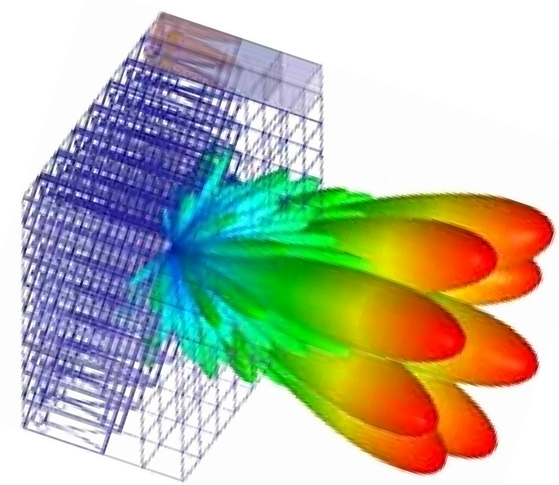


S3 Operation Principle





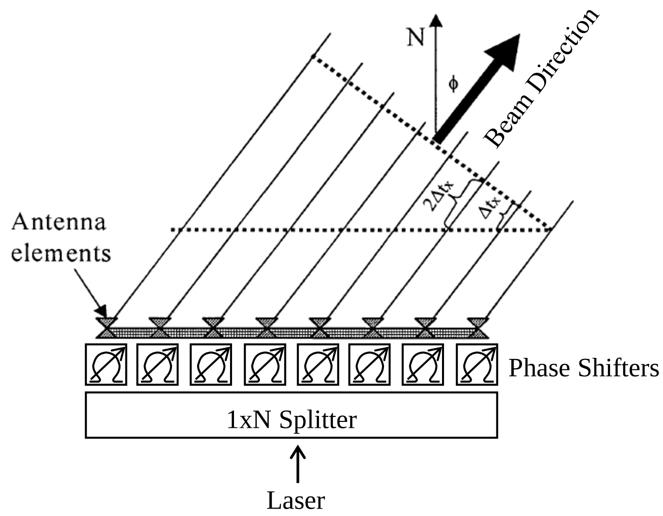




Transmitter OPA (Optical Phased Array) Photonic IC
with far field radiation pattern (laser spot)

Overlaid far-field patterns
for various steering angles

OPA Operation Principle

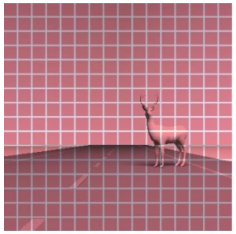


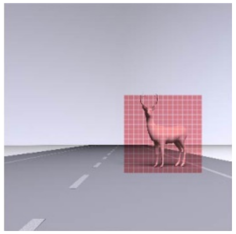
- OPA stands for Optical Phased Array
- Optical analog of Phased Array Radar
- An optical phased array has multiple optical antenna elements that are fed equal-intensity coherent signals
- Variable phase control is used at each element to generate a far-field radiation pattern and point it in a desired direction

S3 Unique Capabilities

Software-controlled in real time:

- Adjustable window within total available field of view
- Arbitrary distribution of points in point cloud; point density within a frame not necessarily uniform (e.g., denser distribution around horizon in vehicle)
- Random access for maximum SNR at receiver
- Largest VFOV (matches 120 HFOV)
- Zoom in & out for coarse & fine view



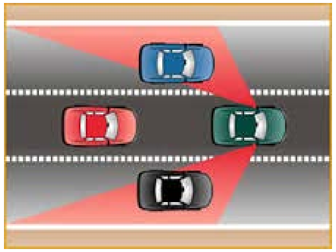


- Adjustable frame rate based on situation analysis
- Directional range enhancement based on location in pre-existing map (e.g., maximum forward range on highway, maximum sideways range at intersection)

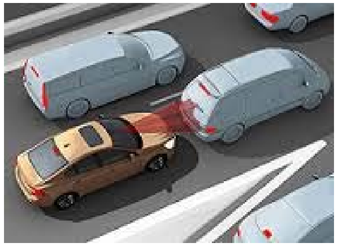
Today's ADAS Use Various Sensors


Lane Keeping

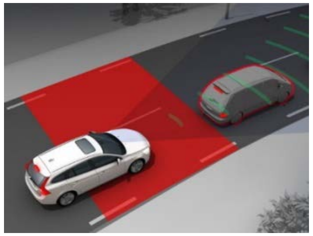

Parking Assist

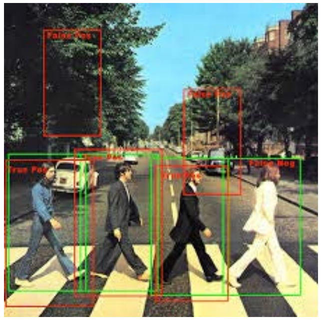

Blind Spot Detection

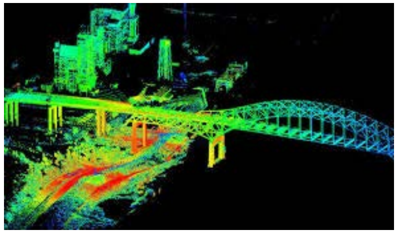

Adaptive Cruise Control
& Traffic Jam Assist


Front/Rear Collision Avoidance


Cross Traffic Alert &
Intersection Collision Avoidance


Autonomous Emergency Braking
& Emergency Steer Assist

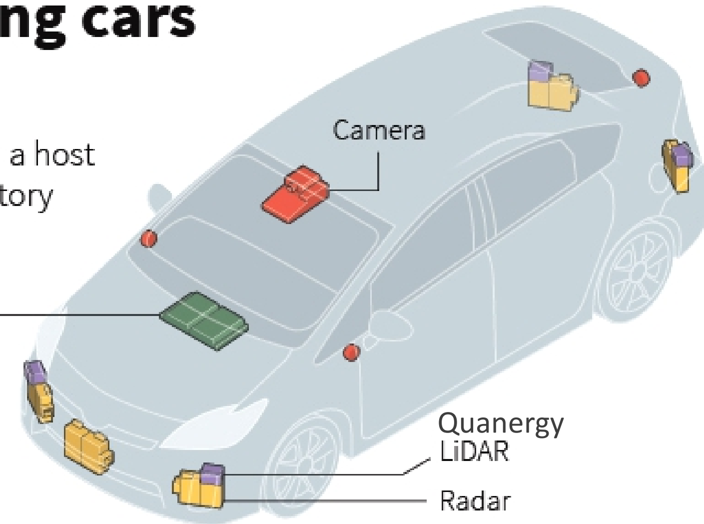

Object Detection,
Tracking, Classification


Scene Capture &
Accident Reconstruction

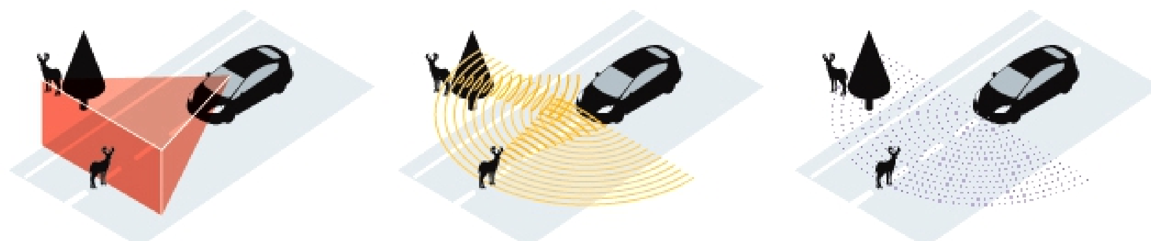
Autonomous Vehicle Sensors

How self-driving cars see the road

Autonomous vehicles rely on a host of sensors to plot their trajectory and avoid accidents.



- **Multi-domain controller**
  Manages inputs from camera, radar, and LiDAR. With mapping and navigation data, it can confirm decisions in multiple ways.



- **Camera**
  Takes images of the road that are interpreted by a computer. Limited by what the camera can "see".
- **Radar**
  Radio waves are sent out and bounced off objects. Can work in all weather but cannot differentiate objects
- **LiDAR**
  Light pulses are sent out and reflected off objects. Can define lines on the road and works in the dark.

Source: Delphi

C. Inton, 24/03/2016 REUTERS

Autonomous Car Sensing Systems

Video Perception for Semi Autonomy	Mechanical LiDAR Perception for Autonomy	Solid State LiDAR Perception for Autonomy
8 video cameras	2 LiDARs	2 LiDARs with video
6 radars	8 video cameras	2 radars
12 U/S sensors	6 radars	
	12 U/S sensors	
Total: 26 sensors	**Total:** 28 sensors	**Total:** 4 sensors
ASP: $4,000	**ASP:** $6,000-$20,000	**ASP:** $1,000

- LiDAR only acceptable sensor for object detection in autonomous cars operating in **all environments**, including urban areas with pedestrians (not just highways)
- Sensors that detect and help avoid collision with 99% of objects (pedestrians, cyclists, vehicles, etc.) are unacceptable in fully autonomous cars – goal: **10 9's**
- When LiDARs are mission critical, as in autonomous cars, they cannot have moving parts and replace sensors in today's sensing suite; must be **solid state**

S3 LiDAR – Launched at CES 2016

- Two S3 LiDARs installed in grill of Mercedes-Benz GLE450 AMG Coupe (Daimler gift)
- Sensors invisible behind IR-transparent fascia (built by Delphi)
- Pedestrians in front of vehicle detected and point cloud displayed in real time

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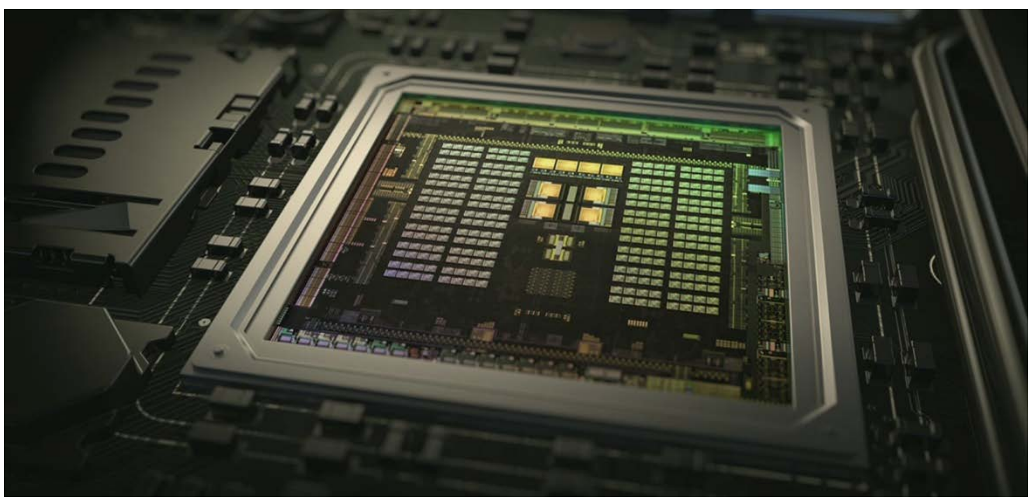
Tegra X1 Based Automotive System

- Real-time object detection, tracking and classification is important in **ADAS** and critical in **Autonomous Vehicles**

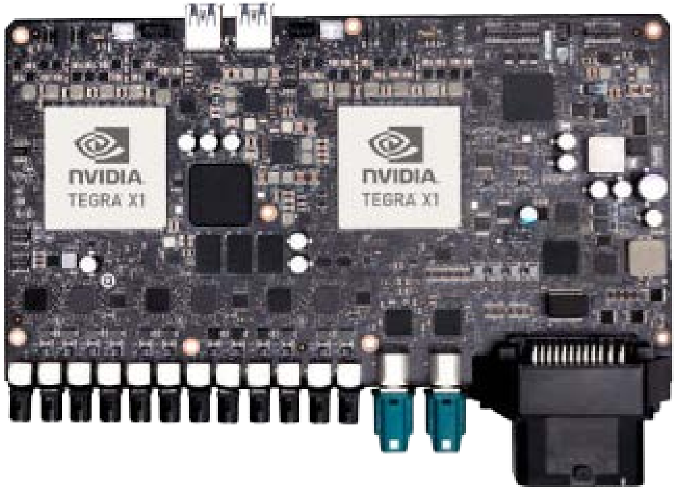
- **Tegra X1** (256-core Maxwell GPU, 8-core 64-bit CPU) is preferred processor for neural network deep learning in 3D sensing applications. GPU parallel cores are leveraged to:
  - Rapidly **train neural networks** using large training sets
  - Perform **classification** and **prediction** on trained sensors



Tegra X1

Nvidia DRIVE PX for AV

- An autonomous vehicle (AV) needs to know its location accurately, recognize objects around it, and continuously calculate the optimal path for a safe driving experience
- The situational and contextual awareness of the car and its surroundings demands a powerful computing system such as DRIVE PX that can merge data from LiDARS, cameras, other sensors, and navigation sources, while figuring out the safest path in real-time
- DRIVE PX combines deep learning, sensor fusion, scenario analysis, decision making, and triggering action
- DRIVE PX enables self-driving applications to be developed faster and more accurately
- Key features of the platform include:
  - Dual NVIDIA Tegra® X1 processors deliver a combined 2.3 TFLOPS
  - Interfaces for up to 12 cameras, radar, lidar, and ultrasonic sensors
  - Rich middleware for graphics, computer vision, and deep learning
  - Periodic software/OS updates



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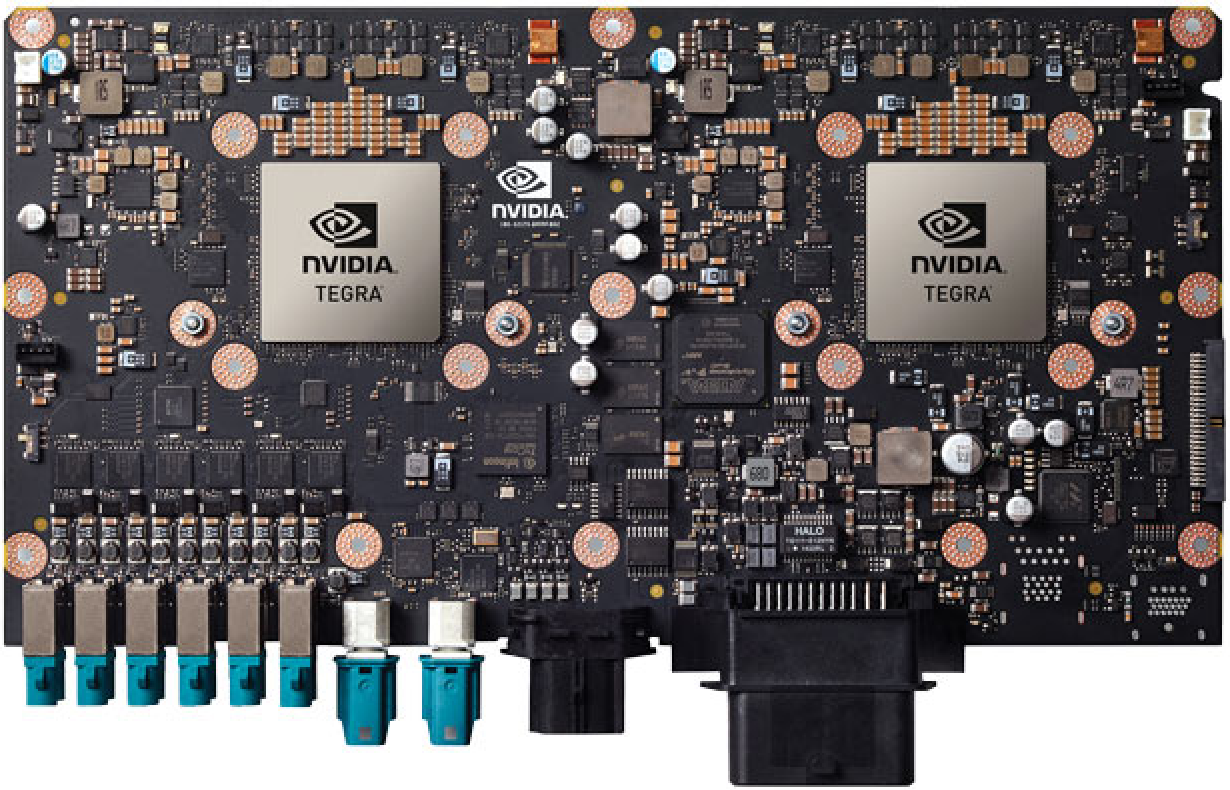
DRIVE PX 2



Nvidia's **DRIVE PX 2** Module: up to 8 TFLOPS

	TITAN X	DRIVE PX 2
Process	28nm	16nm FinFET
CPU	–	12 CPU cores 8-core A57 + 4-core Denver
GPU	Maxwell	Pascal
TFLOPS	7	8
DL TOPS	7	24
AlexNet	450 images / sec	2,800 images / sec

Autonomous Driving Based on Deep Learning

Vehicle Configuration

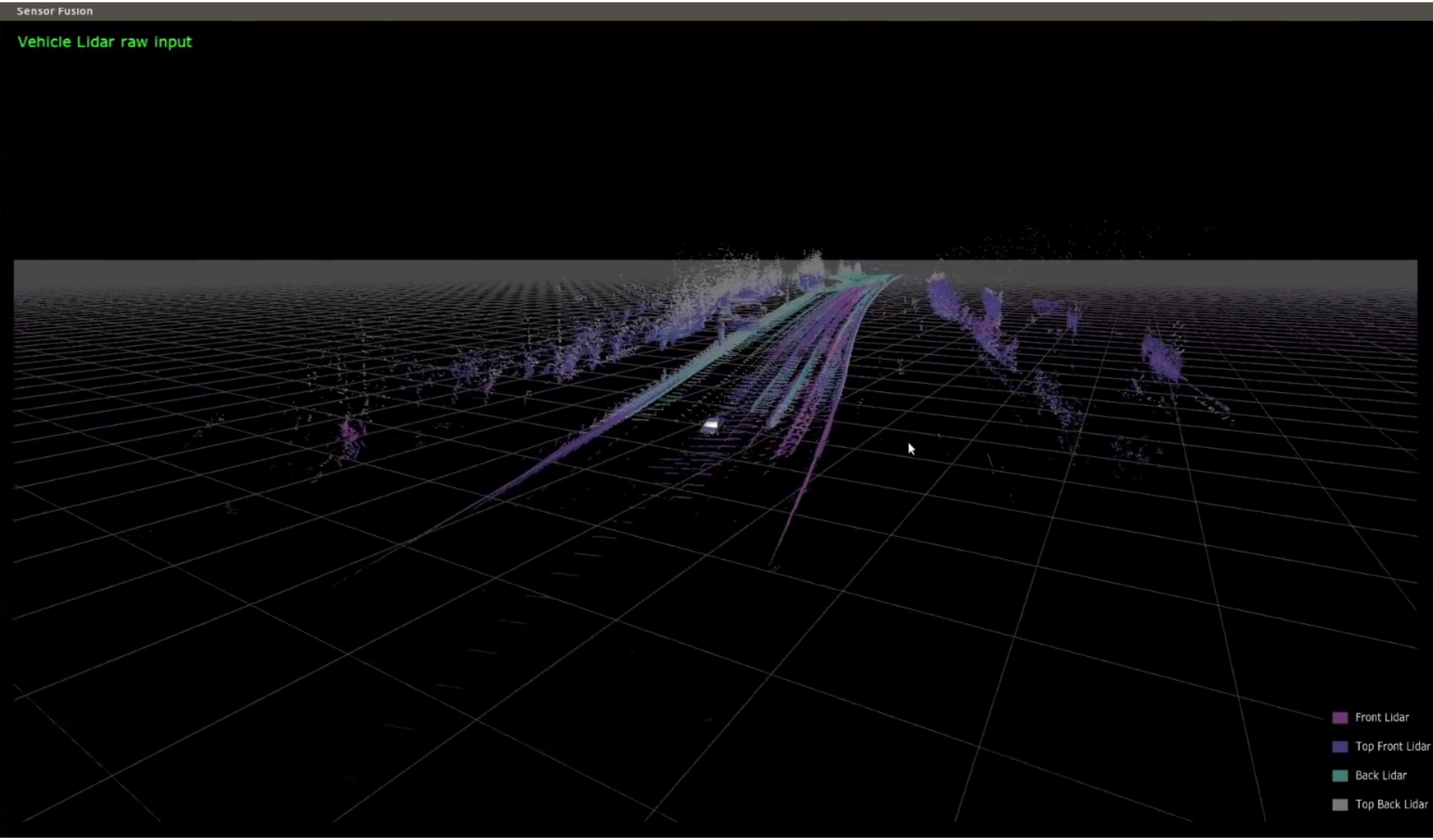
- 4 Quanergy LiDARs on 4 corners of vehicle
  480,000 samples/sec per LiDAR (frame rate 1-1000 frames/sec in S3)
  1,920,000 samples/sec for 4 LiDARs
- 4 surround view video cameras on 4 corners of vehicle, soon to be integrated with LiDAR
  240,000 points/sec per camera (8,000 points/frame, 30 frames/sec)
  960,000 points/sec for 4 cameras
- GPS with 2-3 m positioning accuracy
- IMU (Inertial Measurement Unit) includes accelerometer and gyroscope
- Car sensors: speed of wheels, turning angles of wheels, etc.

Autonomous Driving Based on Deep Learning
Perception Pipeline

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** – Occupancy Grid Detection and 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

Global Positioning of Point Clouds

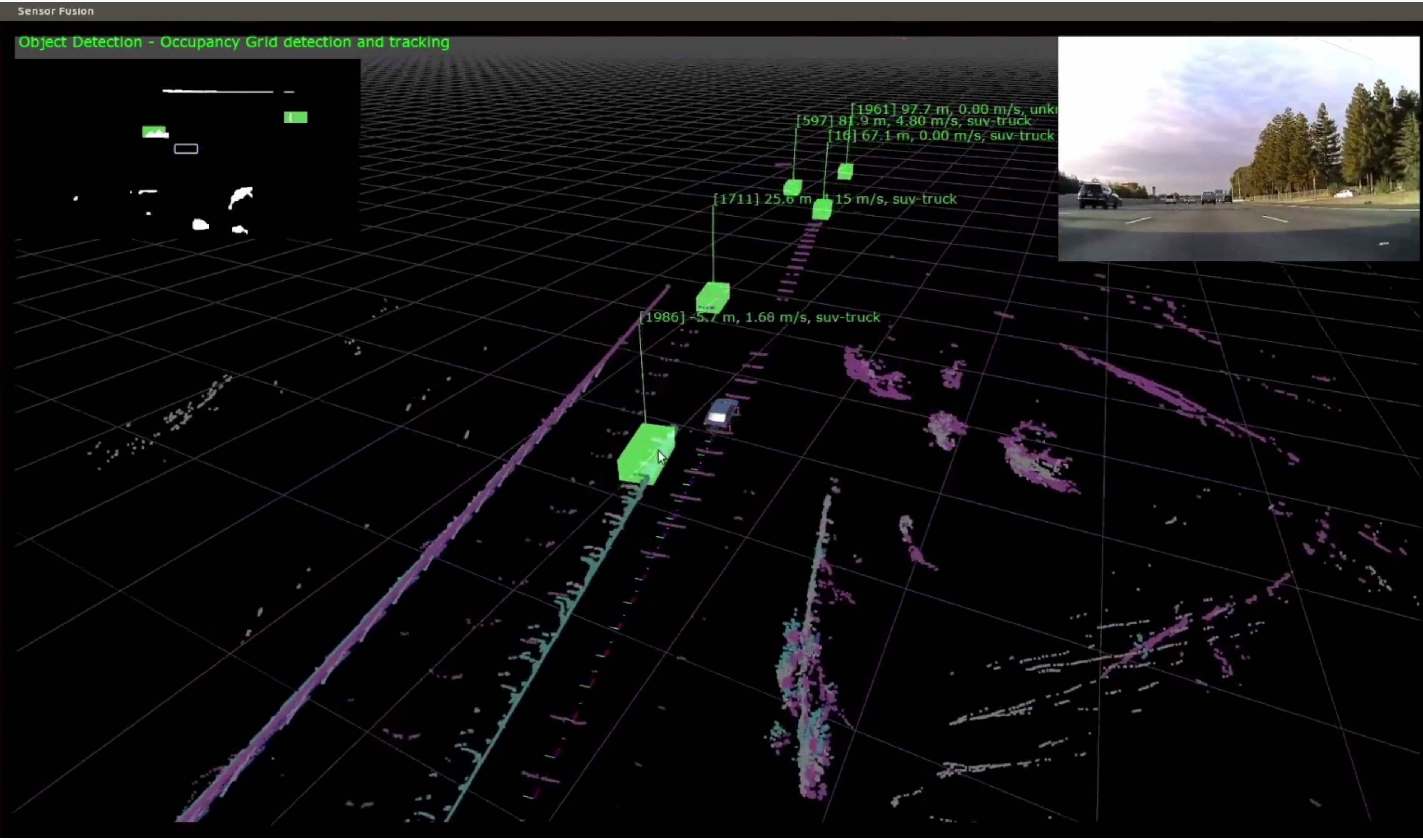
Vehicle LiDAR Raw Data



Nvidia data collected with Quanergy LiDAR sensors

Global Positioning of Point Clouds

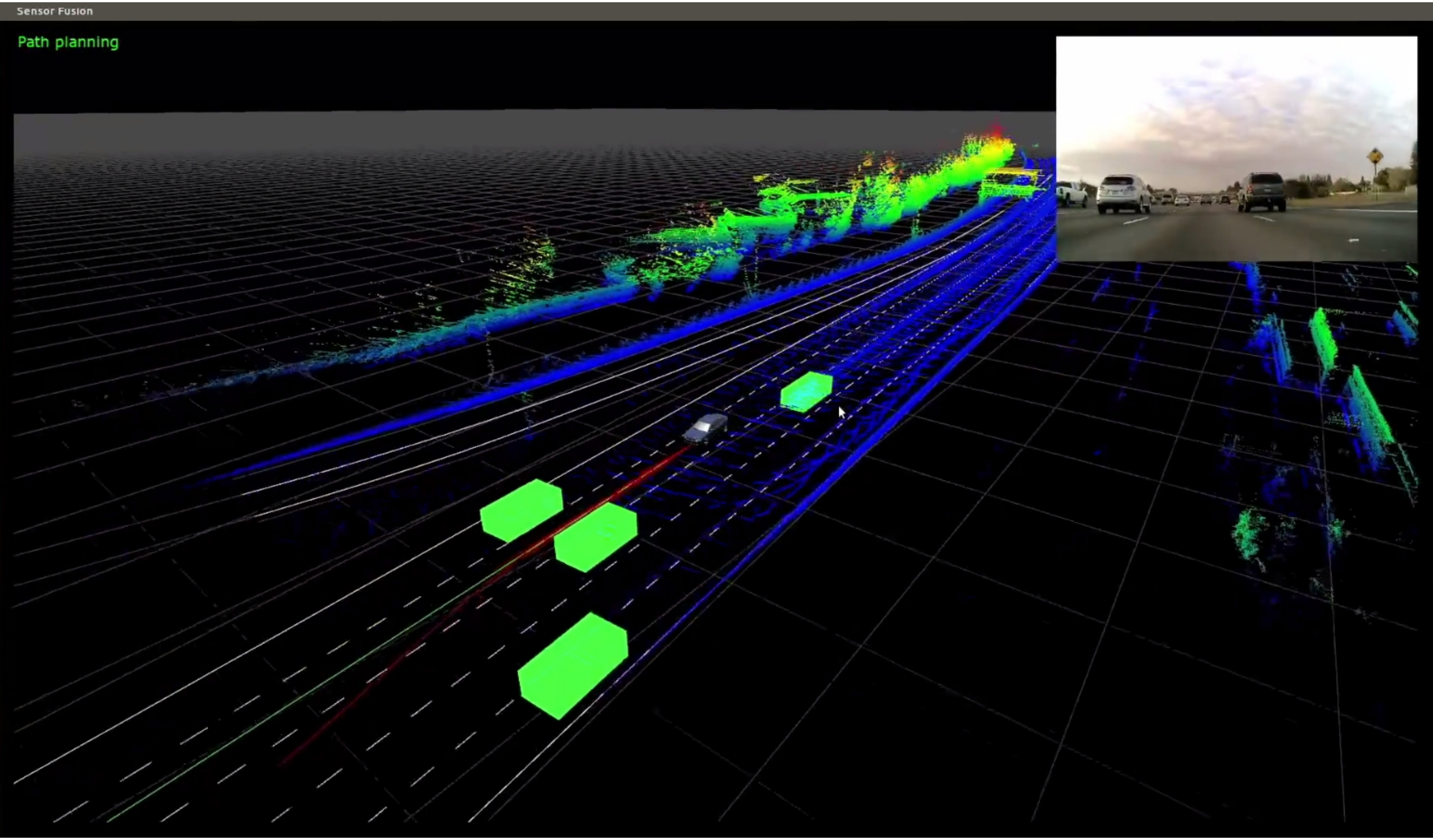
Object Detection – Occupancy Grid Detection and Tracking



Nvidia data collected with Quanergy LiDAR sensors

Global Positioning of Point Clouds

Path Planning



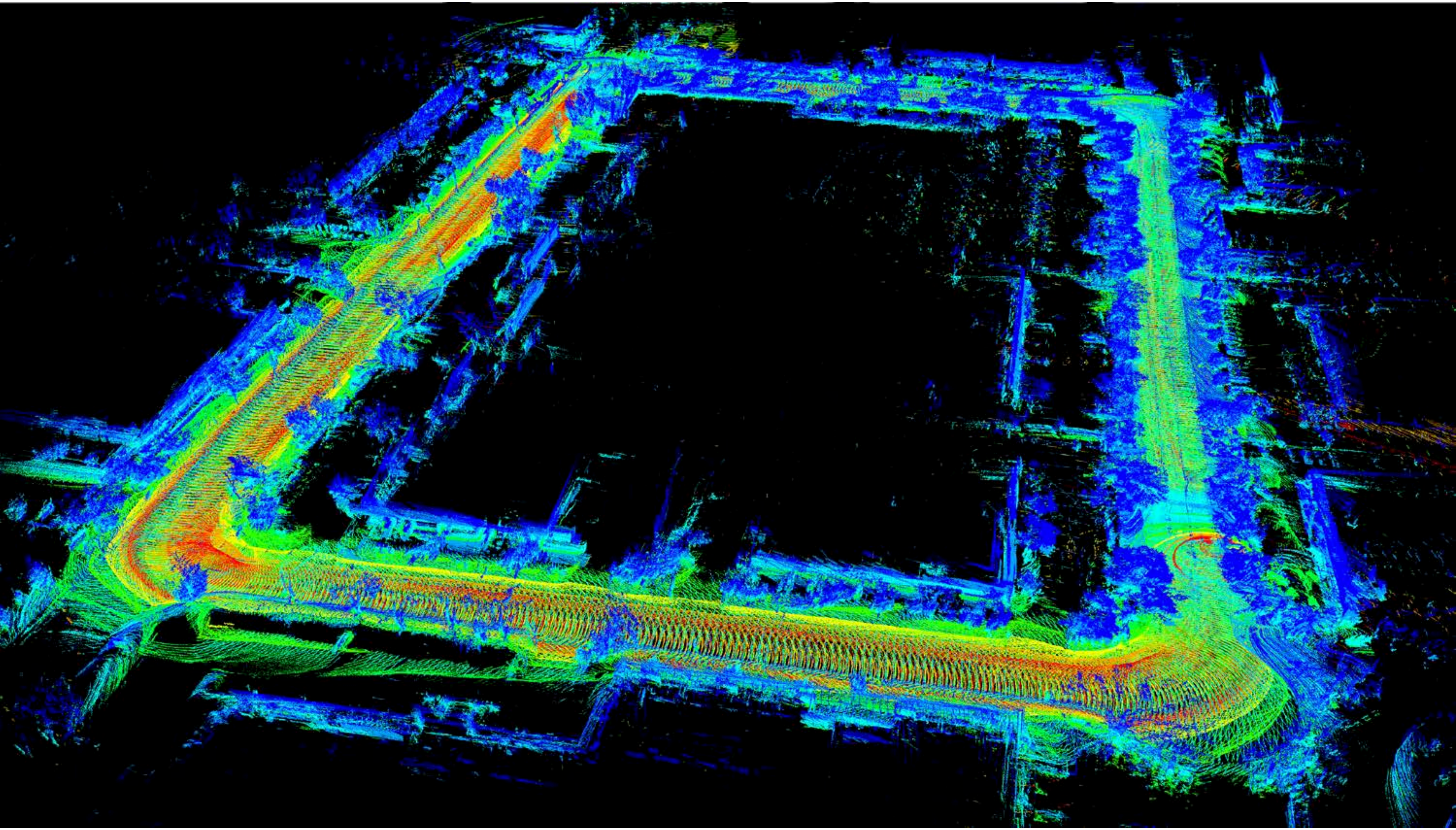
Nvidia data collected with Quanergy LiDAR sensors

LiDAR-Video Fusion & Deep Learning
CES 2016 nVidia Booth

Robotics Trends | All You Need to Know About Self-Driving Cars from CES
By *Brad Templeton*, Autonomous Vehicle Expert – January 12, 2016

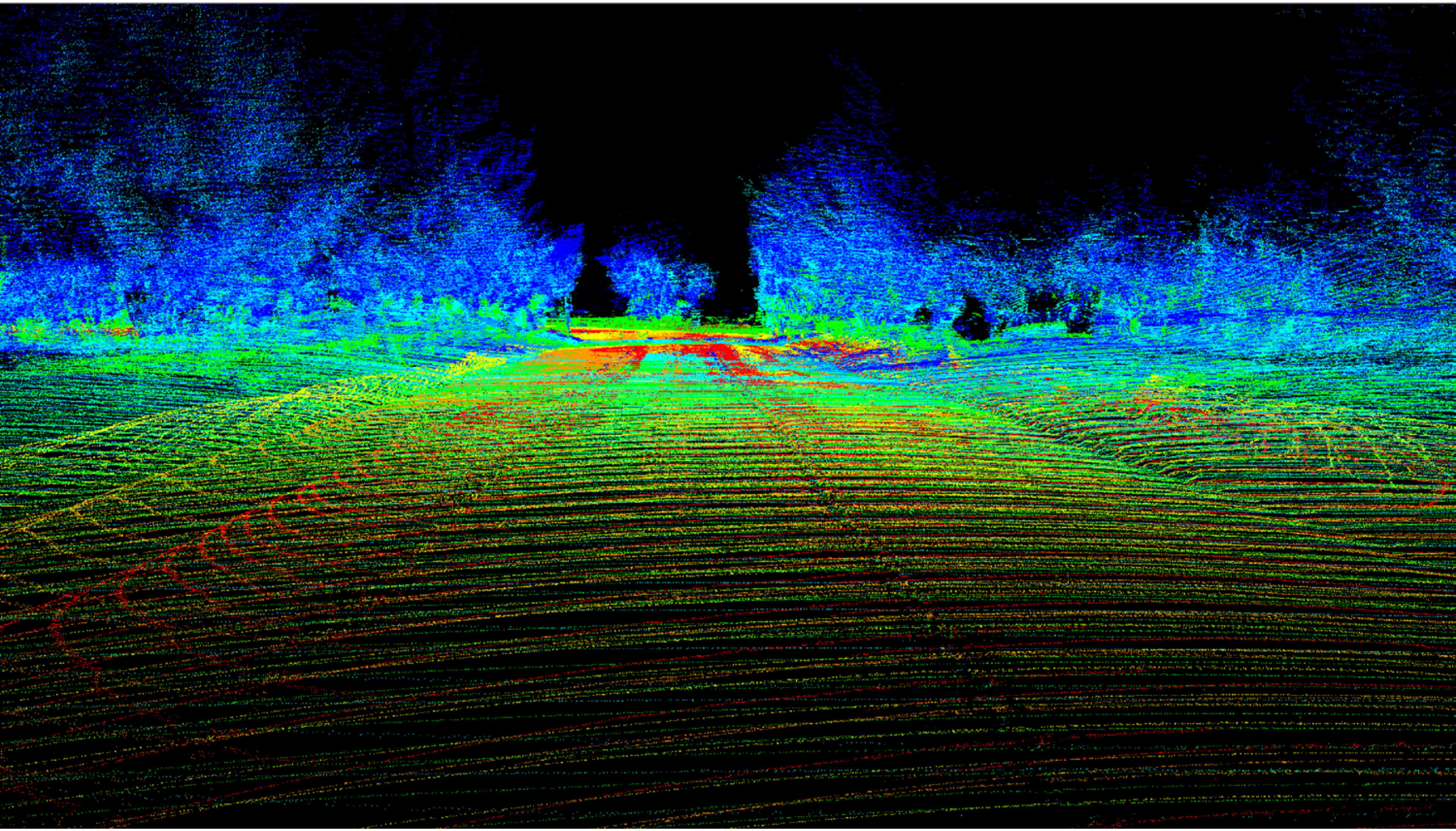
An Nvidia demo in pedestrian detection combined a Quanergy LIDAR and Nvidia cameras. In the demo, they had water jets able to simulate rain, in which case it was the vision that failed and the LIDAR which kept detecting the pedestrians. Quanergy's LIDAR looks at the returns from objects and is able to tell returns from raindrops (which are more dispersed) from returns off of solid objects.

3D Composite Point Cloud



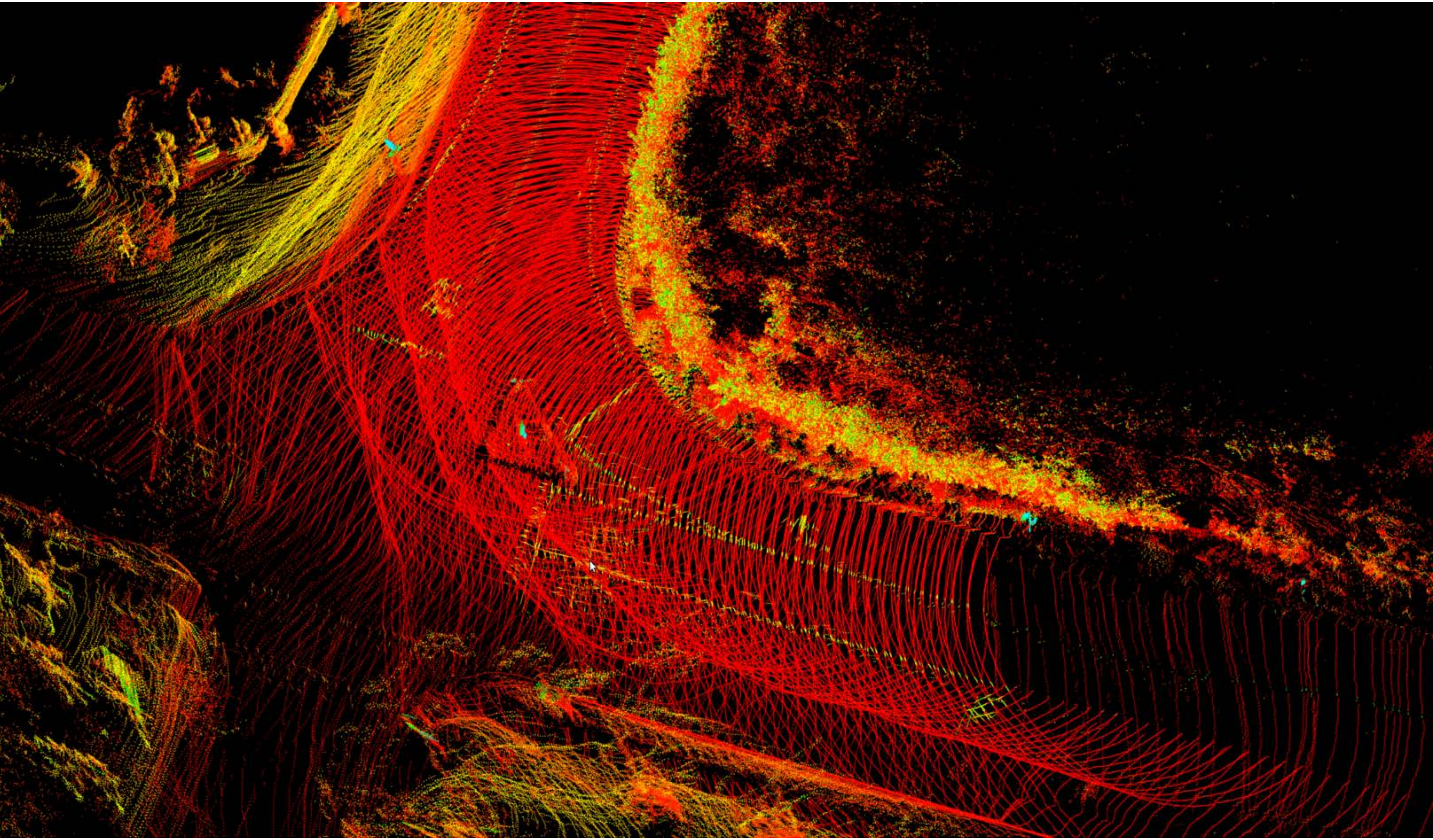
Color Coding: **Height**

3D Composite Point Cloud



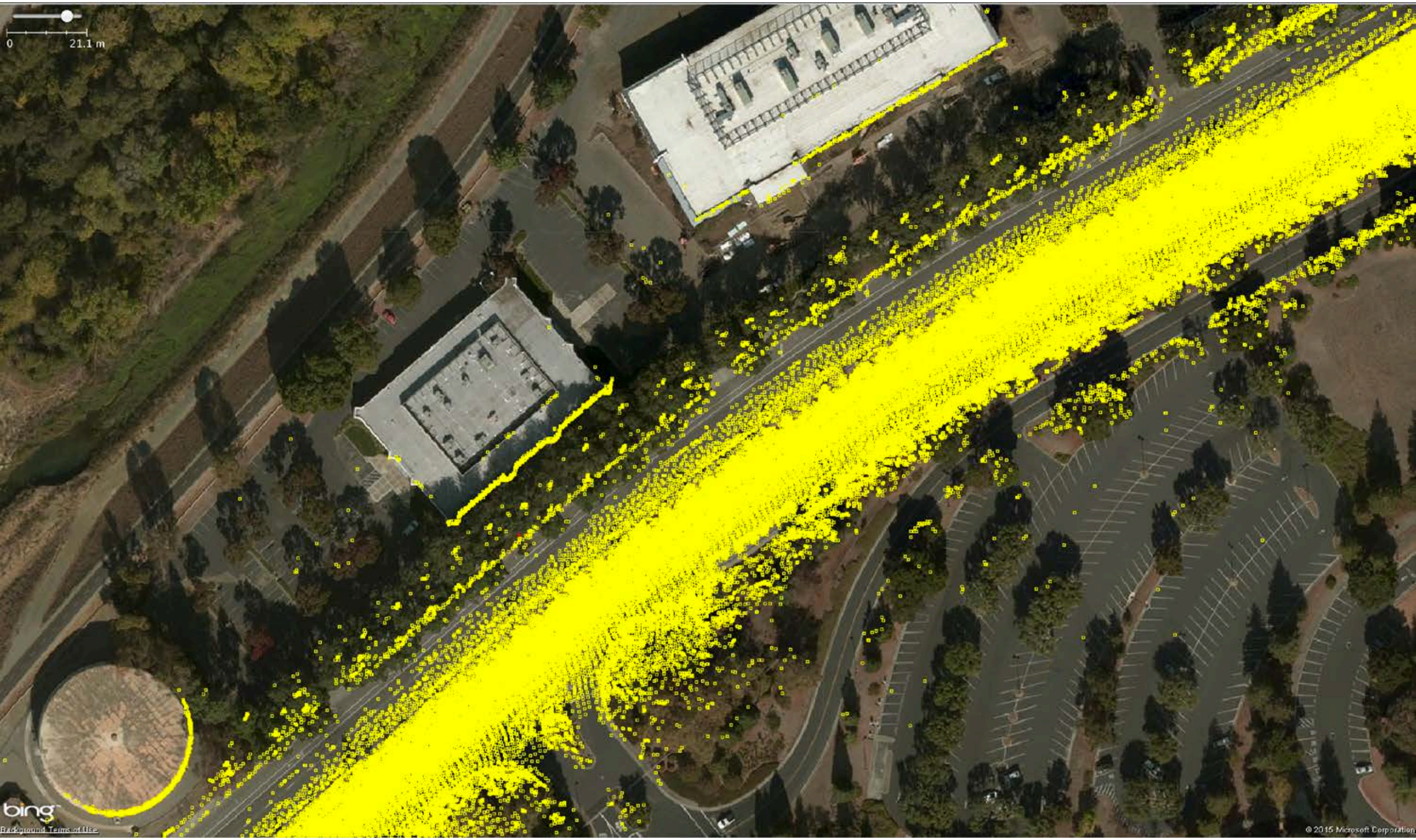
Color Coding: **Height**

3D Composite Point Cloud



Color Coding: **Reflectivity** (Intensity vs. Distance)

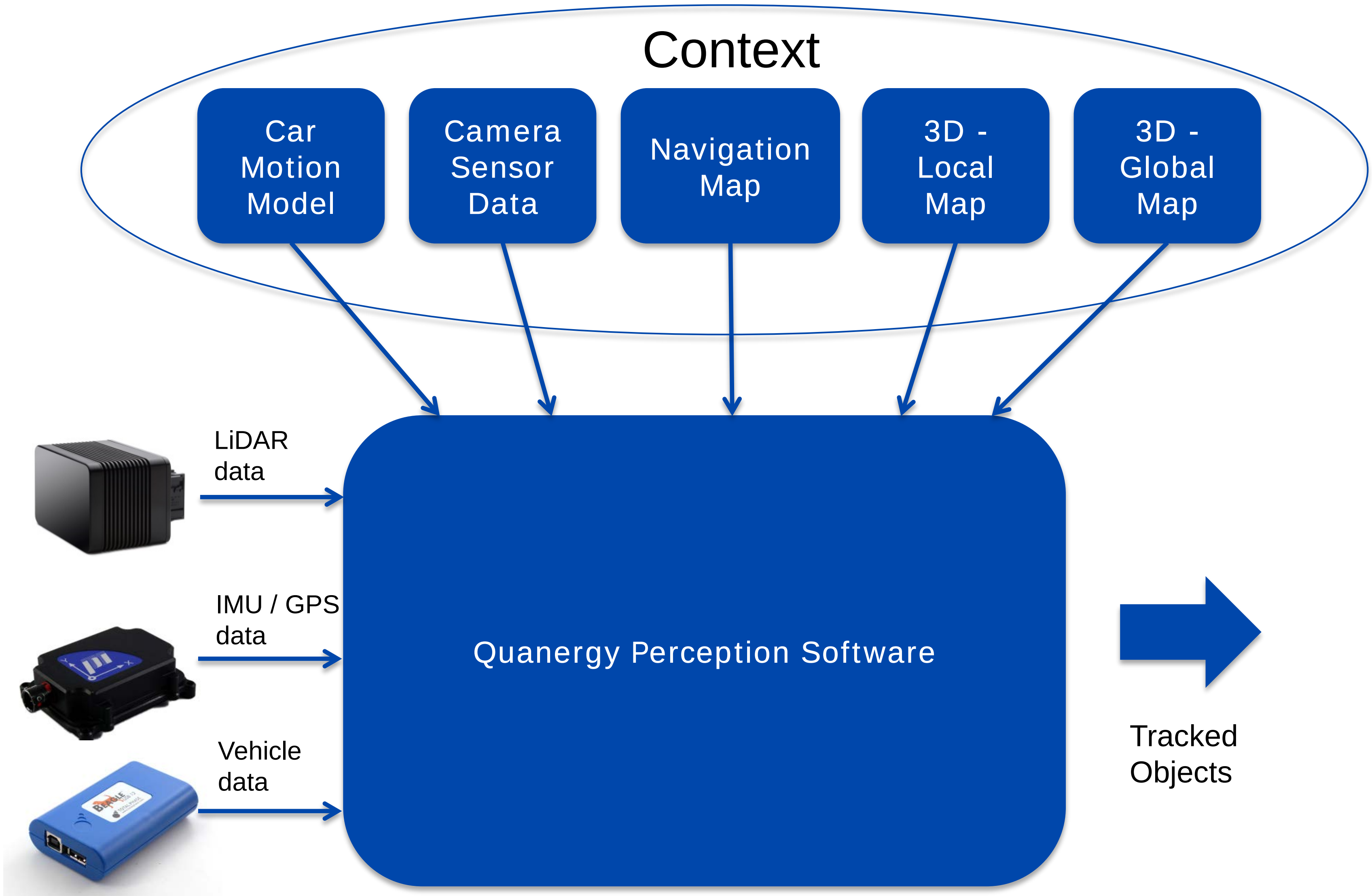
Global Positioning of Point Clouds



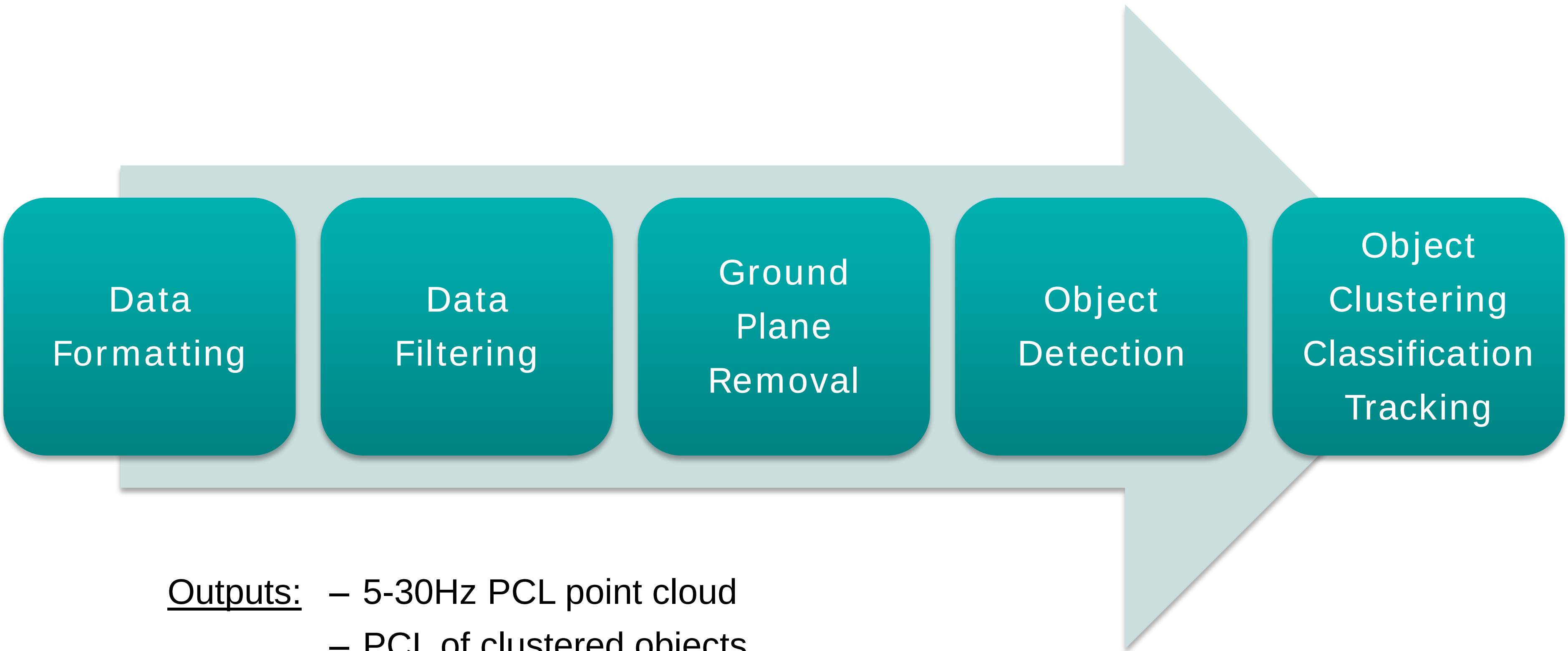
Overlay of LiDAR Point Cloud on Satellite Imagery

Point Cloud Library (PCL) Steps
– 3D Object Perception Pipeline –

Sensing and Perception



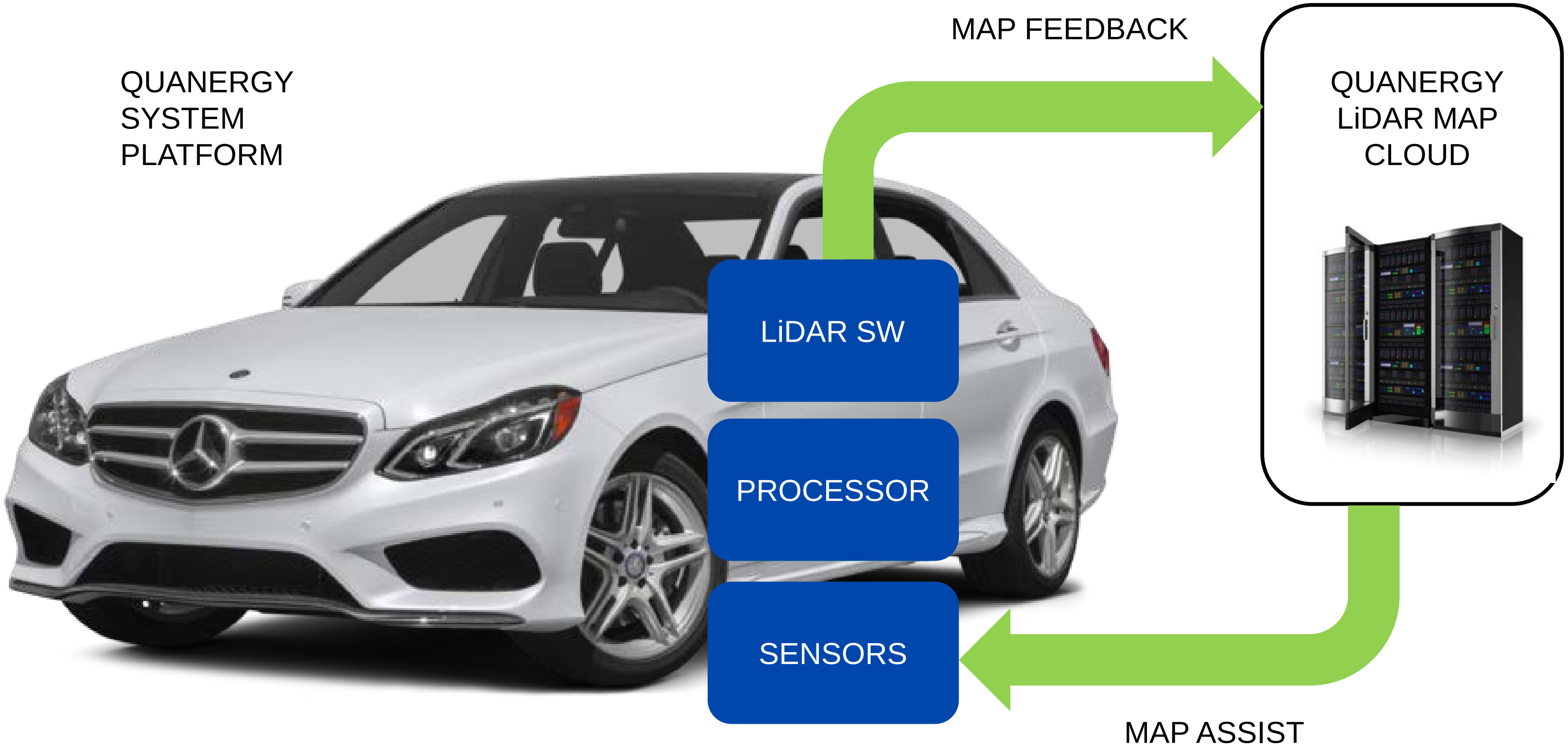
Quanergy 3D Perception Software



Outputs:
- 5-30Hz PCL point cloud
- PCL of clustered objects
- Object list with boundaries
- Object tracks

Formats:
- PCL/ROS (today)
- ADTF (roadmap)

LiDAR Software / Global 3D-Map



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