Autonomous Racing : Perception. Planning. Control

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University of Virginia

CS 4501-03/SYS 4582-002

Meet your instructor

Madhur Behl

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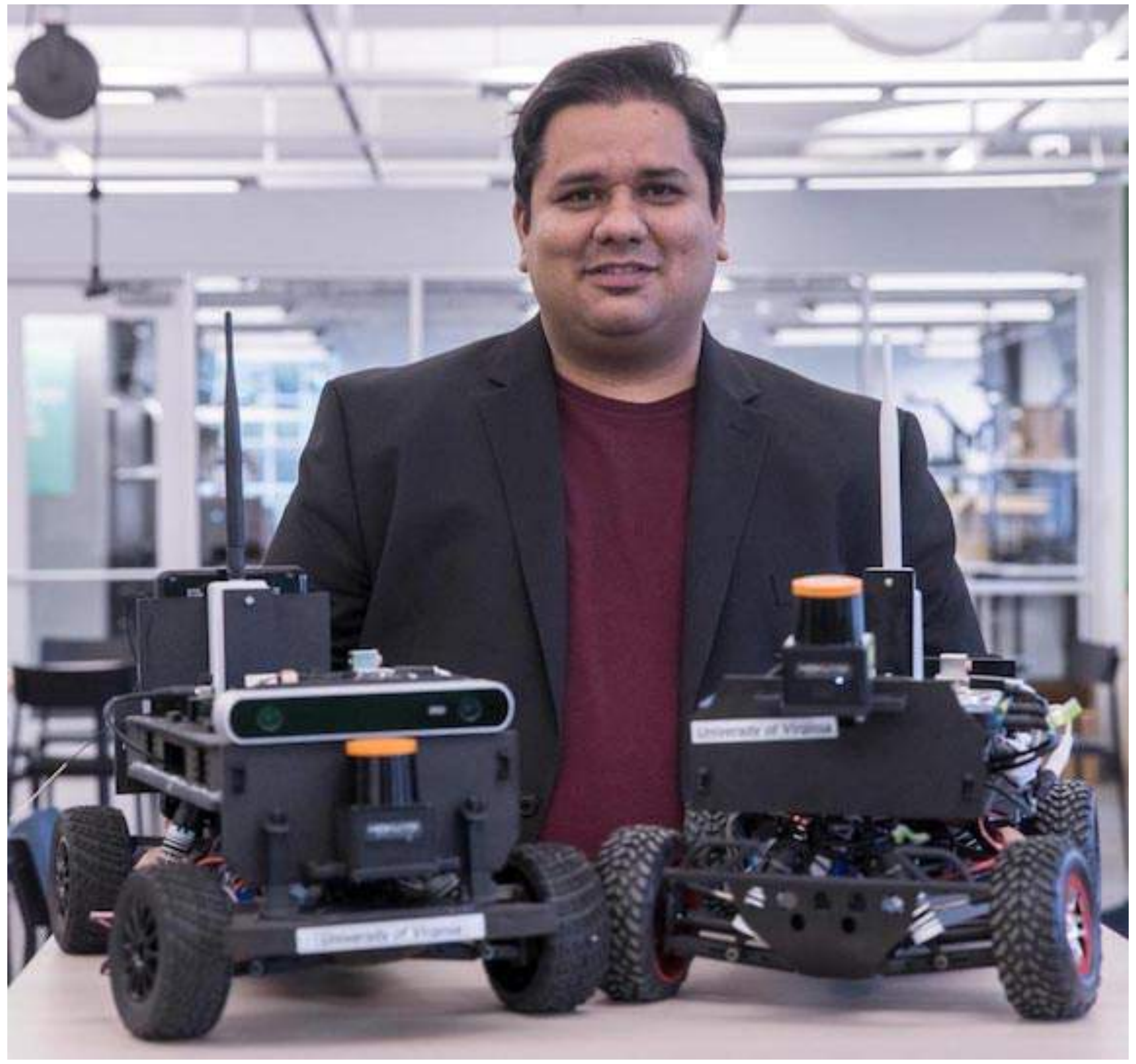
Assistant Professor

Computer Science,
Systems and Information Engineering.

PhD

University of Pennsylvania



What I do..

- Modeling
- Control
- Optimization
- Implementation
- Safety

Cyber-Physical Energy Systems

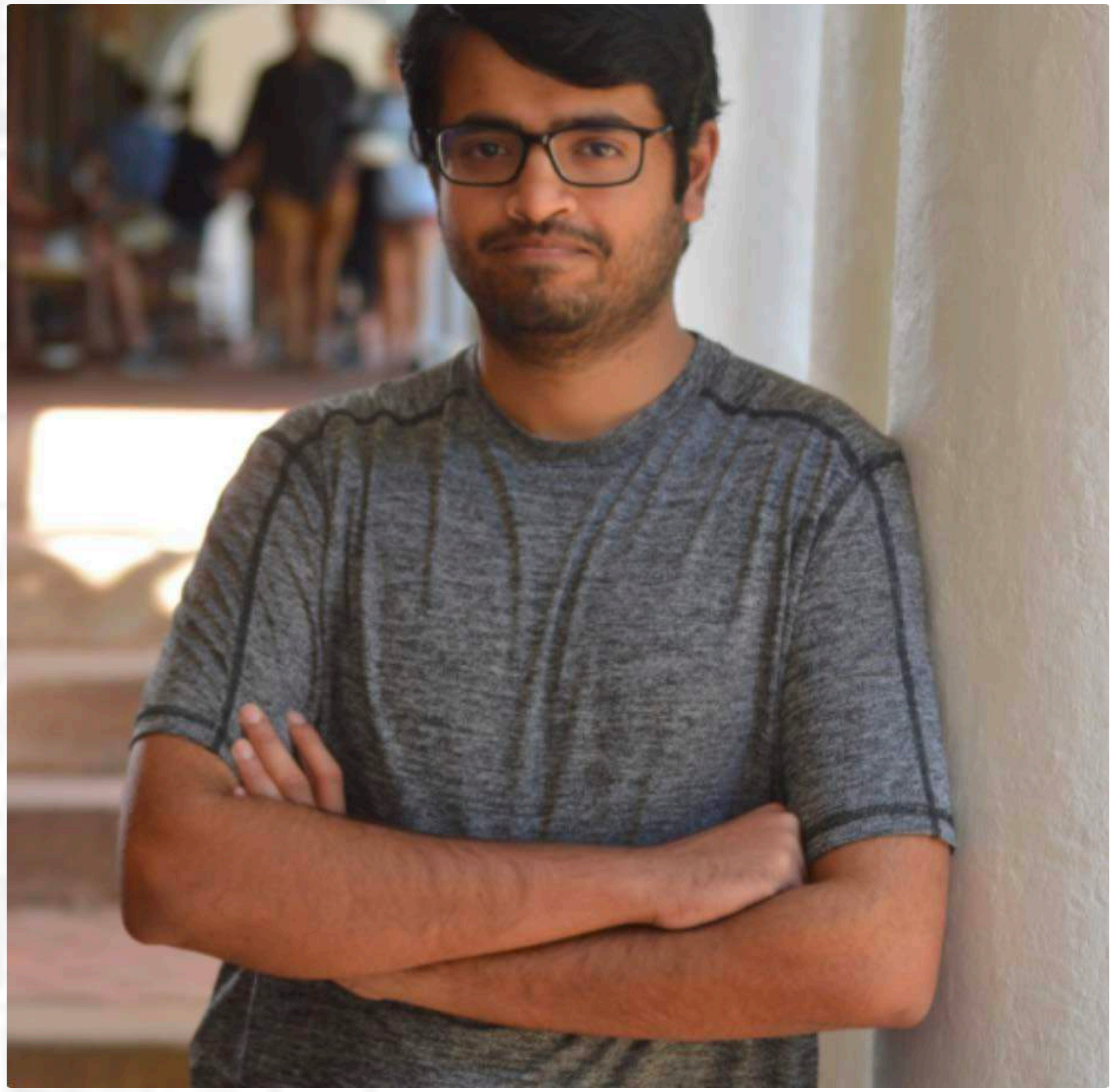
Critical Infrastructures & Smart Cities

Medical Cyber-Physical Systems

Automotive Cyber-Physical Systems

Teaching assistant:

Varundev Sukhil : vss8sm@virginia.edu
Olsson Hall 2nd Floor, Link Lab
Office Hours:
TBD on Piazza



Lecture: Monday 2-3:15pm

Lab: Wednesday 2-3:15pm

Course Website: https://linklab-uva.github.io/autonomousracing/

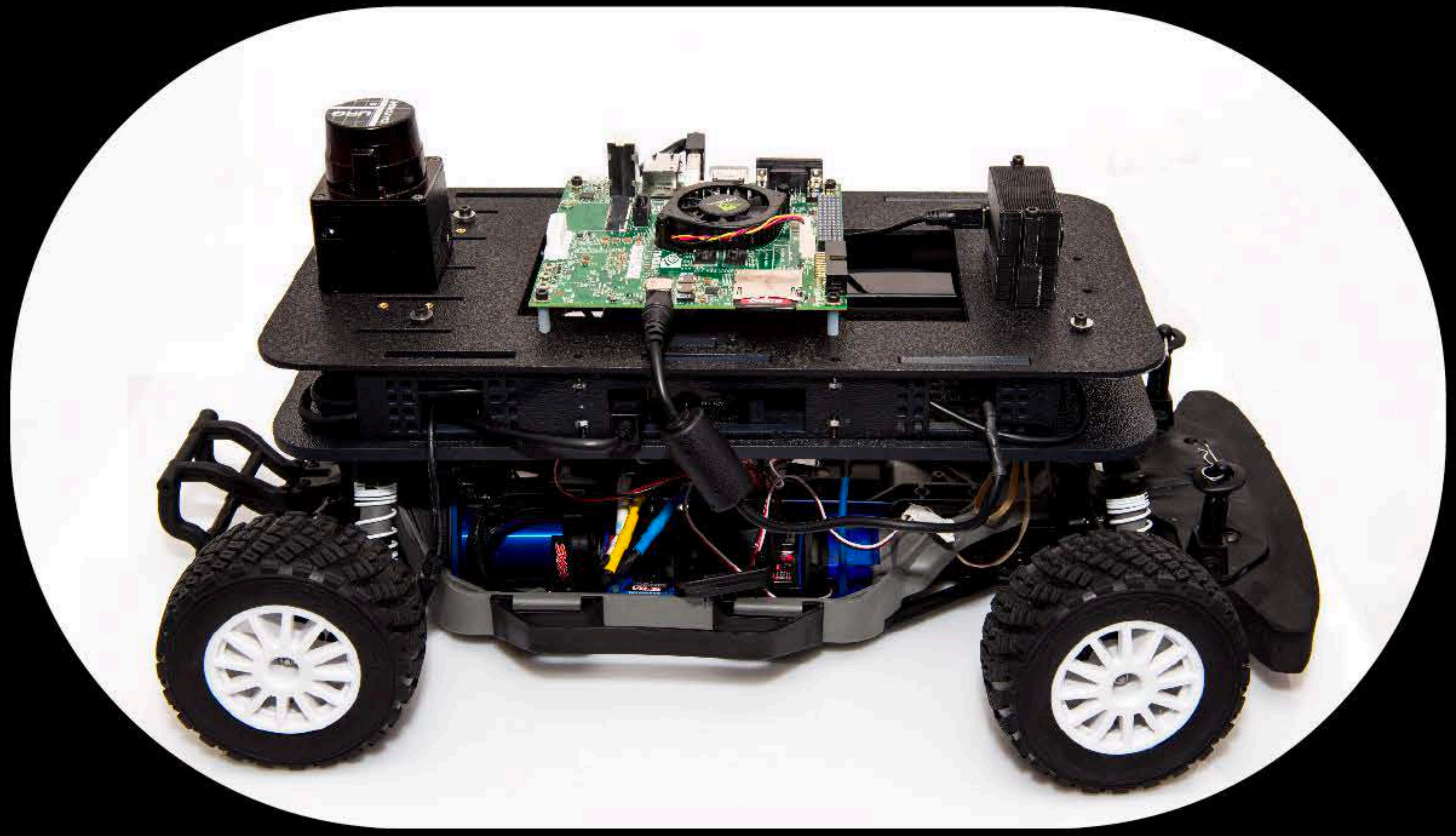
Classroom: Rice 120

F1/10

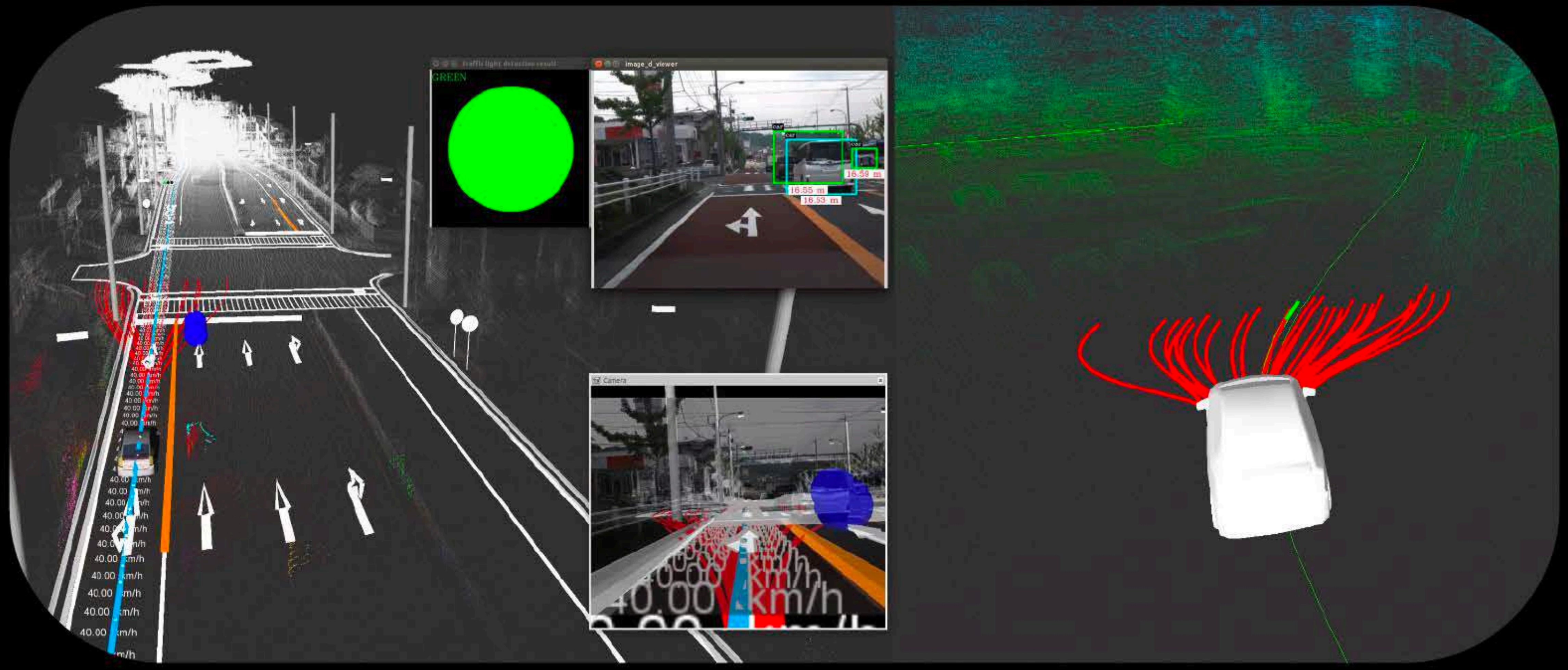
Autonomous Racing

1/10 the scale. 10 times the fun!

Build. Drive. Race.



Perception. Planning. Control

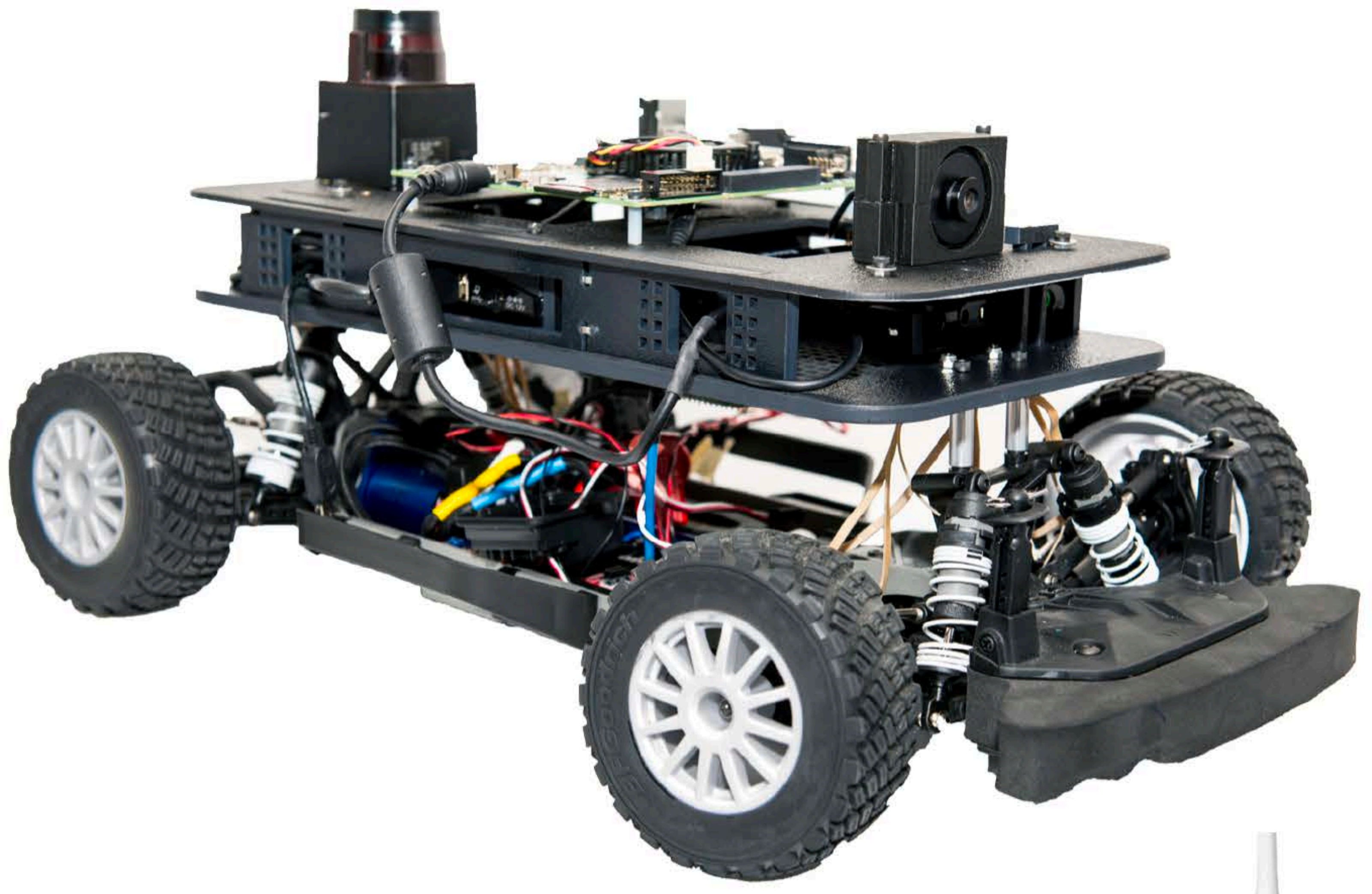


Platform

A 1/10th scale RC car provides the base vehicle.
Components are added to make the car fully autonomous.

For perception, a LIDAR, stereo, and depth cameras are added to a custom-built mounting frame.

An inertial measurement unit (IMU) is used to aid in vehicle control, while an embedded microcontroller provides the necessary support for controlling the motor.
All computation and motion planning is done using an on-board NVIDIA Jetson.

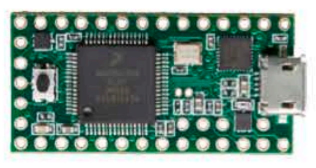


NVIDIA Jetson

LIDAR

Camera

IMU



Motor Controller

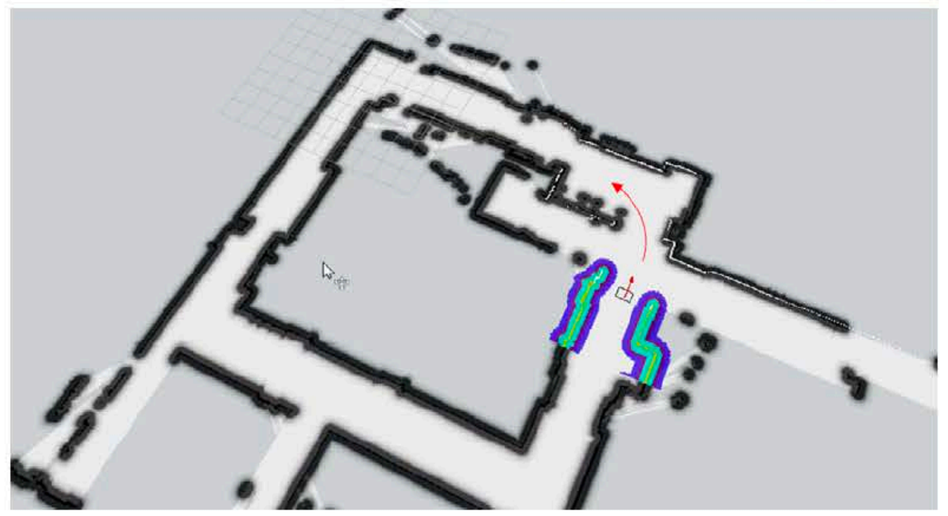
Stereo Camera

Telemetry

Course

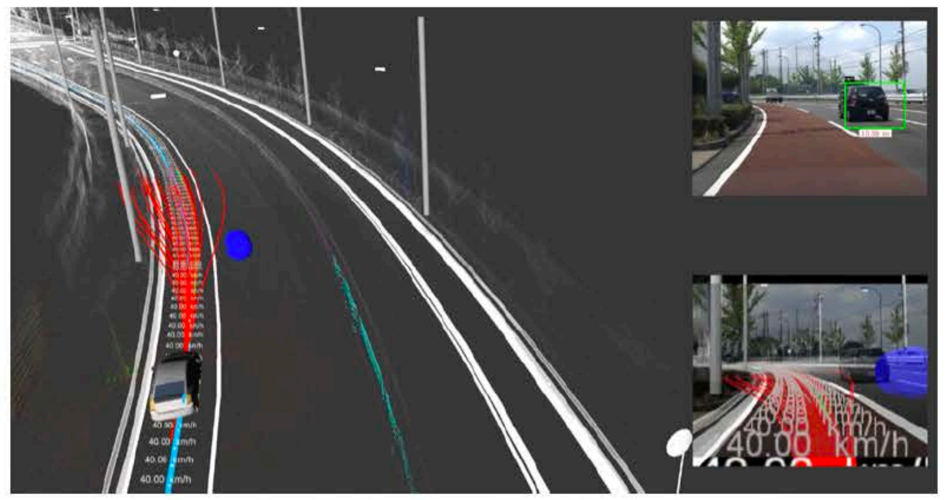
The F1/10 autonomous racing course focuses on learning how to build, drive, and race 1/10th scale F1 race cars (capable of speeds in excess of 20 mph all while learning about **perception, planning, and control** for autonomous navigation.

Learn about the technology behind slef driving cars while building one, on your own.



LIDAR scan map

Topics



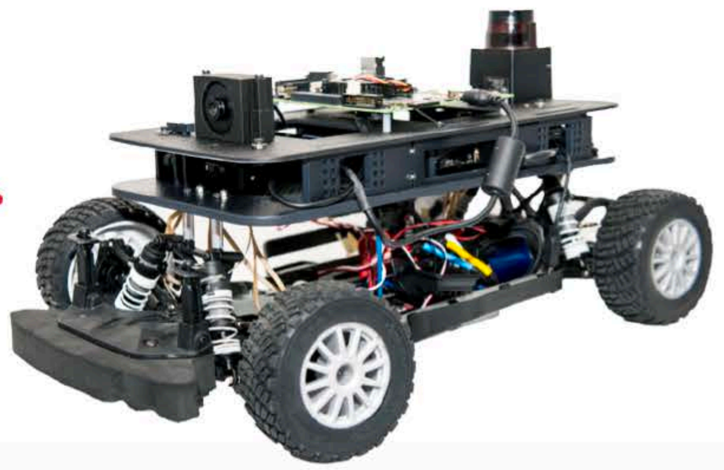
Motion planning simulation run in ROS

Robot Operating System
Perception pipeline using LIDAR, Cameras, and IMU.
Odometry Basics.
Localization and Planning using Scan matching, kalman filter, particle filter (AMCL), vanishing point.
Mapping using Hector SLAM
PID control.
Command the steeting and acceleration inputs of the car.
Data visualization and debugging tools.

Advanced topics in scene understanding: obstacle detection, lane detection
Collision avoidance
Optimal racing lines and racing strategies.

The course will end with a *battle of algorithms* F1/10 GP race amongst teams

VS.



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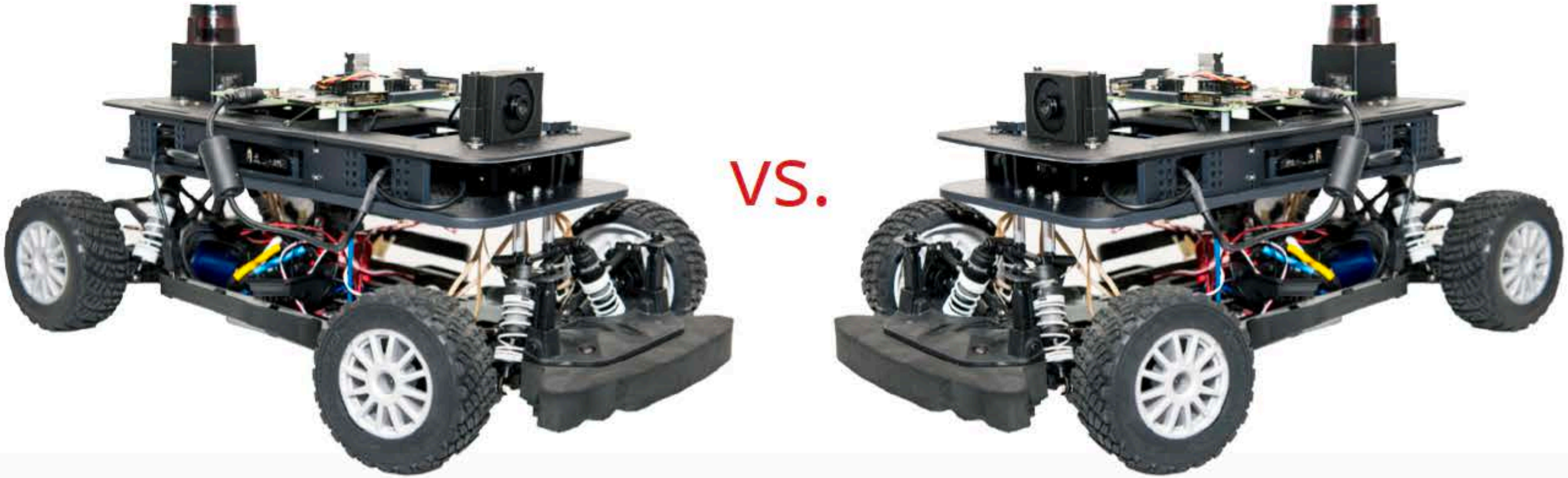


Grading Criteria

This course does not have a midterm or a final exam.

The final grade will be determined on the basis of:

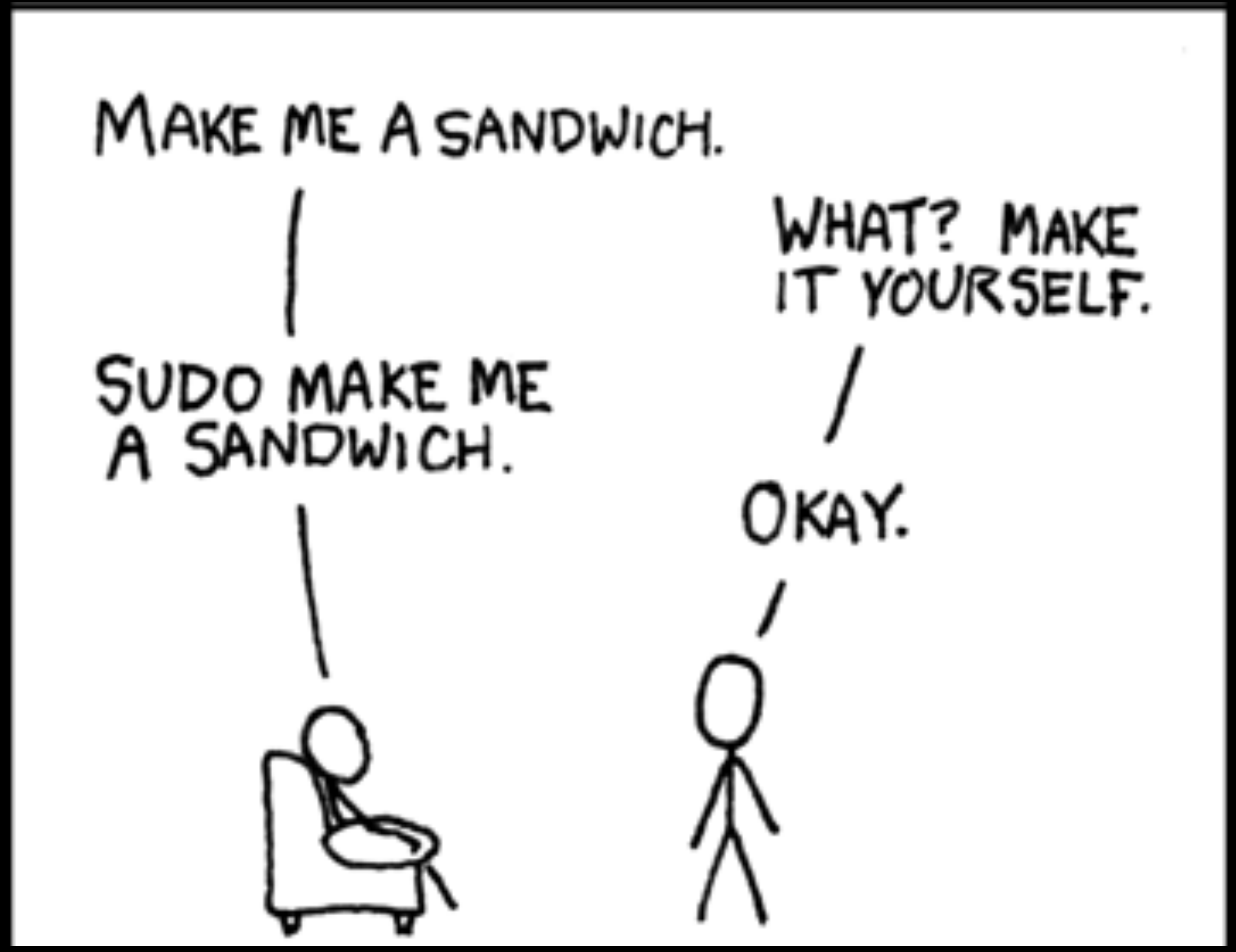
- Weekly assignments
- Lab exercises
- Short project
- Final race performance

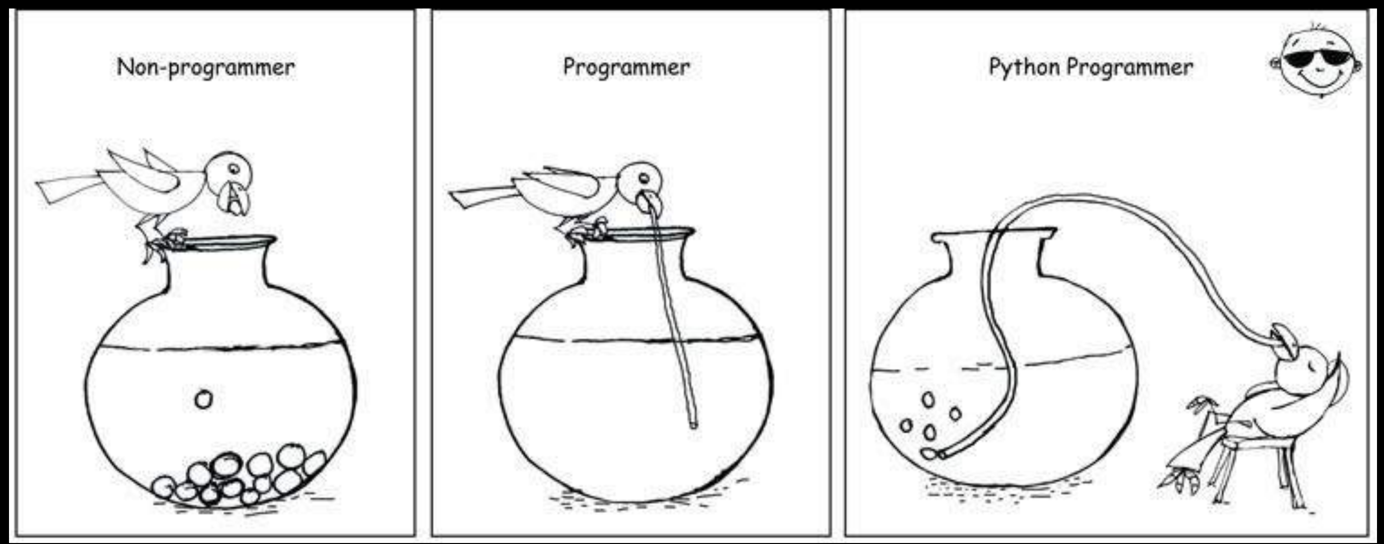
Students will be graded individually and in teams.

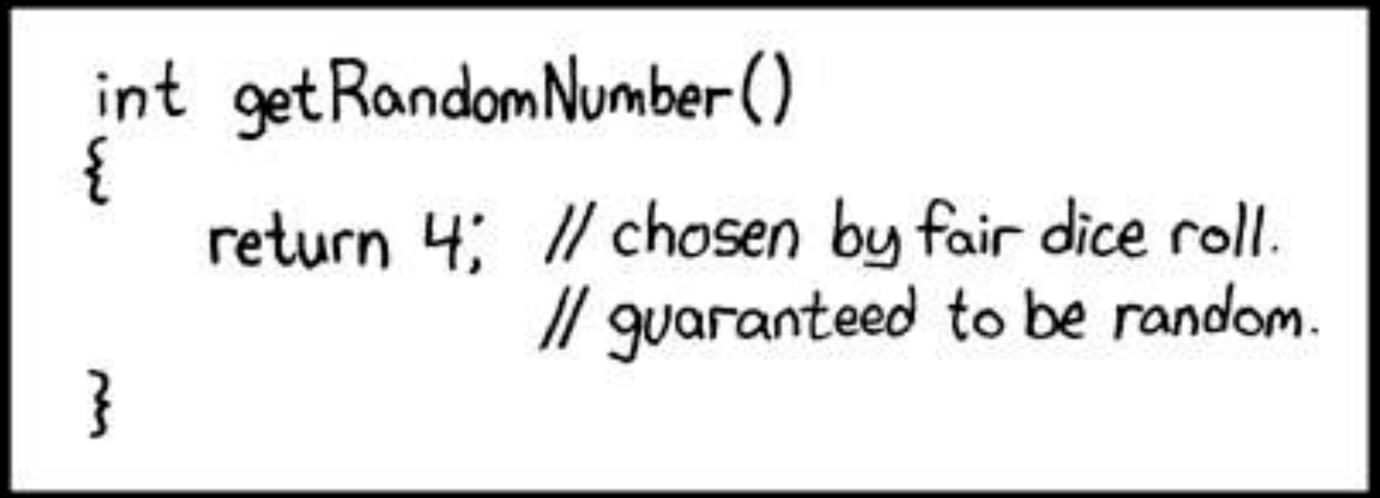
This is an *advanced* special topics class. Which means, that although, we will cover everything which is required to build, drive, and race the cars; it is assumed that students have some familiarity with the topics highlighted below.

To succeed in this course, you need to have some experience with the following topics:

- Calculus and linear algebra:
  - Single variable calculus and differential equations.
  - Matrix operations- transformations and rotations.
- Basic statistics and probability:
  - What is a probability distribution ?
  - What is sampling ? Mean, and variance of samples.
- Intermediate Python:
  - Function calls, conditional statements, loops and recursion
- Unix/linux command line/shell basics
  - File commands/file permissions: *ls, cd, pwd, mkdir, rm, cp,mv, touch, chmod, tar*
  - Process management: *ps, top, kill pid*
  - *ssh user@host.., grep, locate, echo*
  - Installation: *./configure, make, make install*
  - Ports: */dev/ttyACM**
- Basic physics (Newtonian mechanics)







Background in the following is recommended, but not required:

- Intermediate C++
- ROS programming
- Integrating sensors with microcontrollers (master/slave configurations)
- Machine learning

If upon, looking at these topics, your conclusion is: *I'm qualified, but not* **that** *qualified.* Then it is likely that you are qualified.
If you are still unsure, feel free to email the instructor for permission to register.

Syllabus – Topics to be covered

Week 1	**Course Introduction**
Week 2	**Introduction to Robot Operating Systems**
Week 3	**ROS deep dive + TurtleSim**
Week 4	**Pulse Width Modulation - Teensy**
Week 5	**Perception – Sensing your surroundings**
Week 6	**PID Control and path following**
Week 7	**Wall following, boundary detection**

Syllabus – Topics to be covered

Spring Break	
Week 8	**Basics of Navigation - Localization**
Week 9	**Mapping - SLAM**
Week 10	**Trajectory planning**
Week 11	**Open CV, Visual Odometry**
Week 12	**Advanced topics in scene understanding**
Week 13	**Racing strategy**

Lab exercises

Practice Session 1:

Understanding ROS | Setting up the Car

Practice Session 2:

Perception/Sensing | Driving Straight

Practice Session 3:

Driving in a loop | Visual Odometry

Practice Session 3:

Race | Time trials | Head-to-head racing

We will use Ubuntu 14.04 LTS on the F1/10 car

Everyone must have access to Ubuntu **14.04** or **16.04** or **18.04**

Two options:

- Dual boot your laptop.
- Install an Ubuntu virtual machine on any OS.
  (Announcement will go out on Piazza, with instructions.)

No lab session this week.

Bring your laptop to the lab session next Wednesday.

So what is F1/10 ?

Everything that moves will go autonomous


Cars


Trucks


Carts


Drones

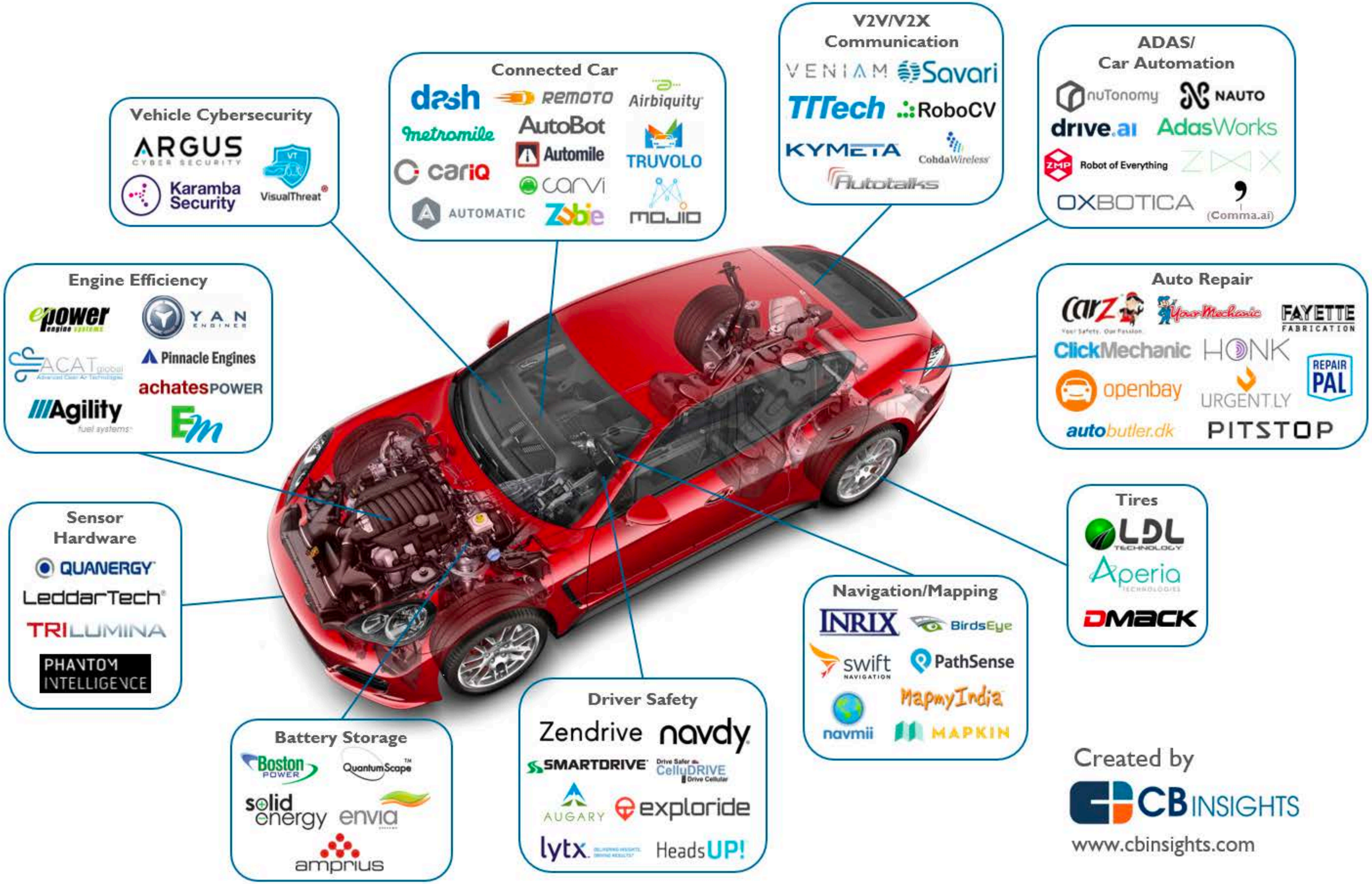
Audi
Autoliv
Baidu 百度
BMW
BOSCH
DAF
DAIMLER
DELPHI
DiDi

FCA
Ford
GM
HONDA
HUAWEI
HYUNDAI
intel
IVECO
JAGUAR
LAND ROVER
lyft

MAGNA
MAN
Mercedes-Benz
Microsoft
MOBILEYE
NISSAN
RENAULT
NVIDIA
PACCAR
PSA GROUPE
SAMSUNG

SCANIA
SoftBank Group
TATA ELXSI engineering creativity
TESLA
TOYOTA
Valeo
Volkswagen
VOLVO
VOLVO Volvo Group
WAYMO
YUTONG

Unbundling The Automobile



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THE FUTURE OF TRANSPORTATION STACK

COMET LABS

SERVICES

ROUTE PLANNING
SPATIAL, CITIVIZ, waze, CommuteMaster, X, moovit, Citymapper

PARKING
Waypals, Cloud Parc, Aware, VoicePark, SpotHero, PEARL, seev, der, Parko, FenSens, LUXE, airsys

CAR HAILING + POOLING
TESLOOP, lyft, RideCell, 3C, 滴滴

OTHER: AFTERMARKET, REPAIR, RENTAL
CARVUE, upshift, WRENCH, PATROL, zipcar, Getaround, URGENTLY, Tantalum, bitkar

SAFETY & SECURITY

PHYSICAL CAR & DRIVER SAFETY +ACCIDENT DETECTION
drivebetter, splitsecnd, nexar, GUARDIAN Optical Technologies, phrame, LyfeLens, SMART AUTOLABS, tourmalinelabs, iproc, eLSys, FORESIGHT

EMOTION, FATIGUE & ALCOHOL DETECTION + DISTRACTION AVOIDANCE
CORTEX LABS, eyeris, ALMA care, C6, CARMA, saverone, SMART wheel, Radiomize, EASY, carvi

CYBERSECURITY
CYMOTIVE, cognomotiv, VisualThreat, ARGUS, Olympus Sky, Karamba Security, Trillium, Arilou

INTRUSION, TRACKING & RECOVERY
trackstop, nonda, gmt Connect, ROADEYE, caruma

IN-CAR INTELLIGENCE + ASSISTANCE

VEHICLE DIAGNOSTICS & PREDICTIVE MAINTENANCE + SENSOR-BASED VEHICLE SAFETY
TrueMotion, BRAIQ, IQ, metromile, LIGHT METRICS

PASSENGER-FOCUSED SENSORS (INCLUDING USAGE-BASED INSURANCE)
Cartics, Zoobie, nauto, SONICLUE, PREDICTIVE SYSTEMS, P, NEBULA, engie

INFOTAINMENT + DISPLAY
link motion, HUDIFY, carrobot, swedspot, OverDrive, ROAV, FICONIC SOLUTIONS, RIGHTWARE, PELAGICORE, CLOUDCAR

PERSONAL / VOICE ASSISTANCE
novideck, AUTOMATIC, dash, GRIN, carla

NAVIGATION ASSISTANCE + PEDESTRIAN ANALYSIS & COMMUNICATIONS
WAYRAY, PERCEPTIVE AUTOMATA, navdy, hudly

AUTONOMY

AUTOMATION SYSTEM
AutoX, drive.ai, POLYSYNC, OXBOTICA, oryx, ARGO AI, AIMOTIVE, PILOT, cruise, nuTonomy, vector.ai, BWV, MOMENTA, cognivue, 中天安驰 AIDRIVING

MAPPING, SIMULATION, & IMAGE RECOGNITION / ANNOTATION
lvl5, minds.ai, NOMOKO, Mapper.ai, CARMERA, TomTom, IMPROBABLE, UDACITY, DEEPMAP, understand.ai, Civil Maps

AUTONOMOUS VEHICLE MAKER + TOOLS
nuro, WAYMO, ZOOX, FARADAY FUTURE

INFRASTRUCTURE + CONNECTED CAR

SENSOR NETWORKING INFRASTRUCTURE (V2V, V2X) - LPWA, CELLULAR, WIFI
DIGIMONDO, SAVARI, ZiFiSense, EVVOS, Actility

CONNECTED CAR - DATA, PLATFORM, SOFTWARE
ACTIVESCALER, INRIX, SPARC, mobiliuz, carvoyant, vinli, otonomo, mobile assisted driving, bright box, VEHICLE DATA SCIENCE, mojio

FLEET + TRAFFIC MANAGEMENT
BESTMILE, Cloud Your Car, synovia, Fleetmatics, urban engines, Motionlogic, Travelai, Automile, Zendrive, GLYDEL, locoNav, Immense Simulations, MOTORWAY BUDDY, mentis, FR, Brisk Synergies

OTA CAR SOFTWARE UPDATION + SMART PHONE ENABLEDTELEMATICS
FIXD, DRIVEBOT, VOYOMOTIVE, ZENE, arynga

INTELLIGENT MANUFACTURING

NEW/ADVANCED MATERIALS
AQUARIUS, NAWA TECHNOLOGIES, SIRRUS, NANOSTEEL

RAPID PROTOTYPING - 3D PRINTING, MODULARIZATION, OPEN SOURCE
DM, Carbon, nanocore, DIVERGENT, LM, OSVehicle, stratasys, VADER

ADVANCED / AUTOMATED ASSEMBLY LINE
Grabit, SYMBIO, CLEARPATH ROBOTICS, ROBOMOTIVE, rethink robotics

MATERIAL CHARACTERIZATION & TESTING
SynTouch, SASTRA ROBOTICS, VIDI, OPTOFIDELITY

ONBOARD SENSORS

LOCATION - GIS, PRECISION POSITIONING, PATH PLANNING
swift NAVIGATION, radiosense, EXO TECHNOLOGIES

VISION / CAMERA
DEEP VISION, Carnegie Robotics, machines with vision, ROADSENSE, DEEPSCALE, Chronocam, VAYAVISION

LIDAR
face, INNOVIZ, PHANTOM INTELLIGENCE, VOYAGE, QUANERGY, AEYE, TRILUMINA, LeddarTech, Velodyne LiDAR, STROBE

RADAR
OCULii, TOPOSENS, RFISEE, 6TH SENSE, SDS

SPECIALTY VEHICLES

2-WHEELERS
mobike, smarthalo, superpedestrian, Zagster

PUBLIC TRANSPORT
nauva, LM, Varden Labs, AURO, EASY MILE

TRUCKS / FREIGHT
JAYBRIDGE ROBOTICS, OTTO, PELOTON, TESLA, FLEXPORT, TRUELITE TRACE, STARSKY ROBOTICS

FLIGHT
WRIGHT ELECTRIC, ZUNUM Aero, ZEE, JOBY, Kitty Hawk, LILIUM, AEROMOBIL

OTHER: HYPERLOOP, PERSONAL MOBILITY
hyperloop one, ninebot, WHILL

Product Categories: Vehicle Technology ✖ Robotics ✖

Search

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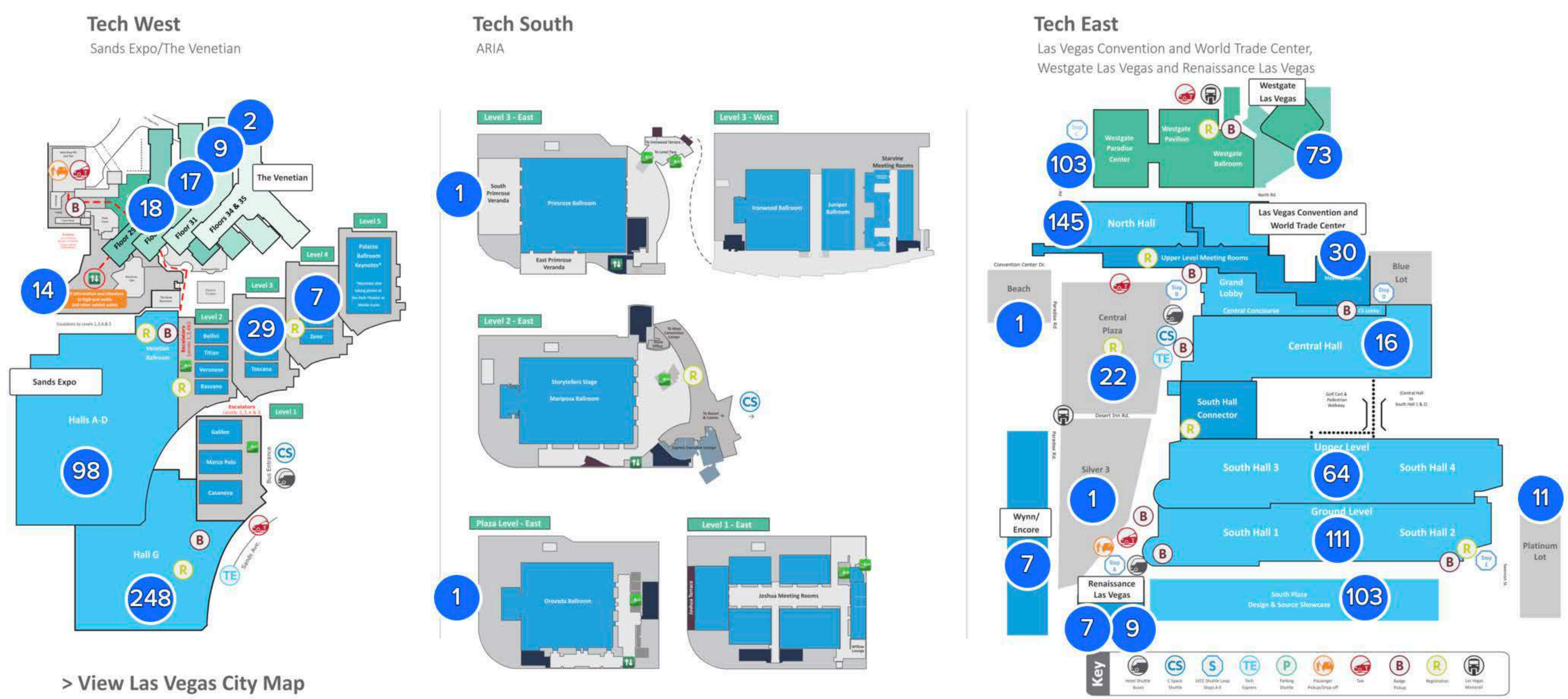
Show Locations Map / All Venues



> View Las Vegas City Map

FEATURED BY BOOTH (45)

- **ROHM Semiconductor** *(Titian 2205)*
- **AEV** *(9126)*
- **Aisin Seiki Co., Ltd.** *(3102)*
- **Baraja** *(Westgate Hospitality Suites)*
- **BeStar Holdings Co., Ltd.** *(36714)*
- **Bosch** *(14020)*
- **Bosch** *(CP-35)*
- **CEVA** *(Westgate Hospitality Suites)*
- **Continental Automotive Systems Inc.** *(7519)*
- **Continental Automotive Systems Inc.** *(Ballroom I)*
- **Continental Automotive Systems Inc.** *(Renaissance Hospitality Suites)*
- **Continental Automotive Systems Inc.** *(Summit Room)*
- **DisplayPort** *(21266)*

Localization and Mapping

Where am I ?

Scene Understanding

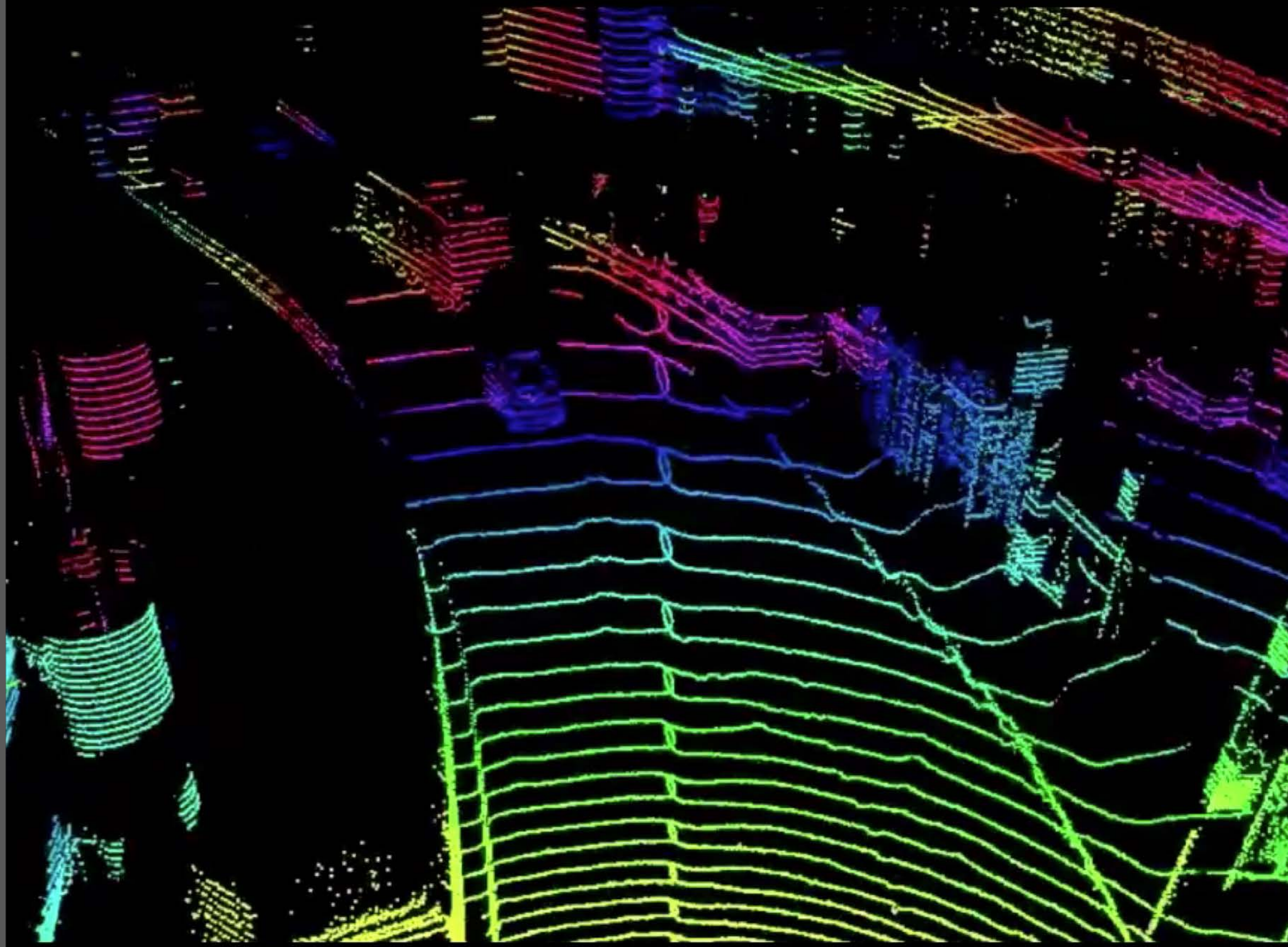
Where/who/what/why of
everyone/everything else ?

Trajectory Planning and Control

Where should I go next ?
How do I steer and accelerate ?

Human Interaction

How do I convey my intent to the
passenger and everyone else ?



SAE J3016™ LEVELS OF DRIVING AUTOMATION

	SAE LEVEL 0	SAE LEVEL 1	SAE LEVEL 2	SAE LEVEL 3	SAE LEVEL 4	SAE LEVEL 5
What does the human in the driver's seat have to do?	**You are driving** whenever these driver support features are engaged – even if your feet are off the pedals and you are not steering			**You are not driving** when these automated driving features are engaged – even if you are seated in "the driver's seat"		
	You must constantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	
	These are driver support features			**These are automated driving features**		
What do these features do?	These features are limited to providing warnings and momentary assistance	These features provide steering **OR** brake/ acceleration support to the driver	These features provide steering **AND** brake/ acceleration support to the driver	These features can drive the vehicle under limited conditions and will not operate unless all required conditions are met		This feature can drive the vehicle under all conditions
Example Features	• automatic emergency braking • blind spot warning • lane departure warning	• lane centering **OR** • adaptive cruise control	• lane centering **AND** • adaptive cruise control at the same time	• traffic jam chauffeur	• local driverless taxi • pedals/ steering wheel may or may not be installed	• same as level 4, but feature can drive everywhere in all conditions

Autonomous Vehicles

(self driving cars, driverless cars)

Save lives

- 1.3 million die every year in manual driving
- Drunk, drugged, distracted, drowsy driving.

Eliminate car ownership

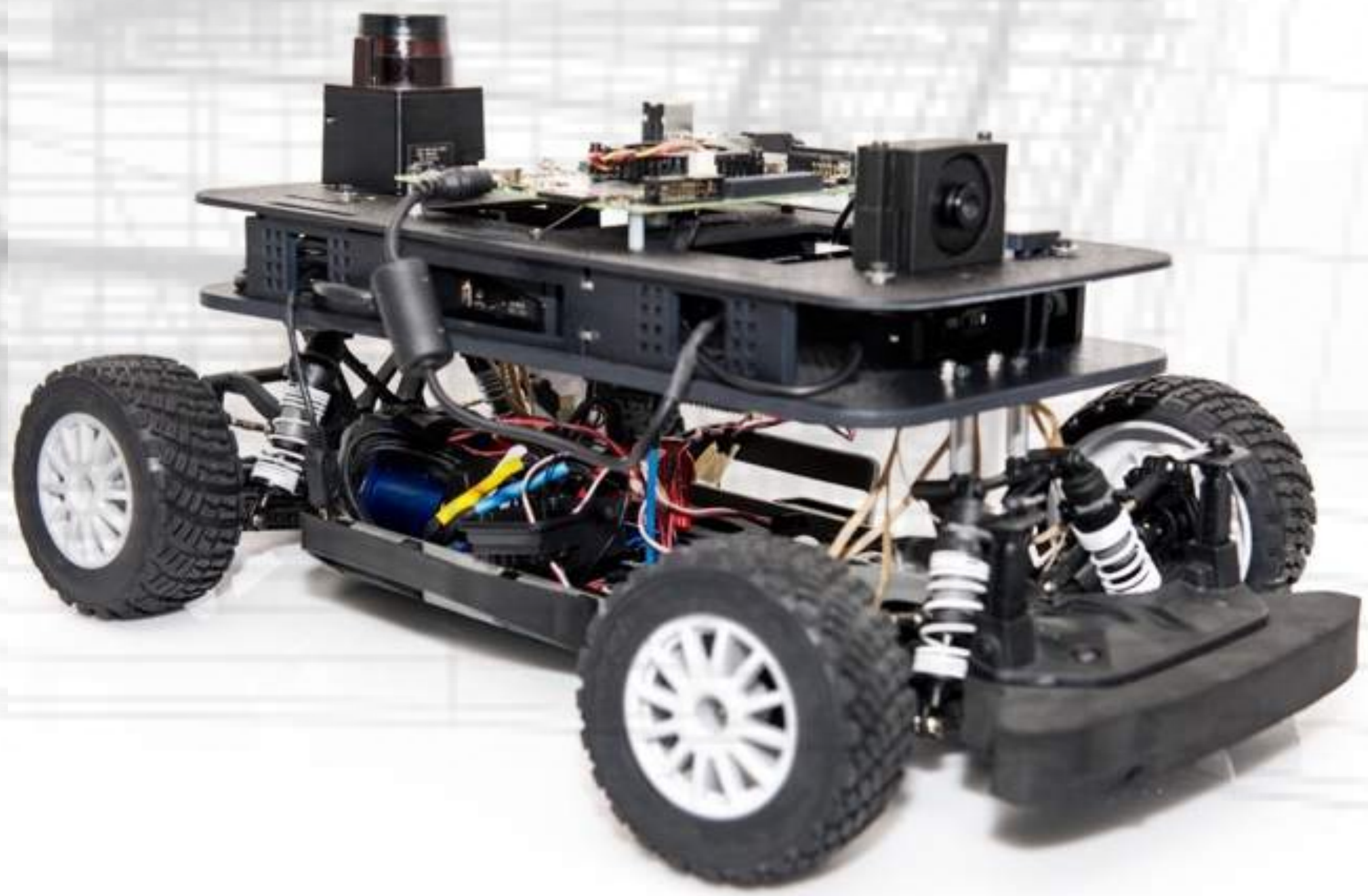
- Increase mobility and access
- Save money

Make transportation personalized, efficient, and reliable

F1/10

1/10th the scale. 10 times the fun!

Research Education Competition



Accessible Autonomy

Expensive, power hungry, large…

Cheap, low power, small…

Same dynamics (different parameters), similar algorithmic challenges…

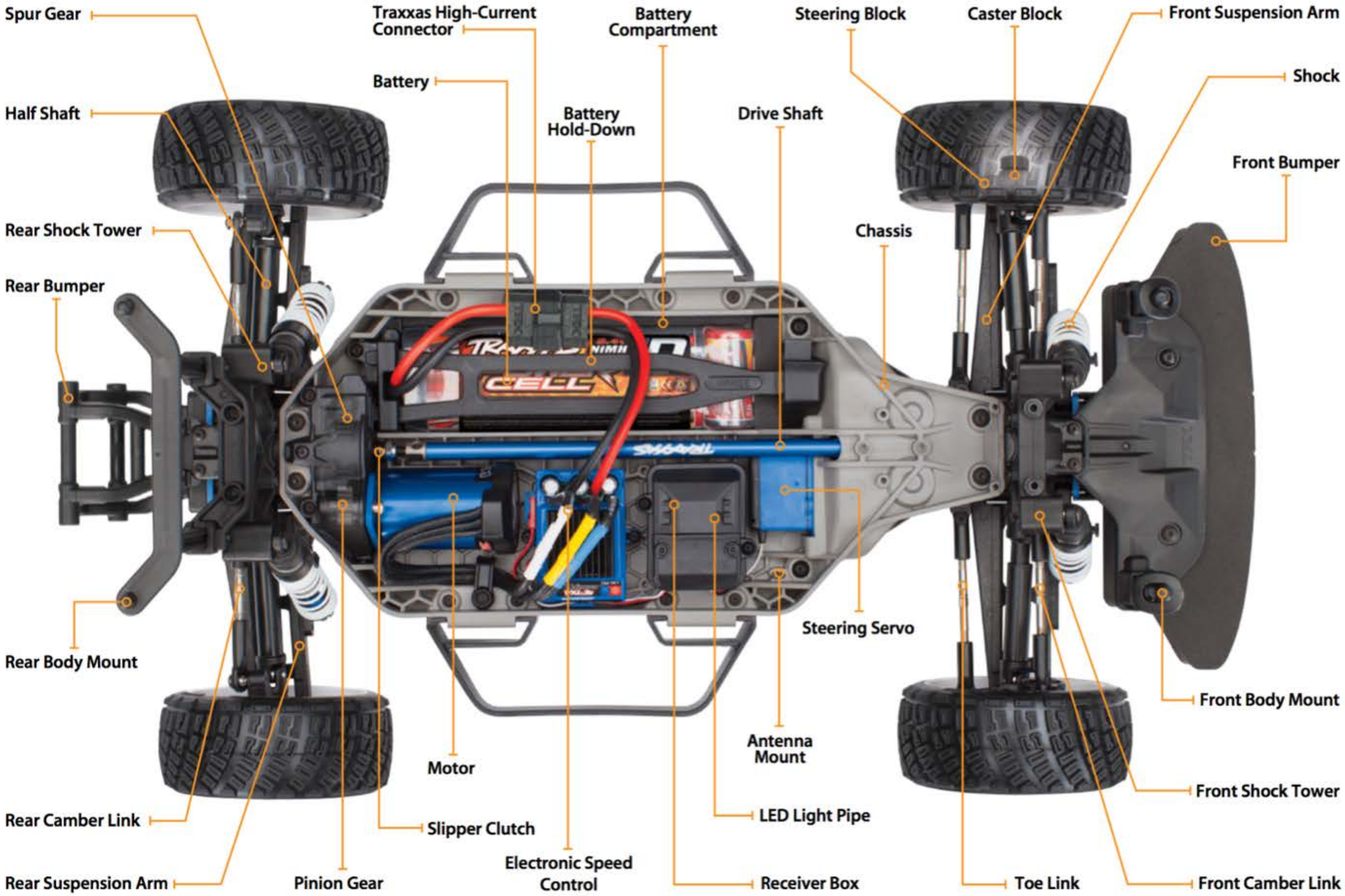
Similar dynamics, different parameters

Build. Drive. Race.

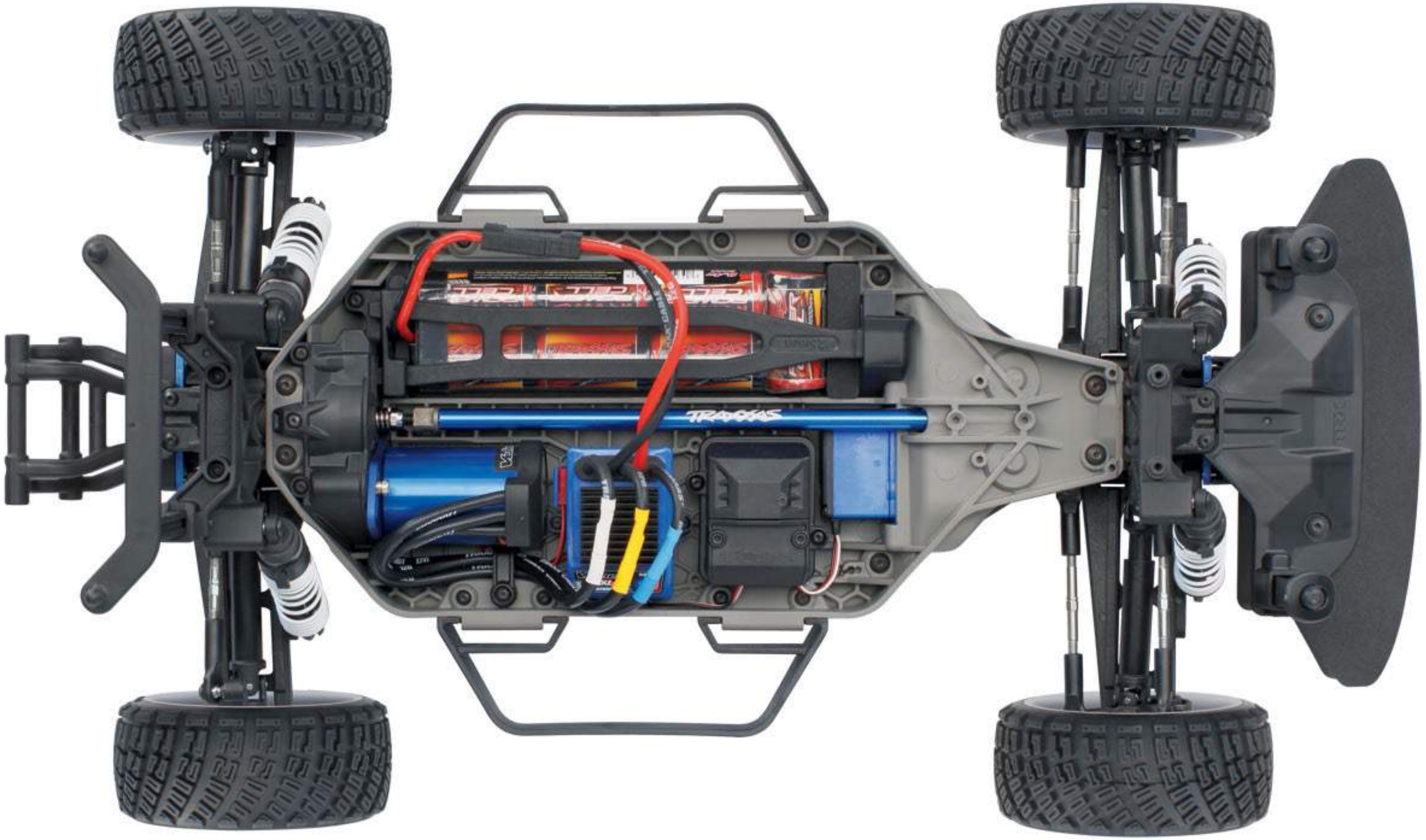
Build

F1/10 racing platform

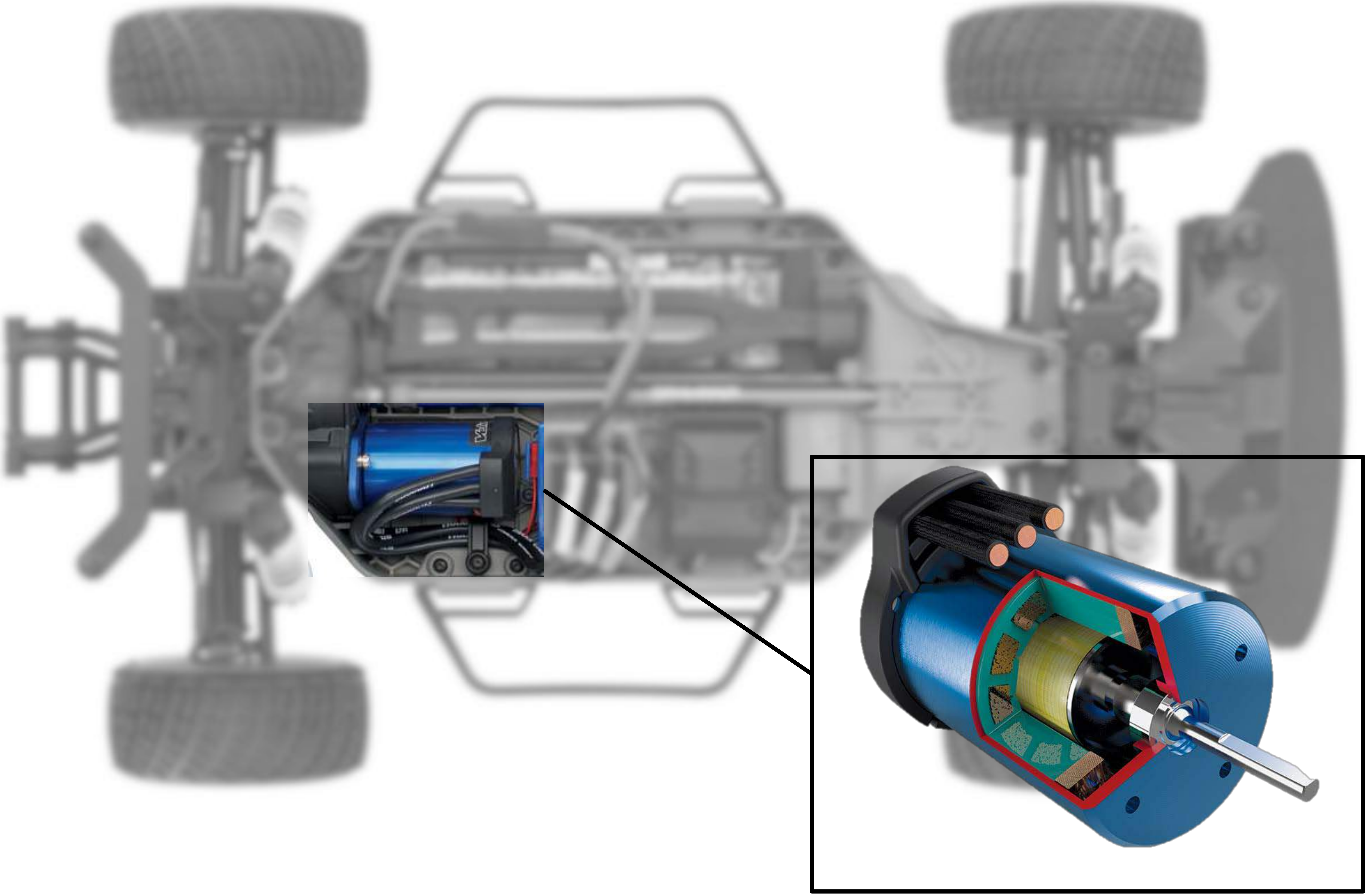
Traxxas 1/10 scale RC race car



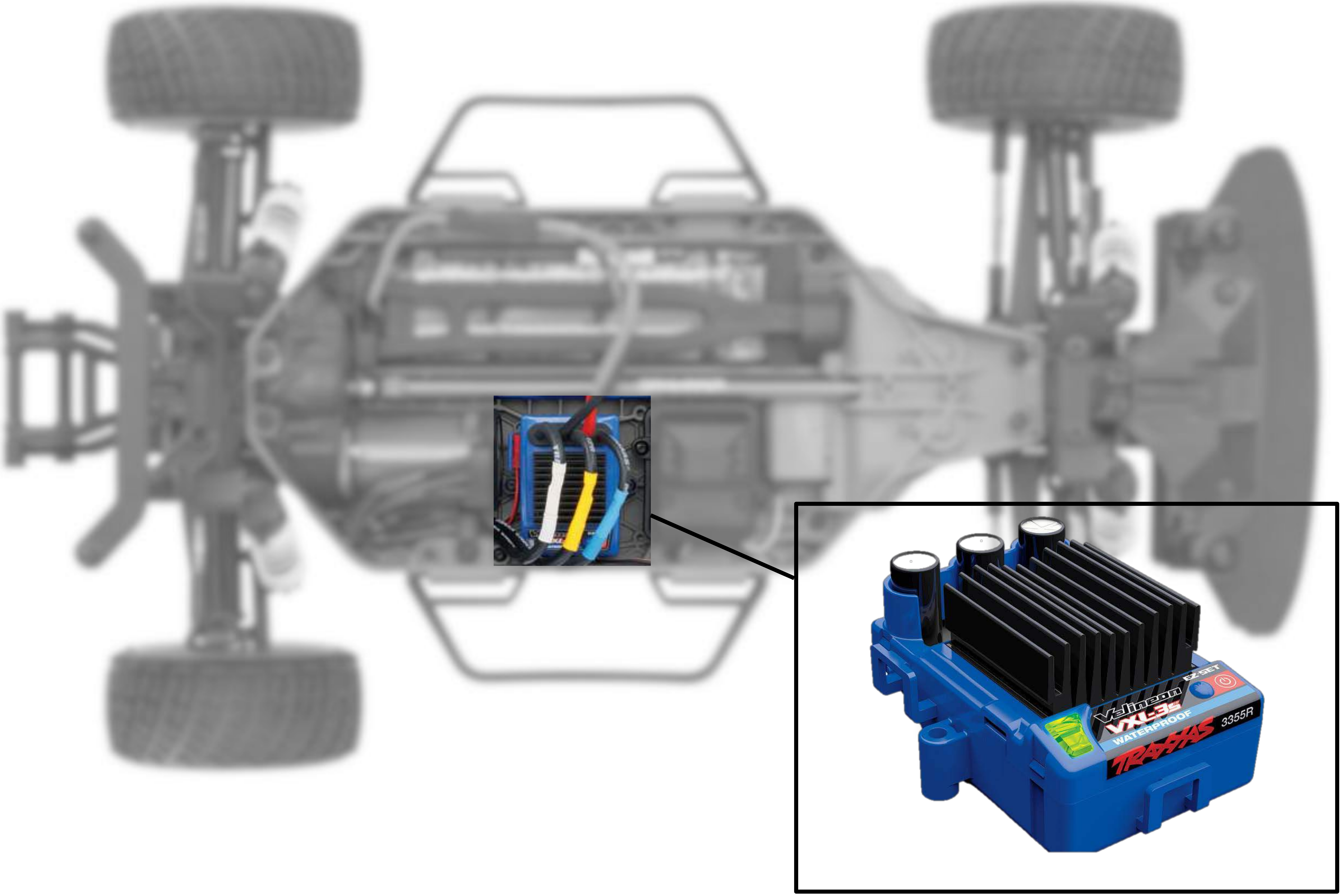
Traxxas 1/10 scale RC race car



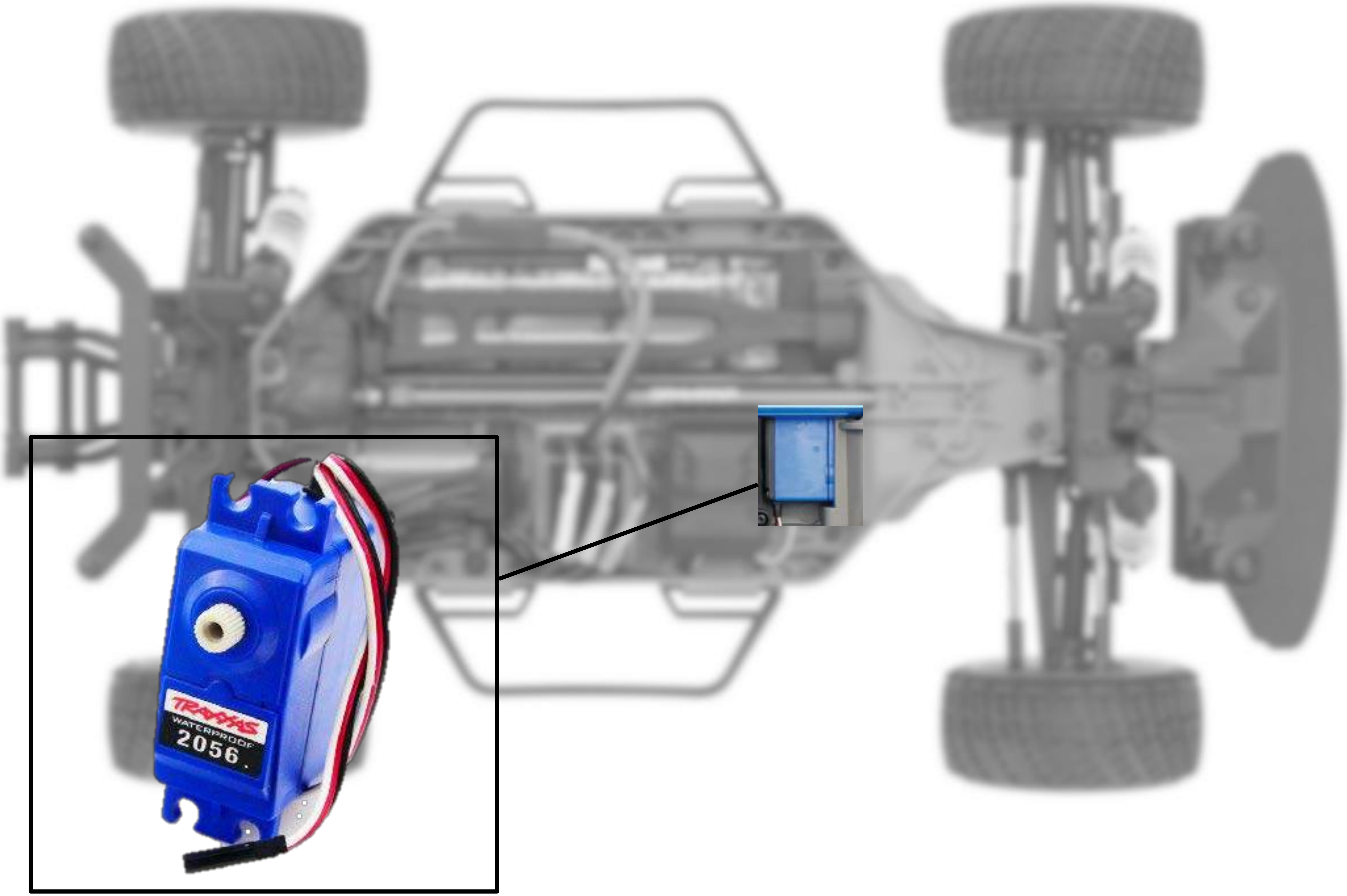
Brushless DC motor



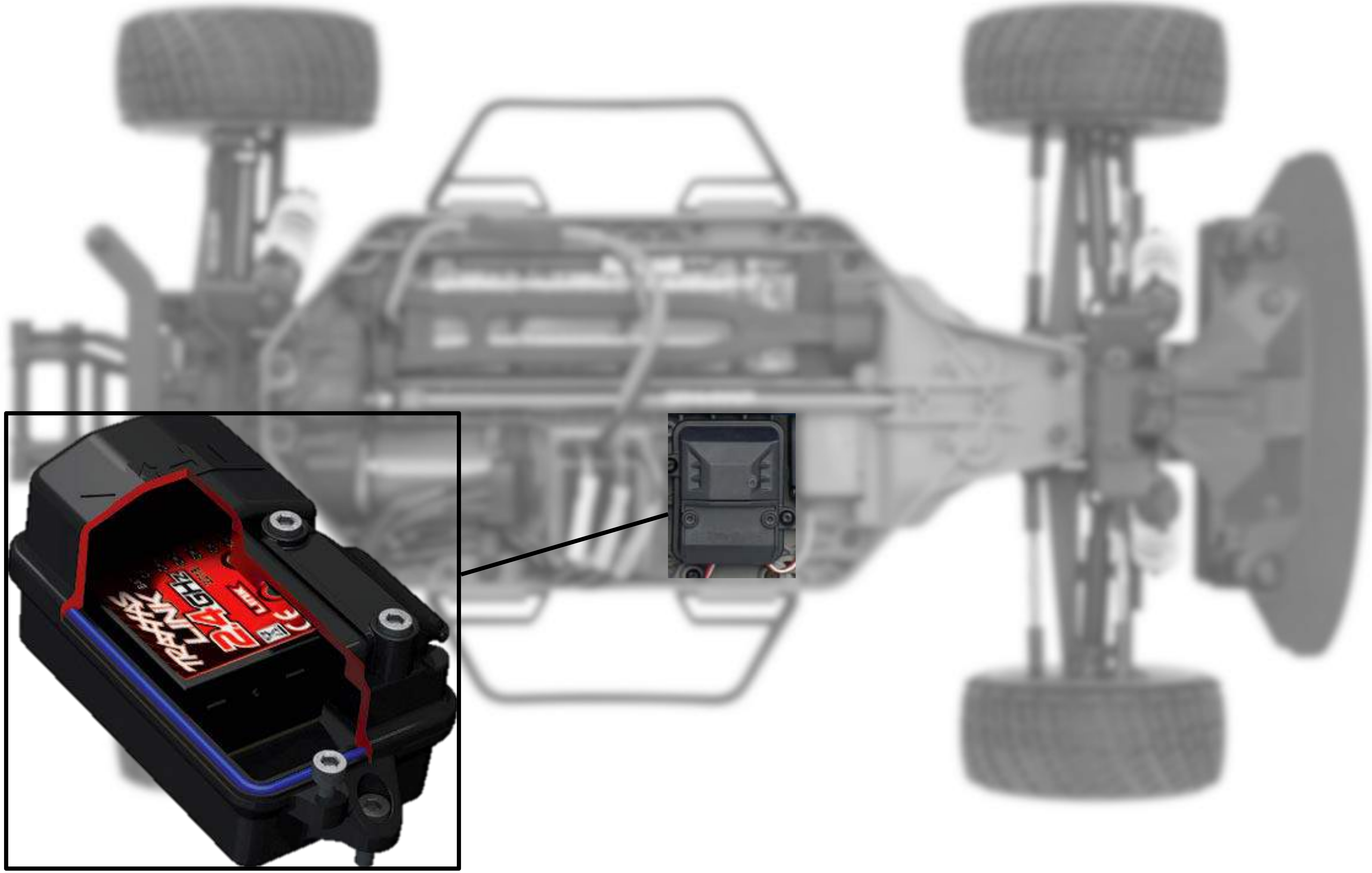
Electronic Speed Control (ESC)



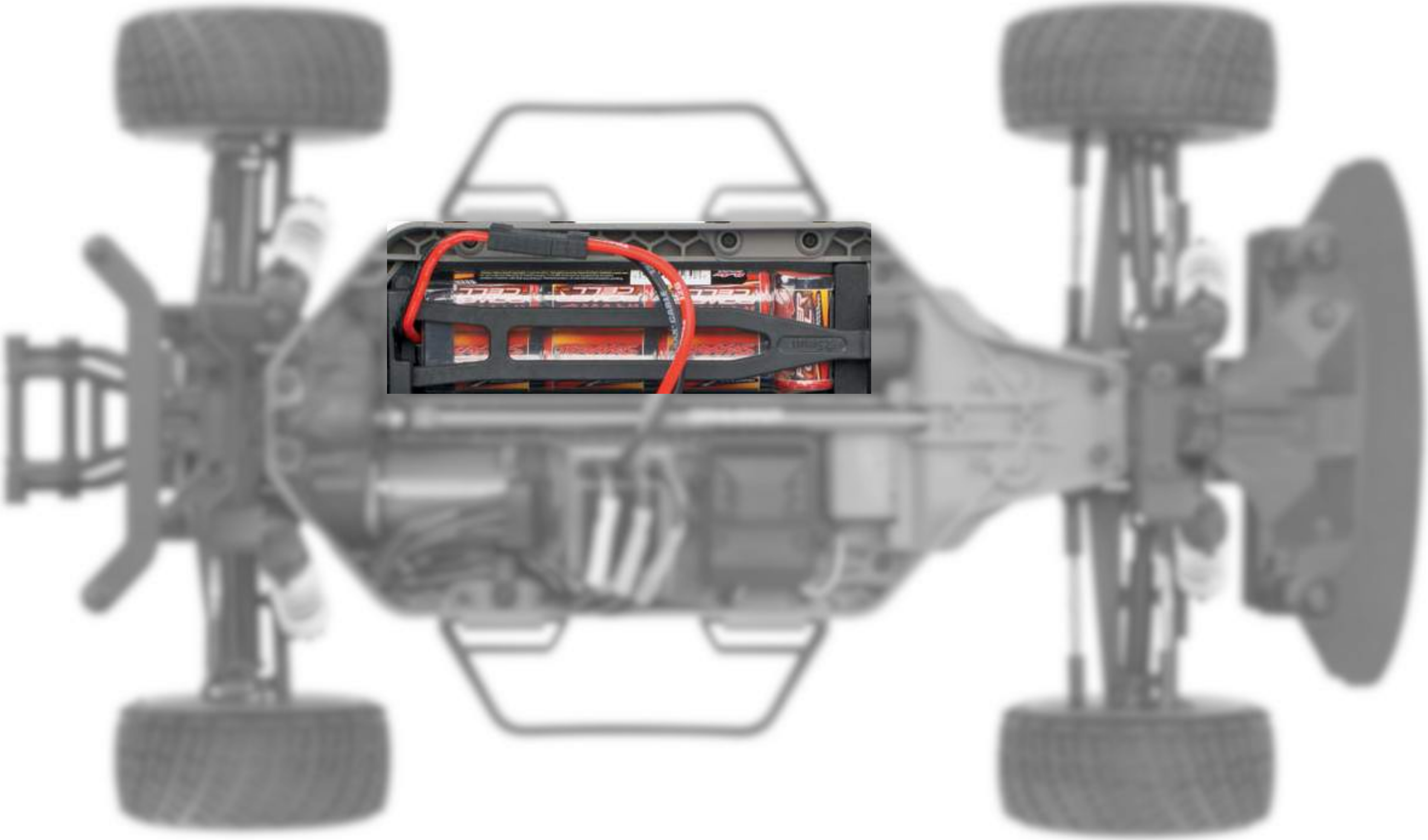
Servo motor for steering



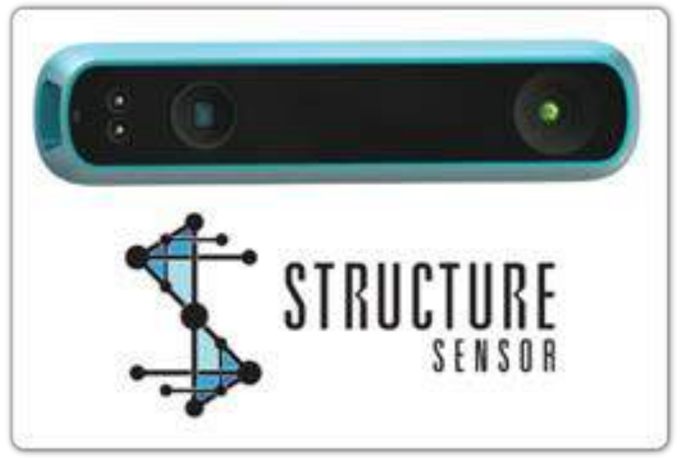
Radio receiver



Battery pack



Sensor Integration

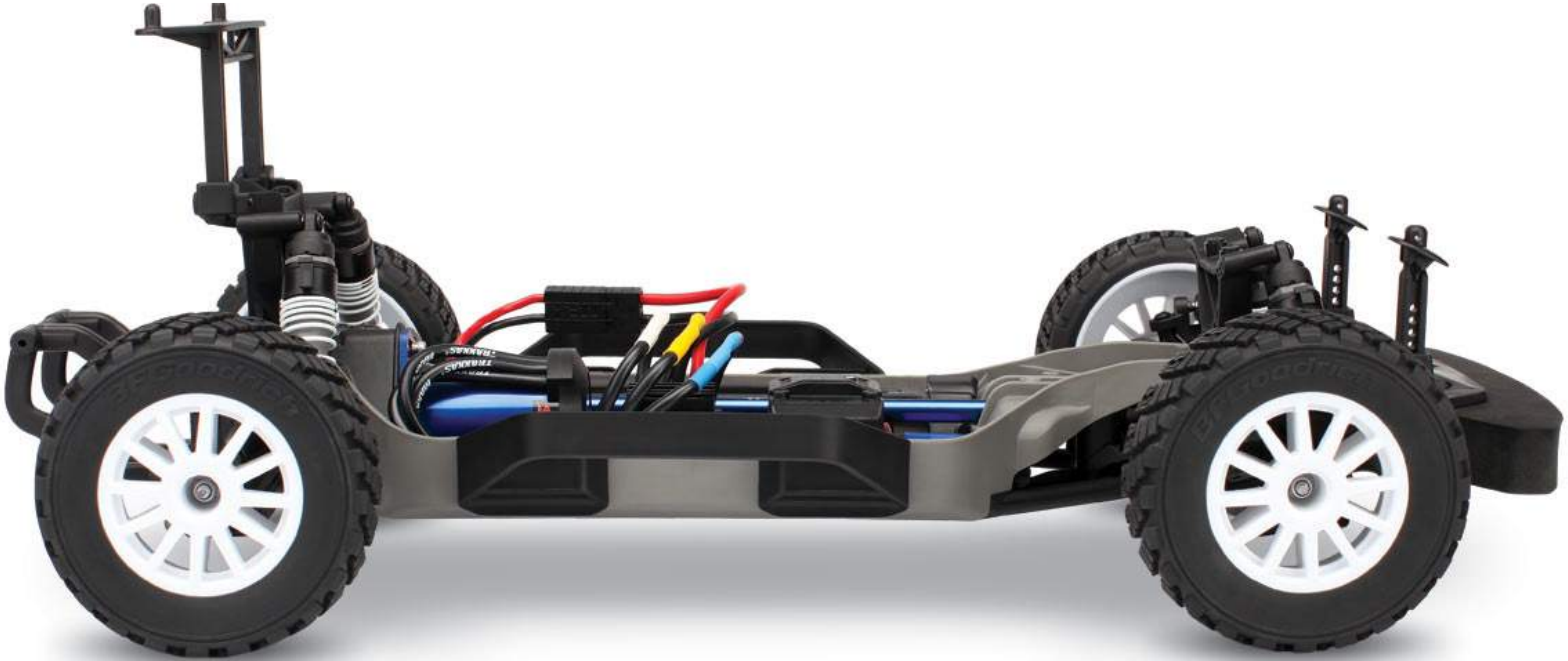


**LiDA
R**

Camera

IMU

IR Depth Cameras

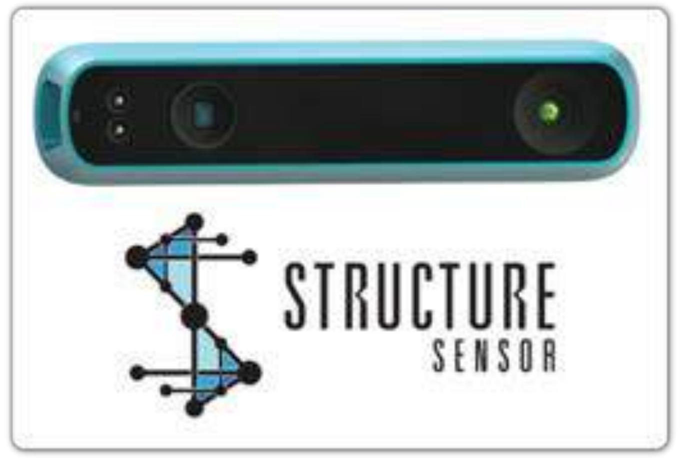


Sensor Integration

LiDA
R

Camera

IMU



IR Depth Cameras

Wi-fi Telemetry

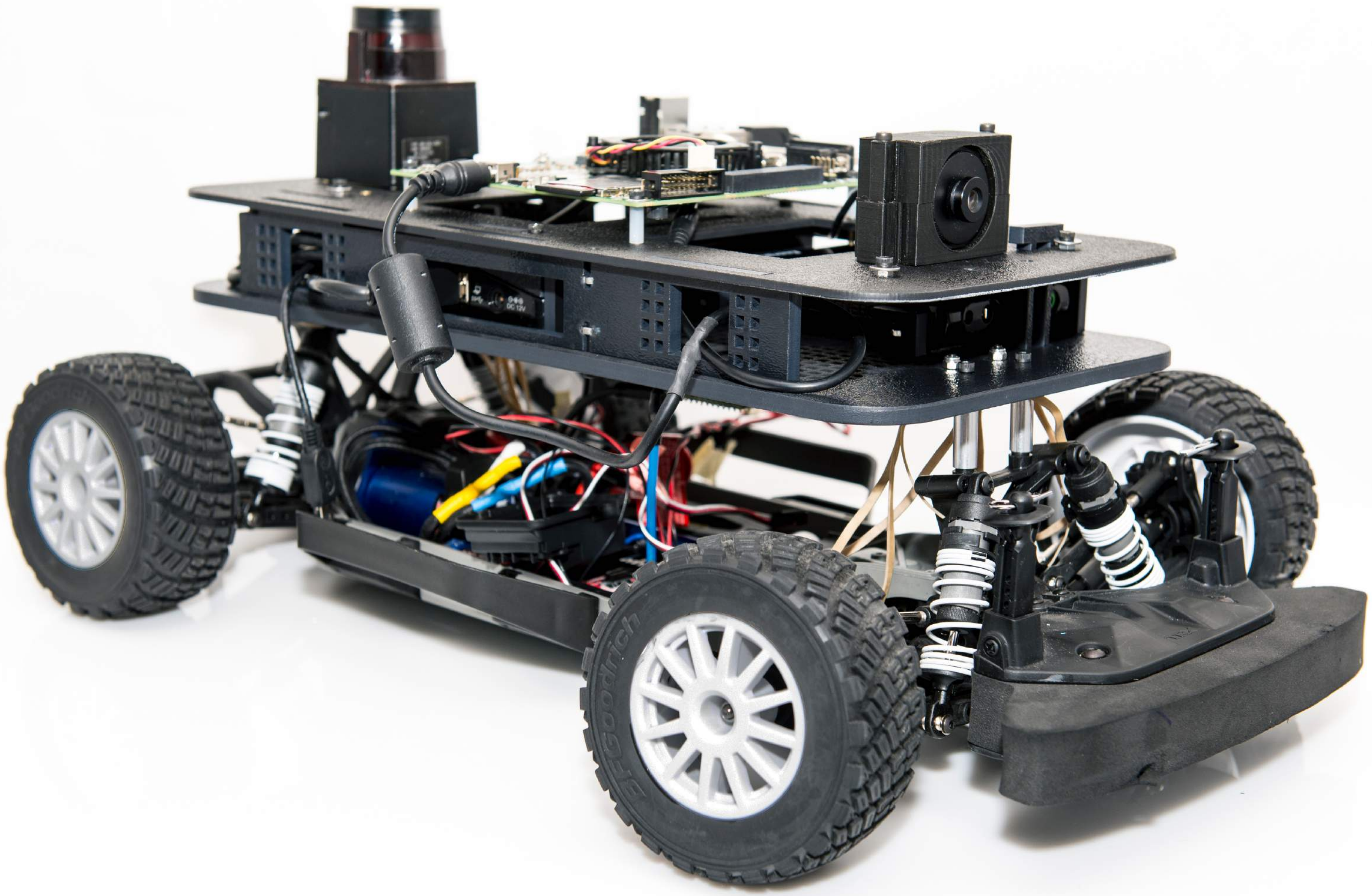
Onboard Computer

Motor Controller

Battery

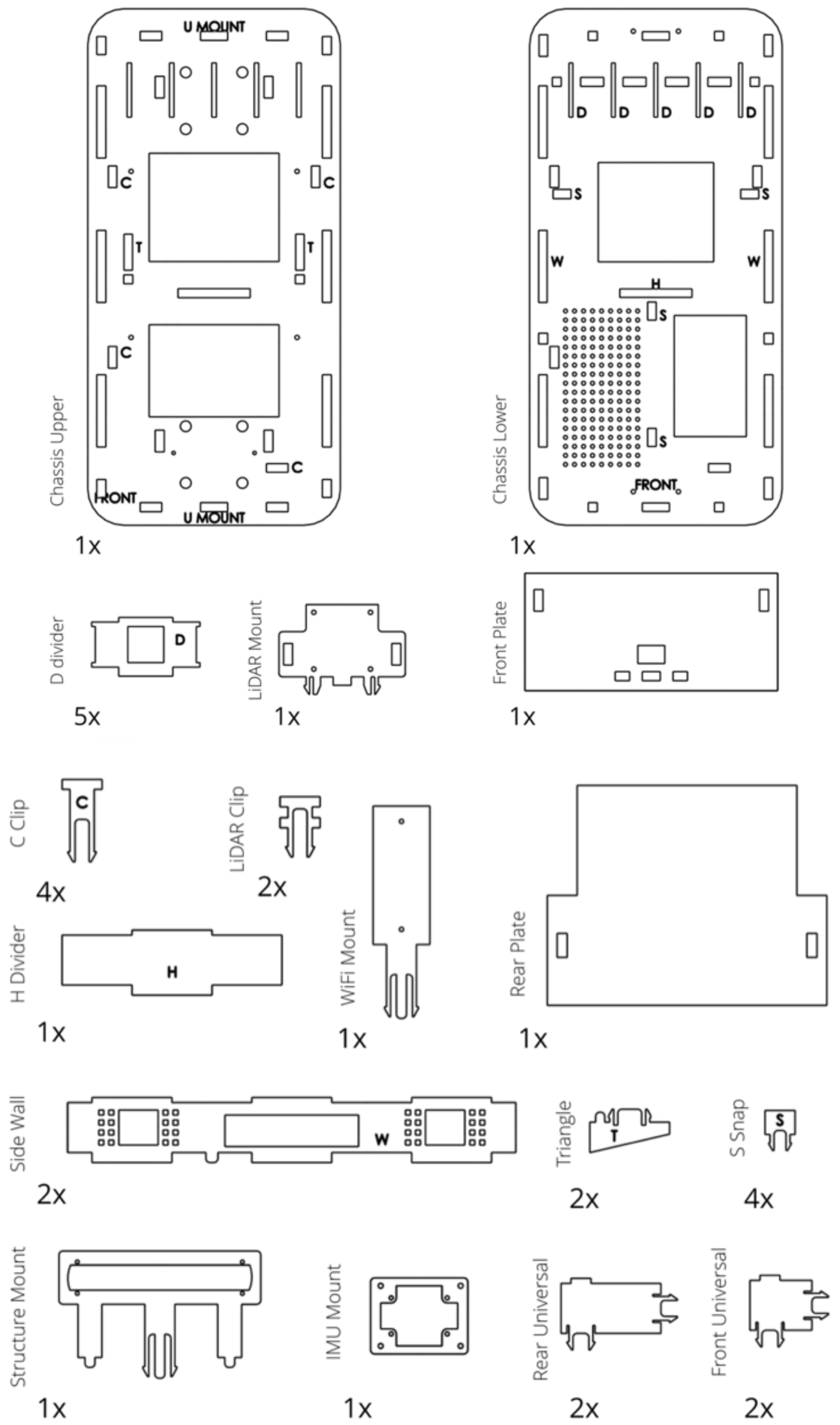
Fastware

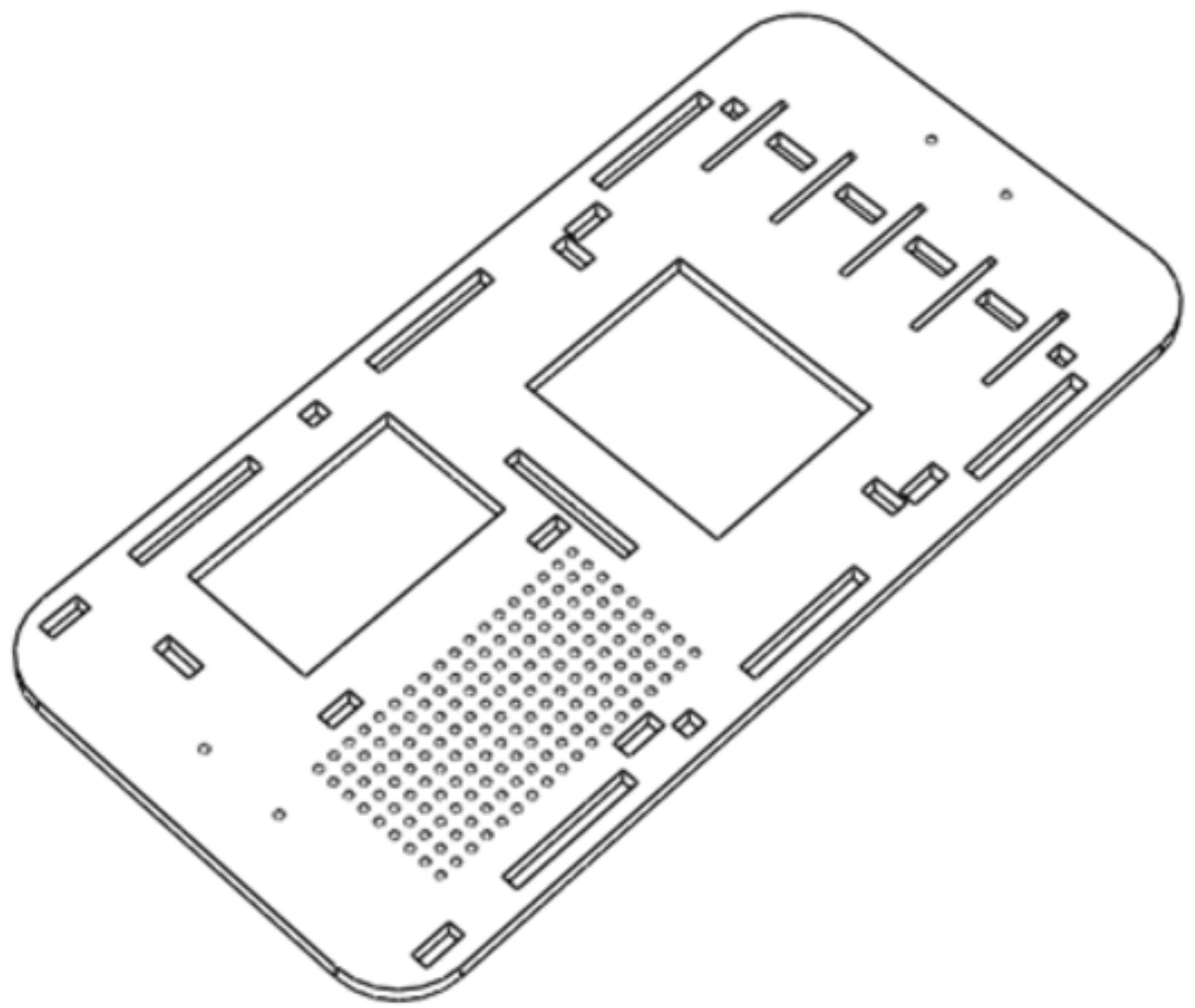
Approximately $2,700



MOVE FAST AND BREAK THINGS

With simple IKEA style instructions:





F1/10 Race Car Assembly
(Time Lapse)

Drive

Perception. Planning. Control

In Spring 2018

a new and unique course
was taught at the University of Virginia.

A novel appraoch to learn the principles of
perception, planning, and control.

Here are highlights from the course

Open Source


F1/10
BUILD / DRIVE / RACE
About
Rules
Forum
Crew
Sponsor
Sign Up
F1/10
f1tenth.org
Autonomous Racing Competition
1/10th the size. 10 times the fun!
Start Your Engines!
Stay in the loop with email updates!
email address
Subscribe
ENG
15:51

https://linklab-uva.github.io/autonomousracing/

Race

All teams have similar cars, with the same sensors

Battle of algorithms

October 1st-2nd

Wean Hall, Carnegie Mellon University

To compete, **register** your team name on our **sign up sheet**

Look at the progress of the Fall 2016 F1/10 teams

Directions/Accomodations

ES Week Track Layout

Wean Hall, 7th Floor

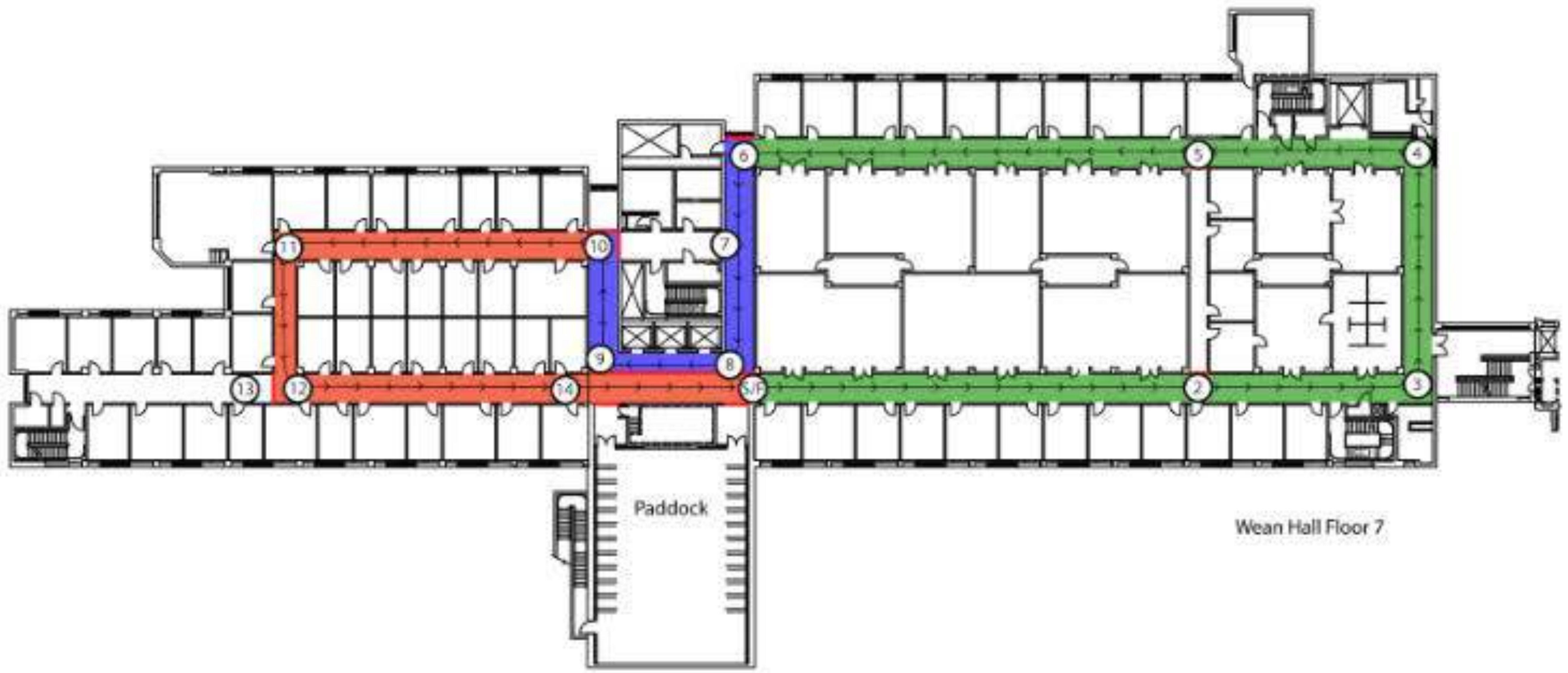
Sector 1:	Width: **8'**
Sector 2:	Width: **6'-8'**
Sector 3:	Width: **6'-8'**

Track length
812
Feet

7
Left Turns
2
Right Turns

Download ROSbags

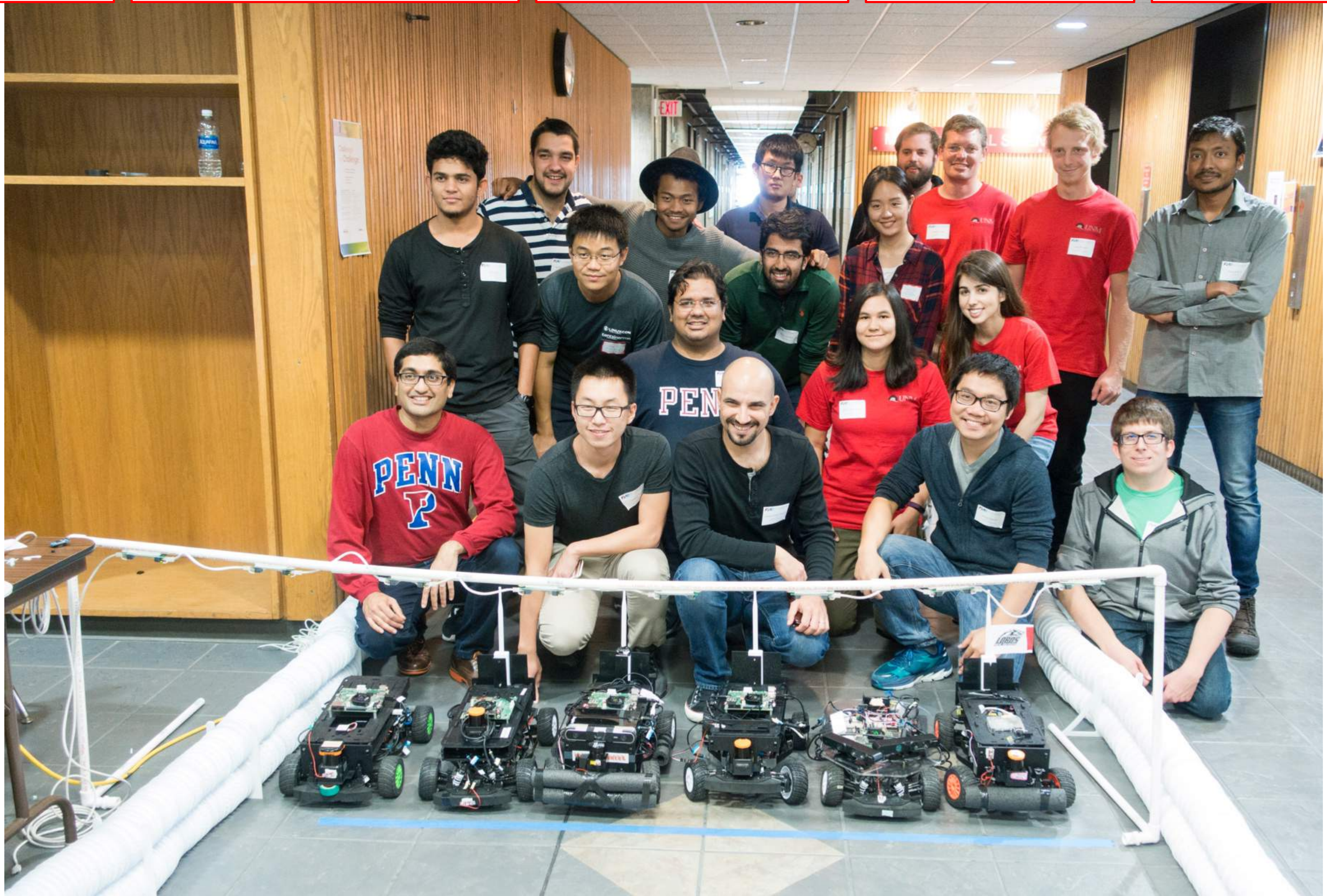
Download DWF



1^{st} F1/10 Autonomous Racing Competition

[Oct 1-2, 2016, CMU, Pittsburgh]

U. Of Penn	U. Of New Mexico	Arizona State	ETH, Zurich	Temple



1st F1/10 Autonomous Racing Competition

[Oct 1-2, 2016, CMU, Pittsburgh]

1st F1/10 Autonomous Racing Competition

[Oct 1-2, 2016, CMU, Pittsburgh]

Fastest Lap

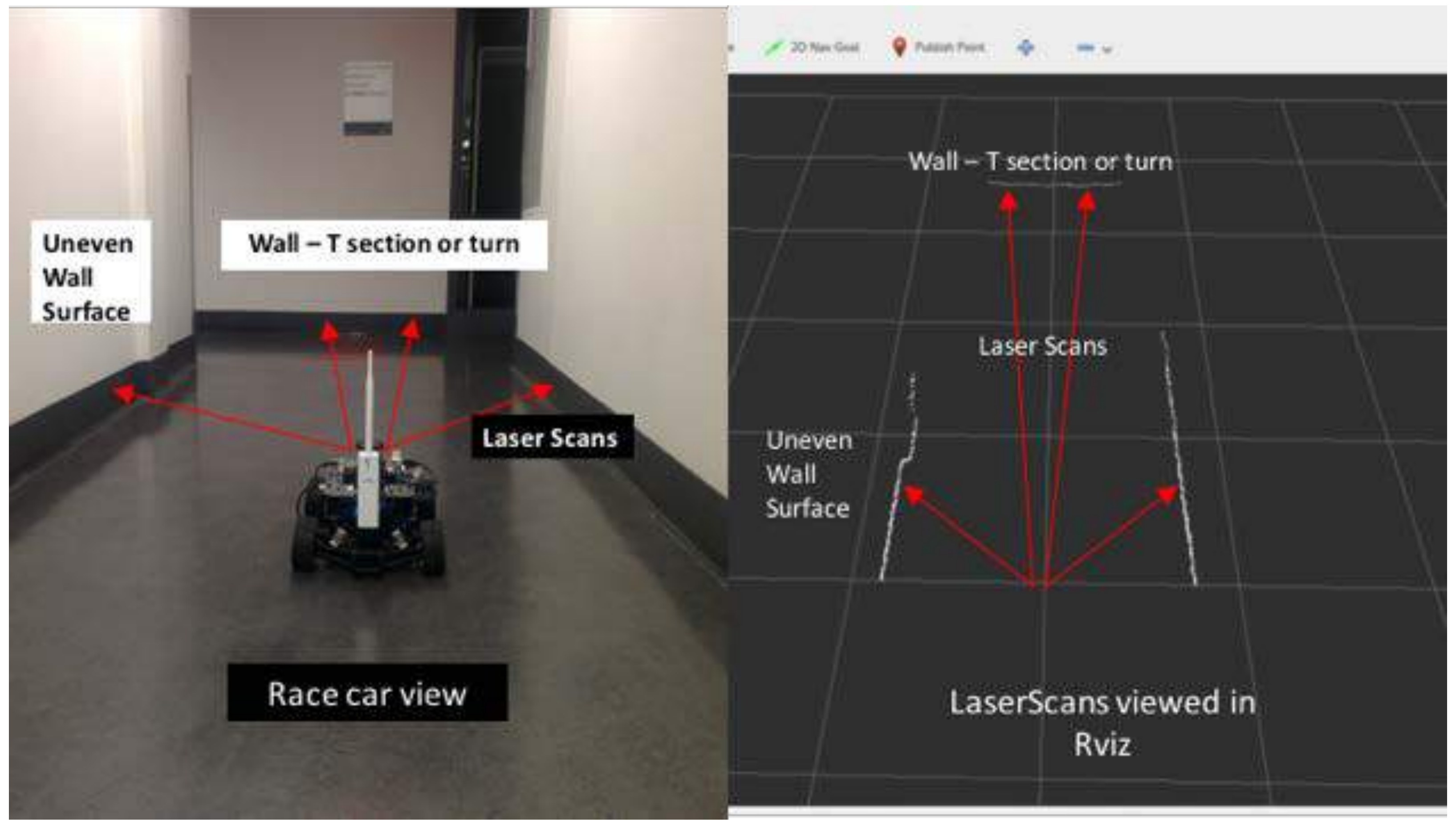
812 ft   63.6 secs   Avg 8.7mph   Top ~16mph

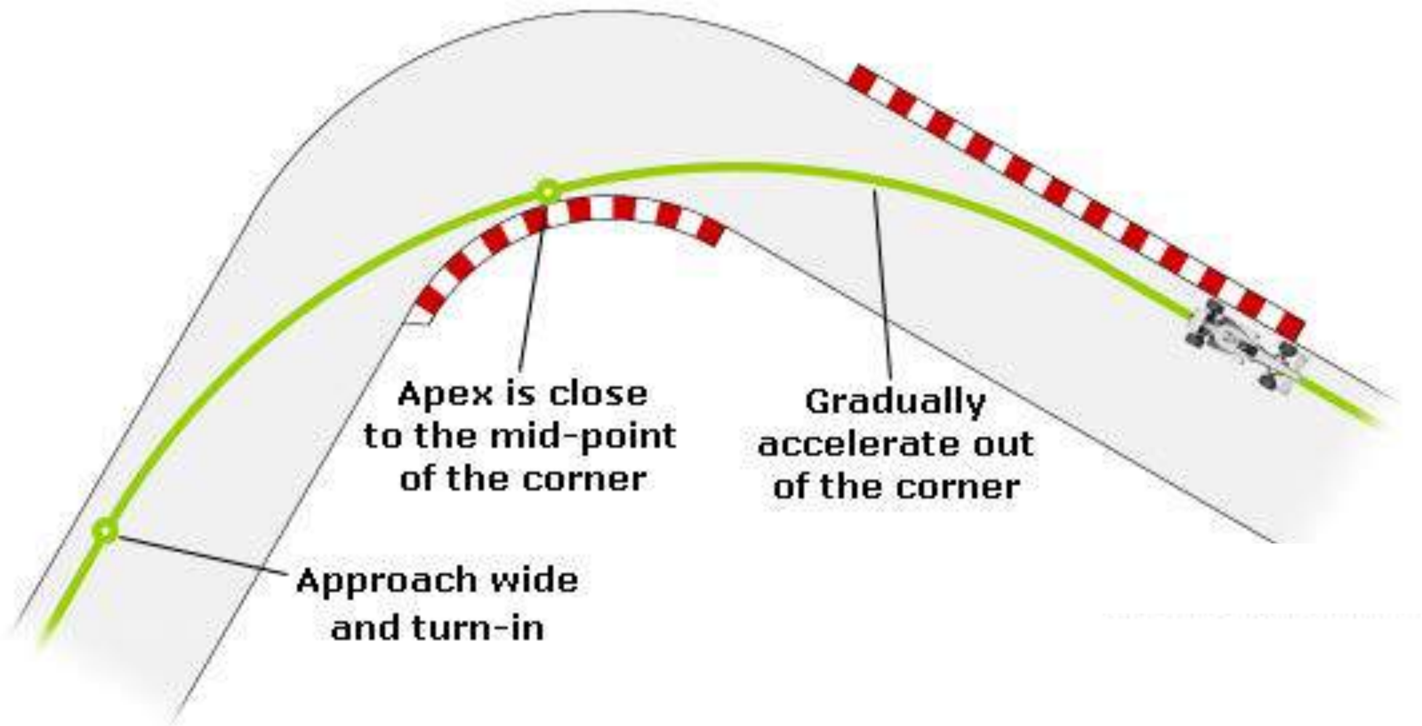

Porto, Portugal

Perception. Planning. Control.

Perception. Planning. Control

Making sense of the surroundings

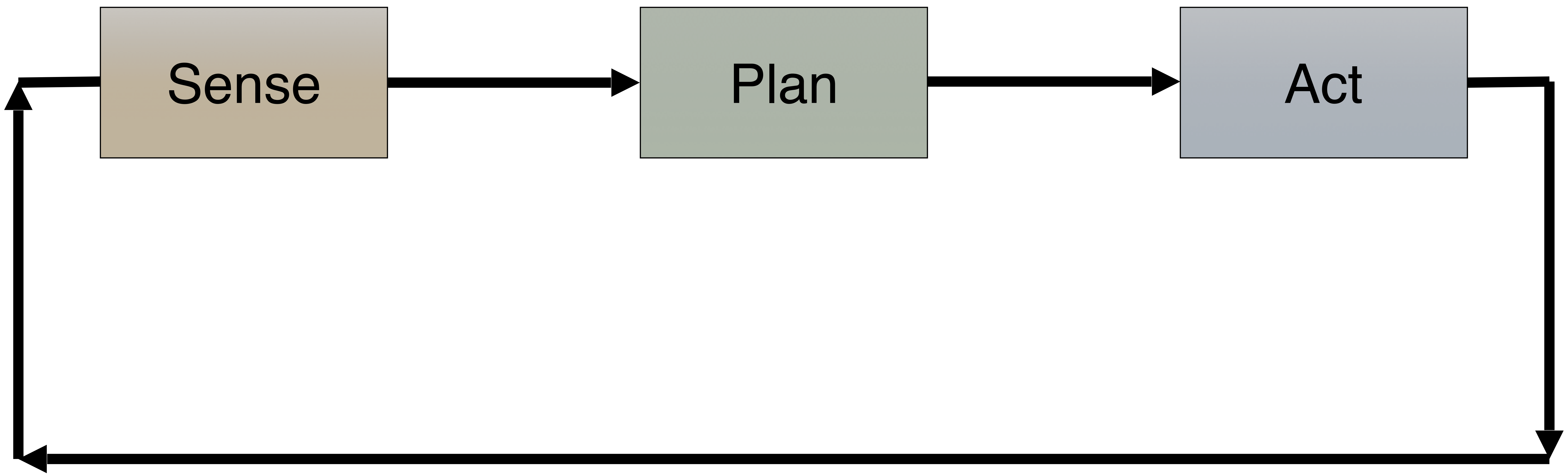


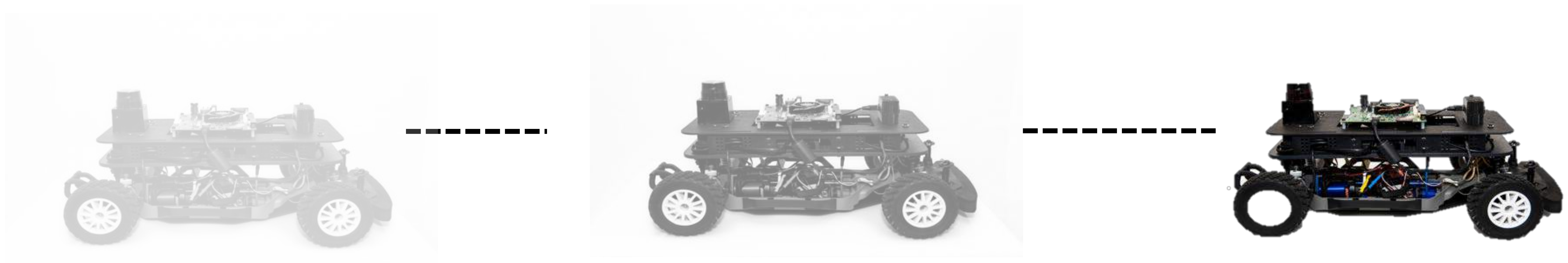


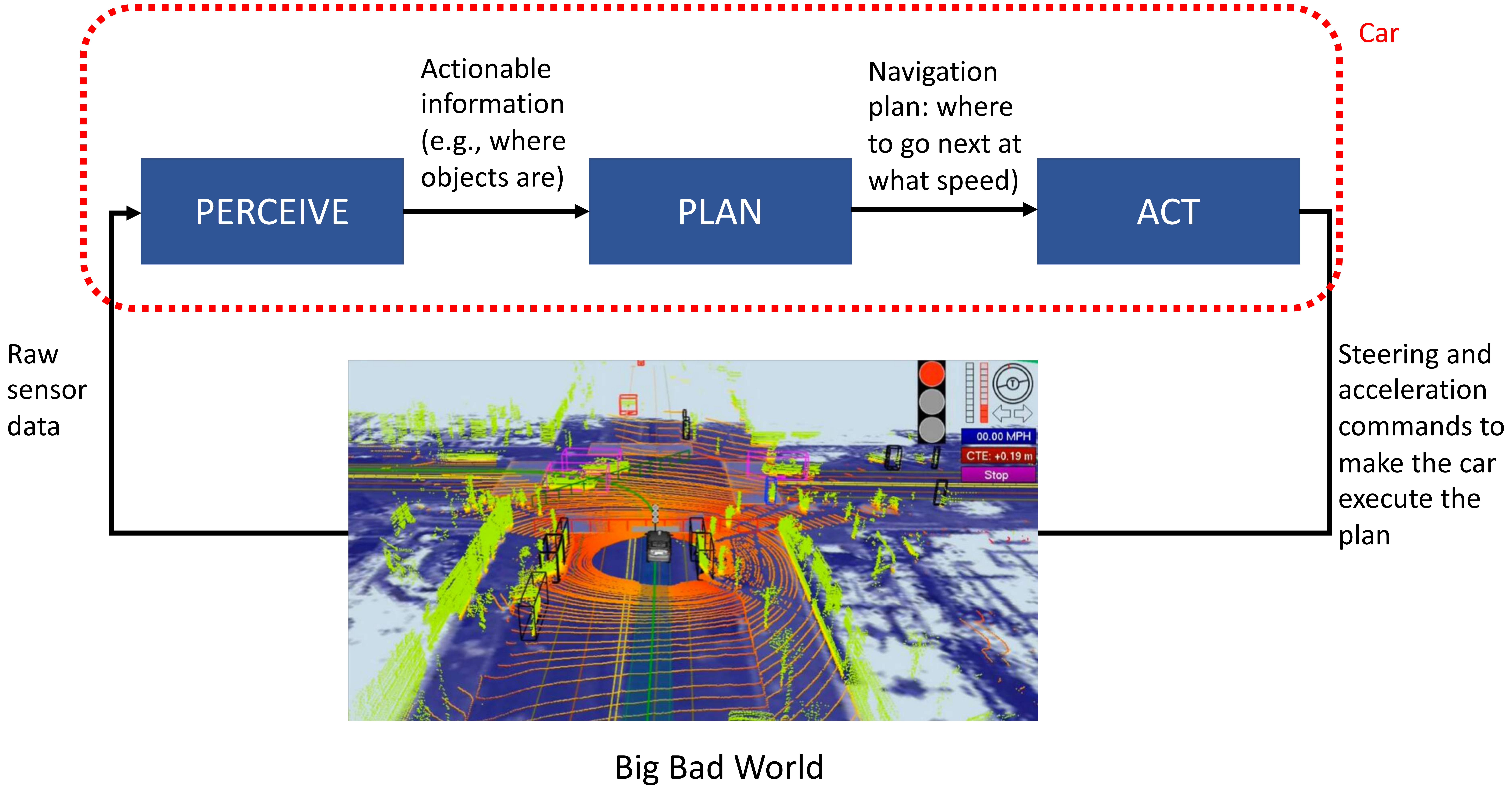
Planning the fastest racing line

Controlling the car to follow the planned path

Closing the loop



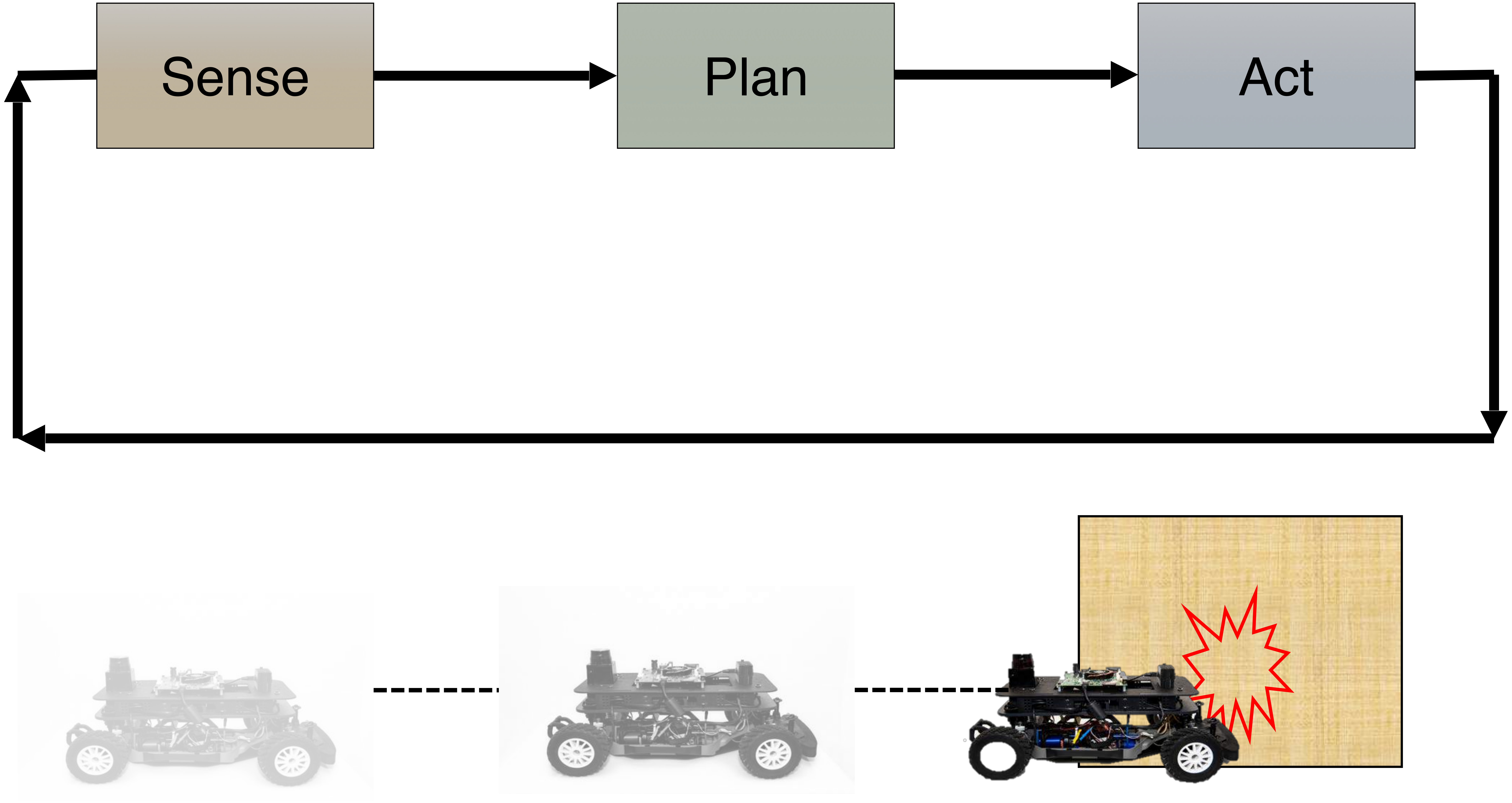


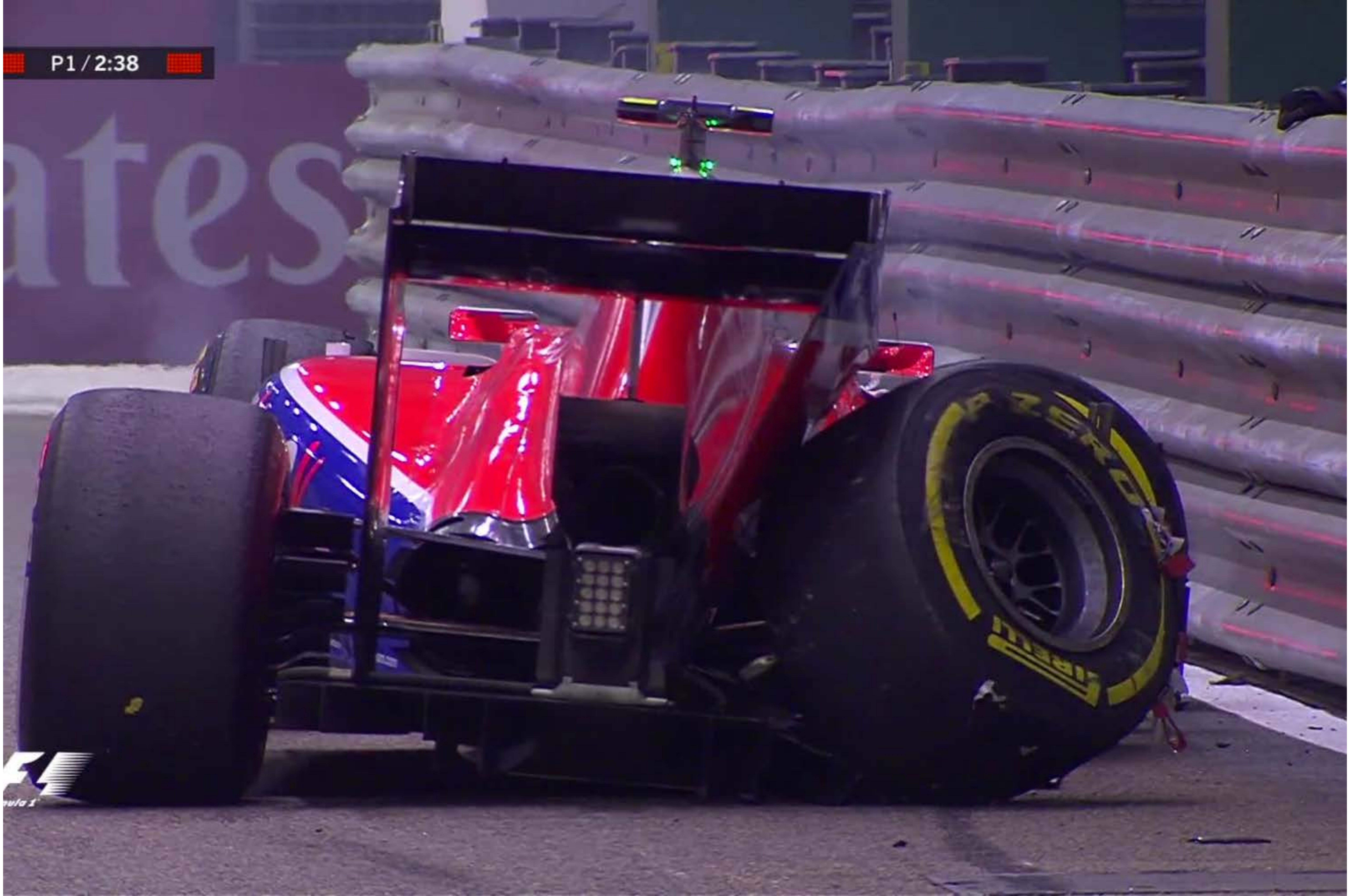


Car
PERCEIVE
Actionable information (e.g., where objects are)
PLAN
Navigation plan: where to go next at what speed)
ACT
Raw sensor data
Steering and acceleration commands to make the car execute the plan
00.00 MPH
CTE: +0.19 m
Stop
Big Bad World

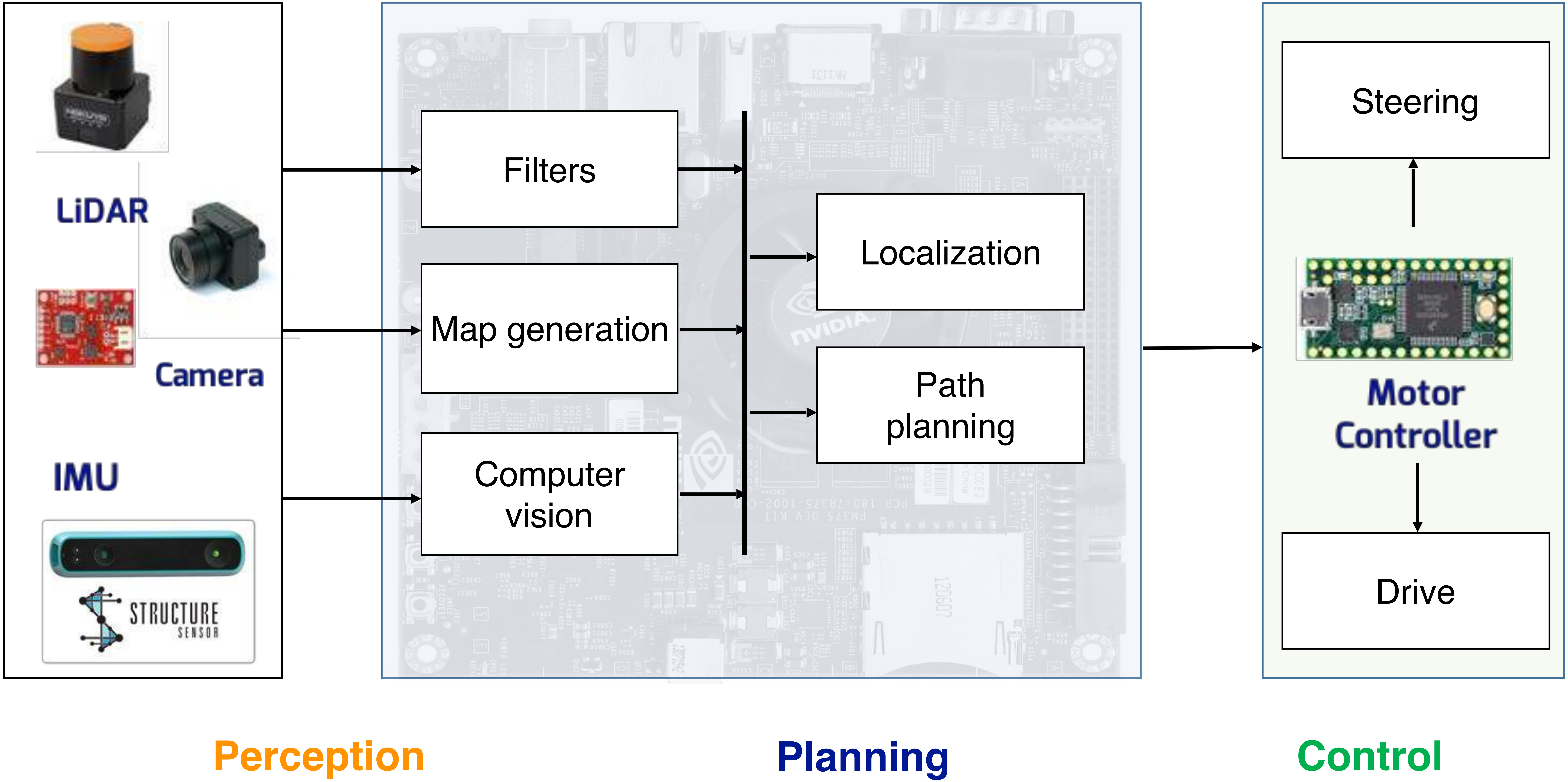

"If everything seems under control,
then you are not going fast enough"

Closing the loop fast




P1 / 2:38
ates
PZERO
Pirelli

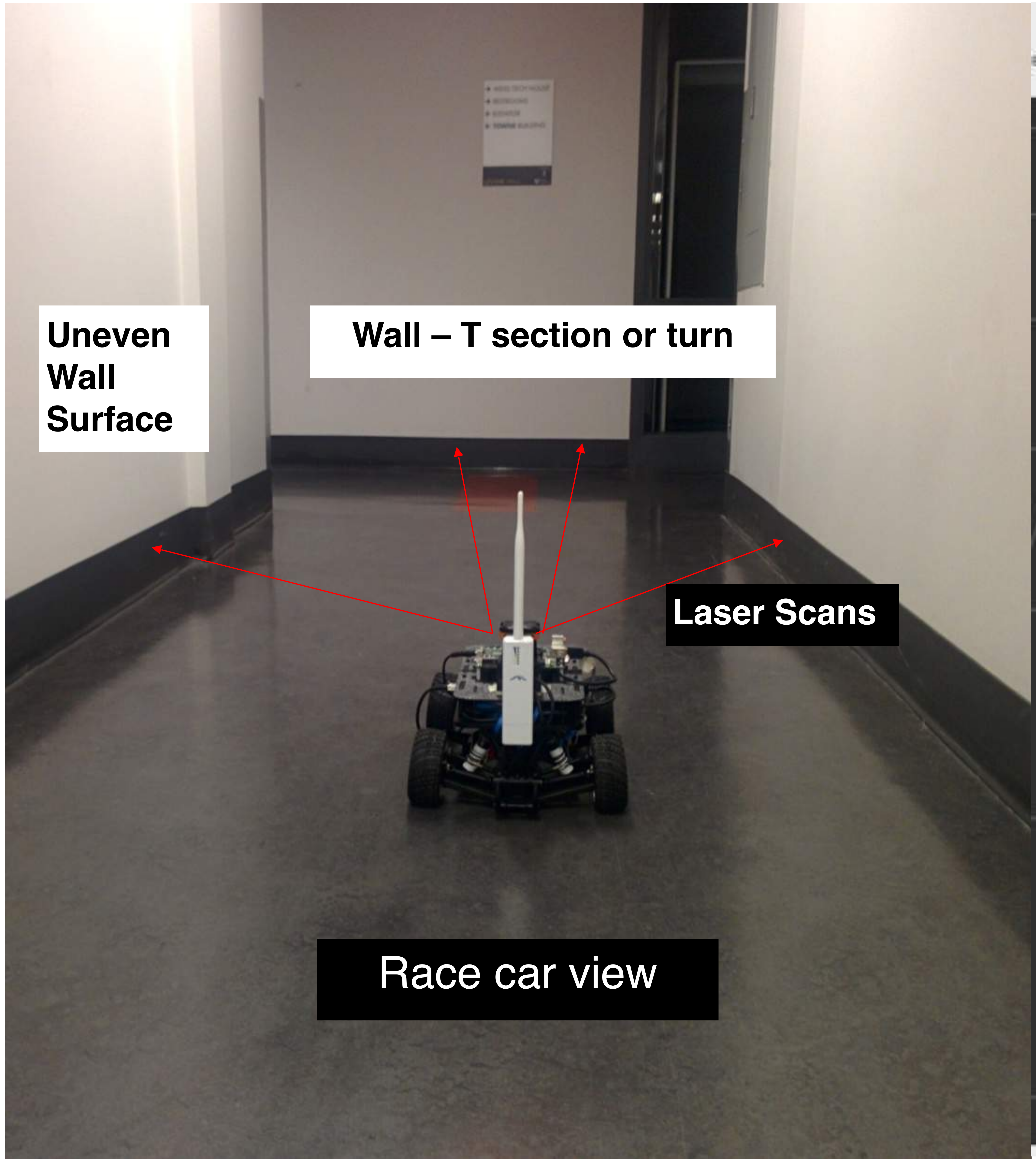
System Architecture

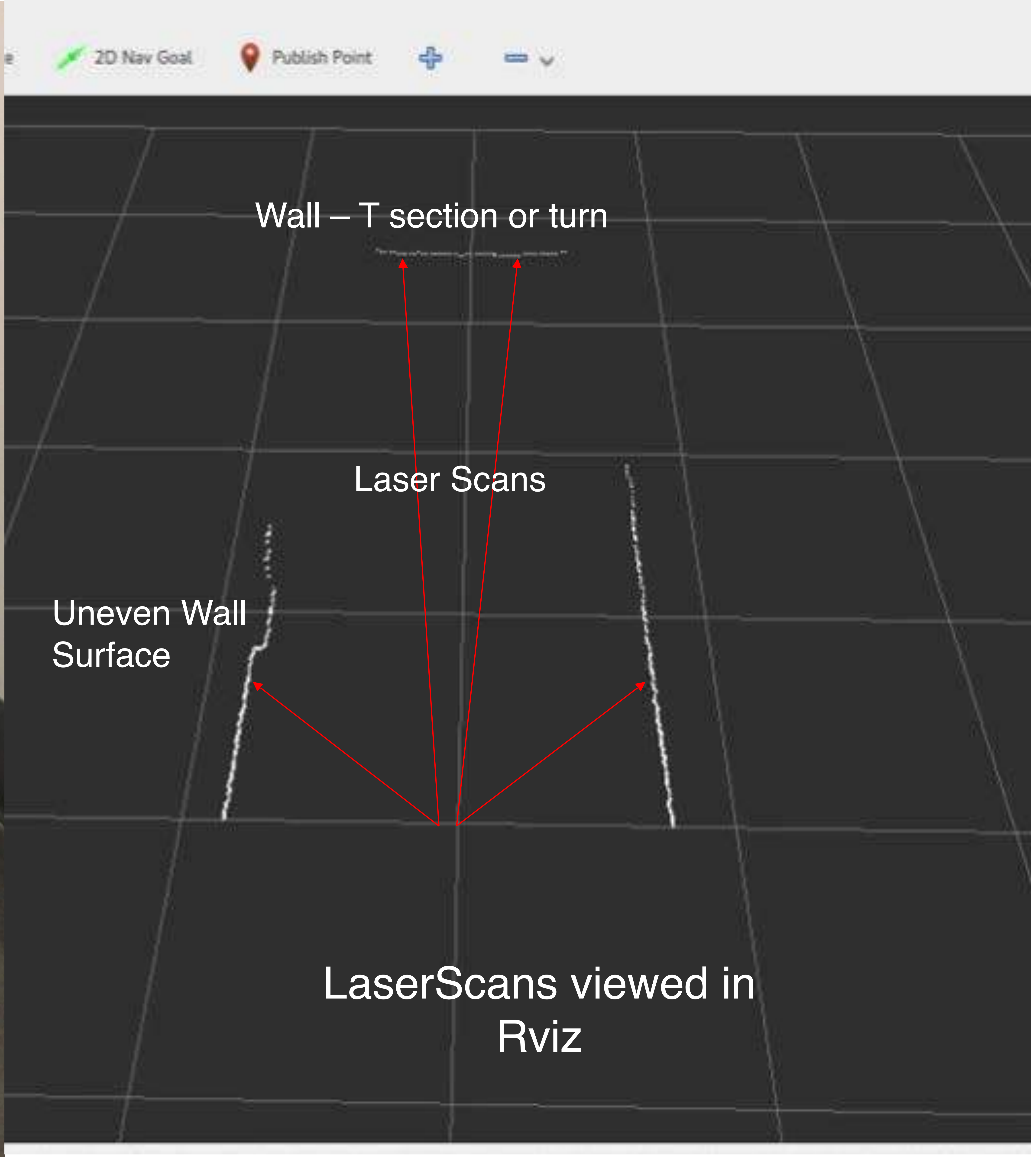


Perception

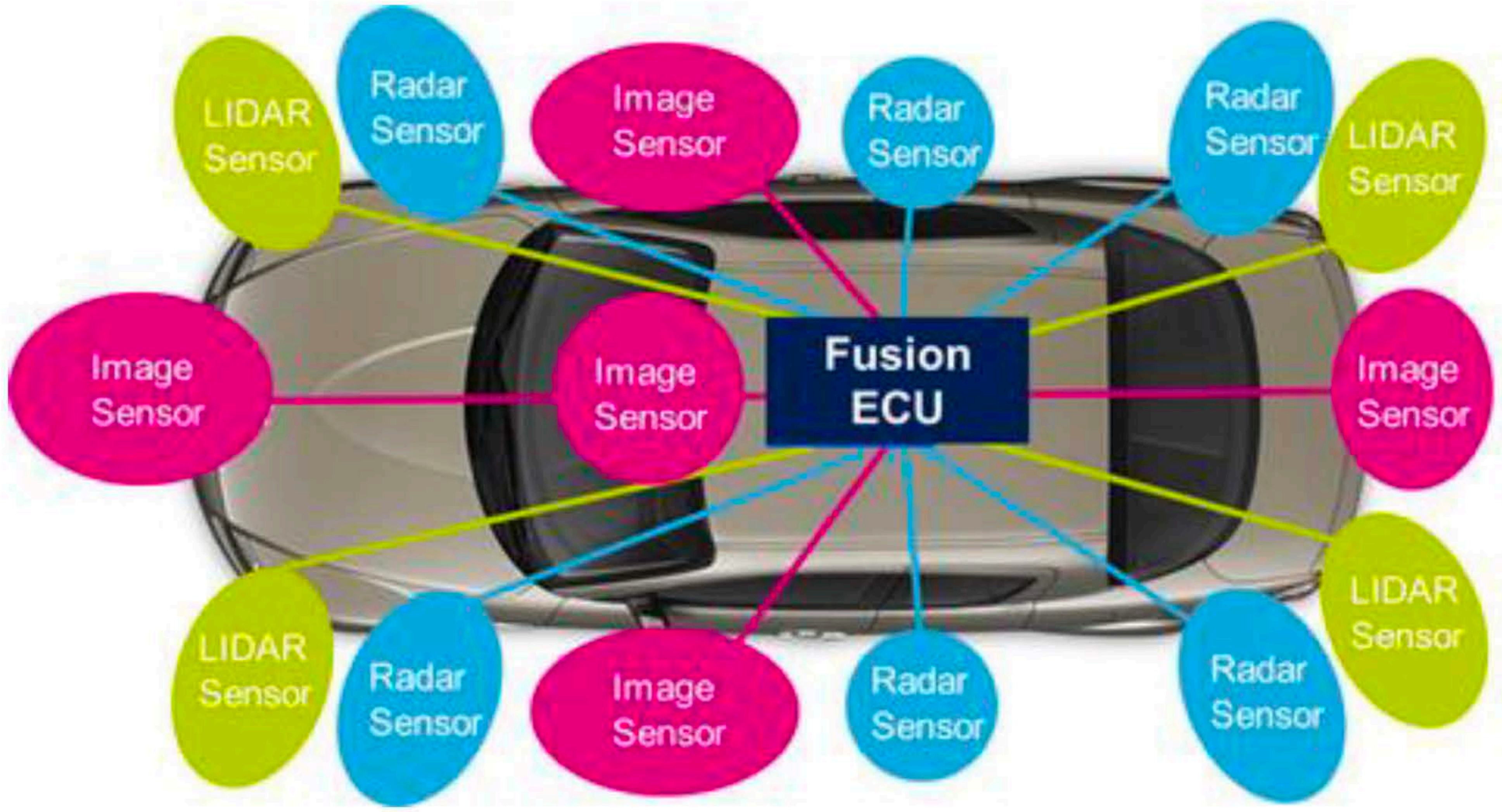

LiDAR
Camera
IMU
STRUCTURE SENSOR
Filters
Map generation
Computer vision
Localization
Path planning
Steering
Motor Controller
Drive

Perception


Uneven Wall Surface
Wall – T section or turn
Laser Scans
Race car view


2D Nav Goal
Publish Point
Wall – T section or turn
Laser Scans
Uneven Wall Surface
LaserScans viewed in Rviz

Automotive AI Sensors

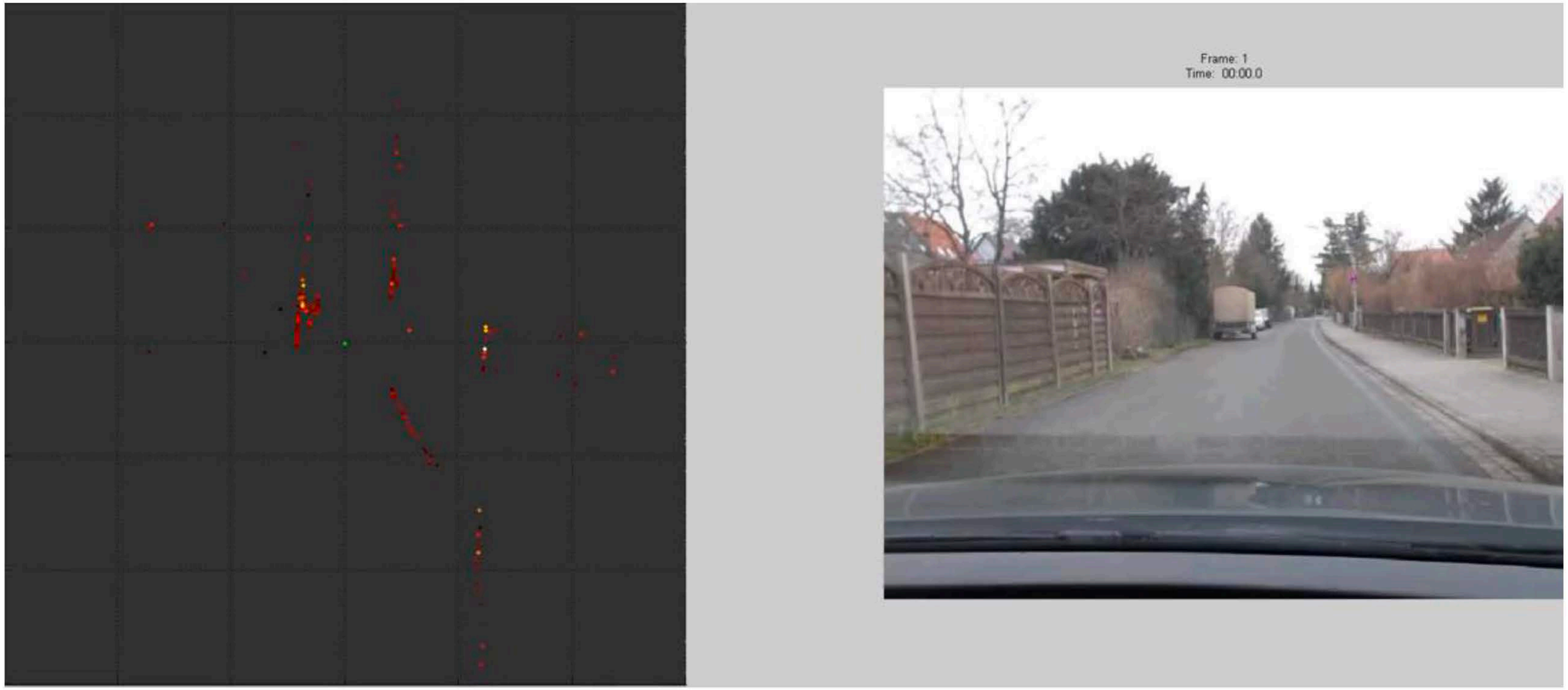


Camera

Radar

LIDAR

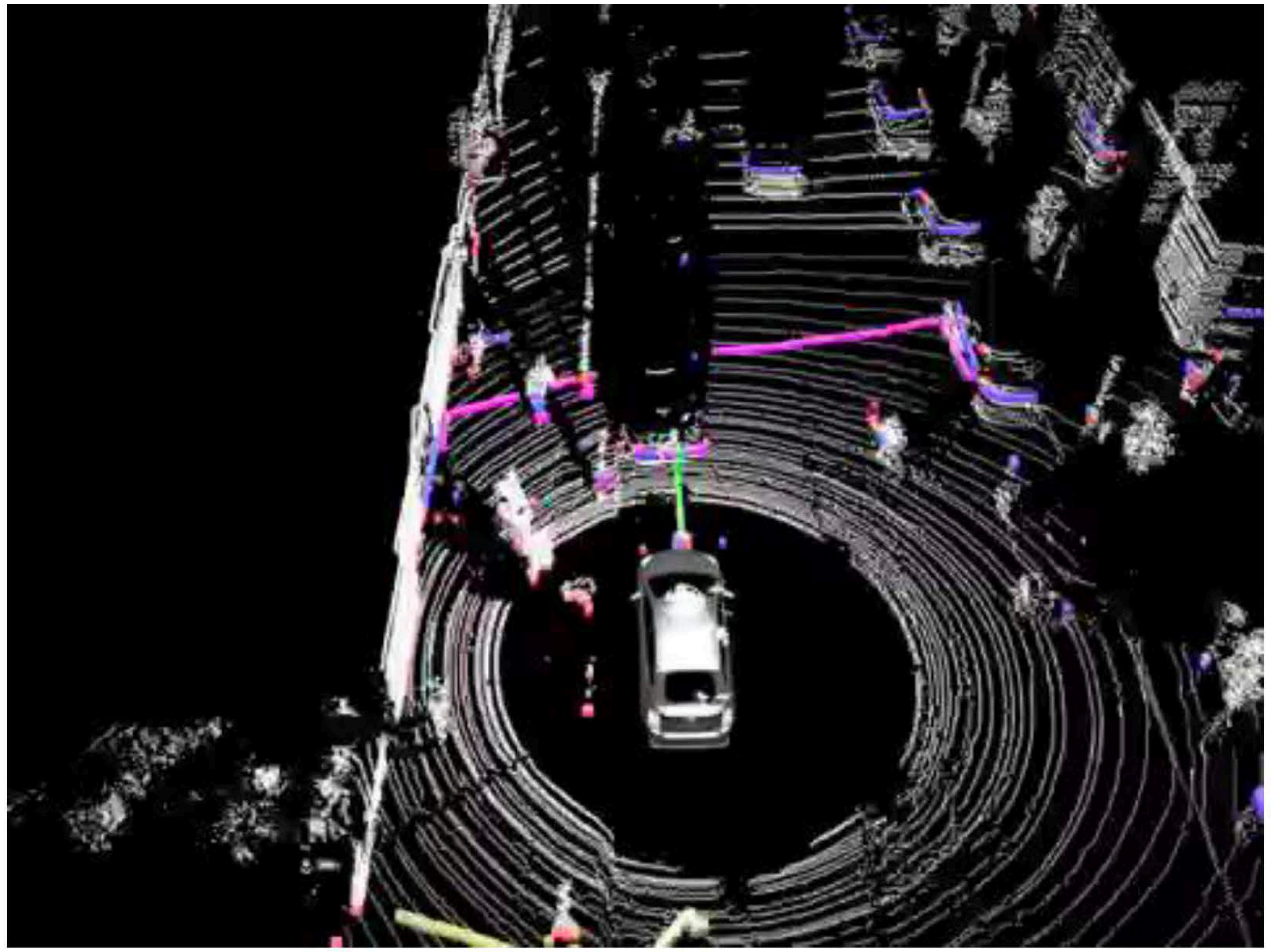
Radar



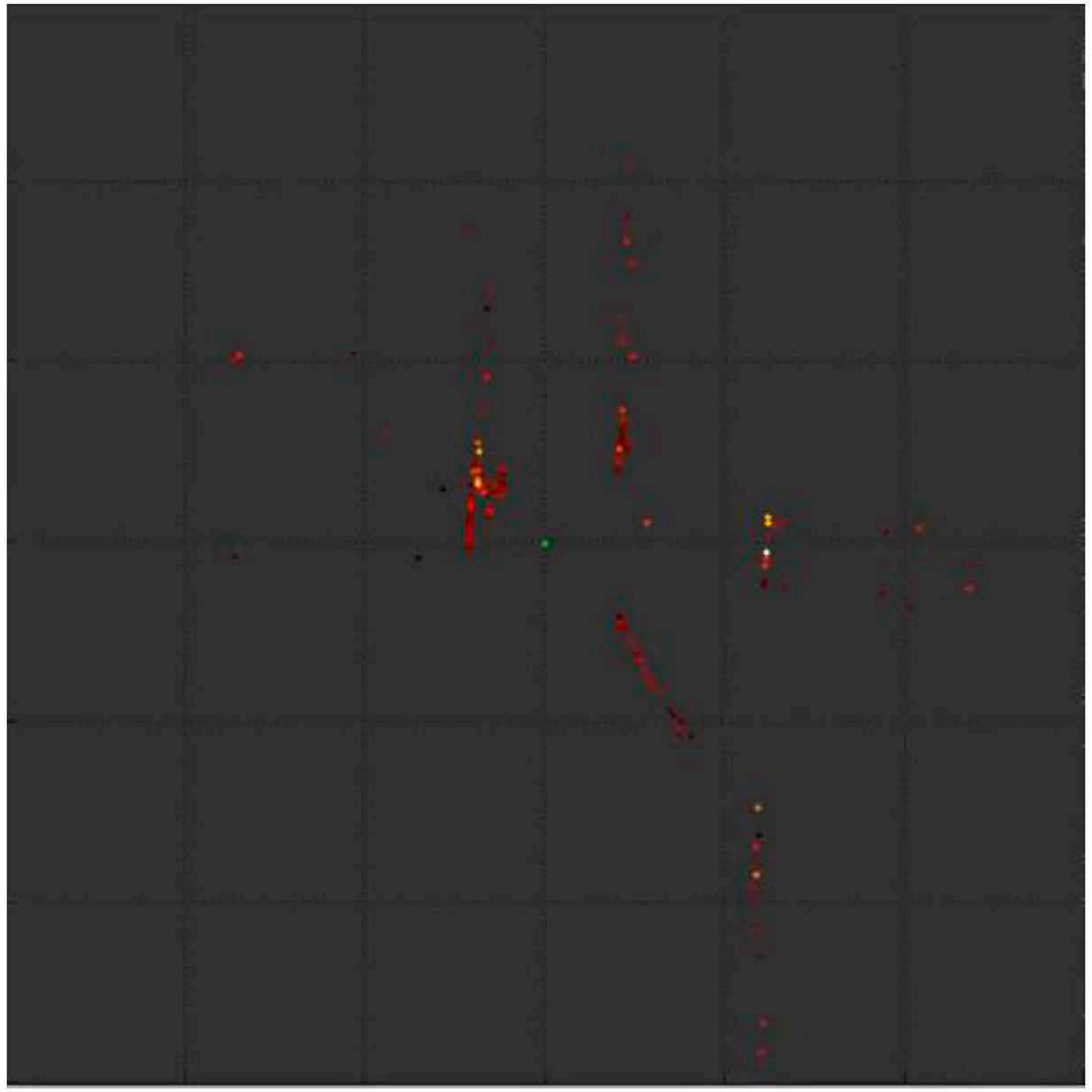
- Cheap
- Does well in extreme weather
- Low resolution
- Most used automotive sensor for object detection and tracking

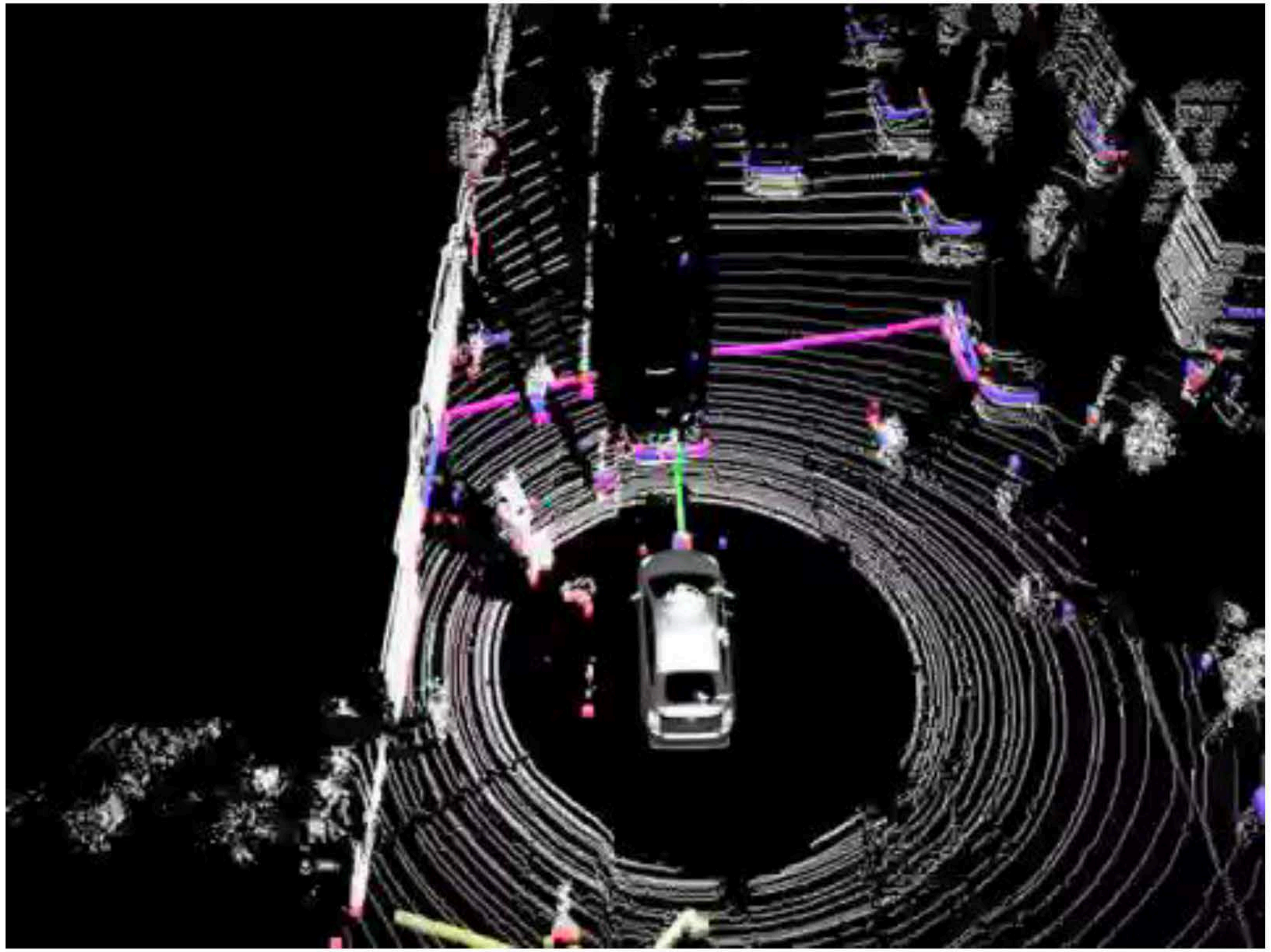
LIDAR

- Expensive
- Extremely accurate depth information
- Resolution much higher than radar
- 360 degrees of visibility



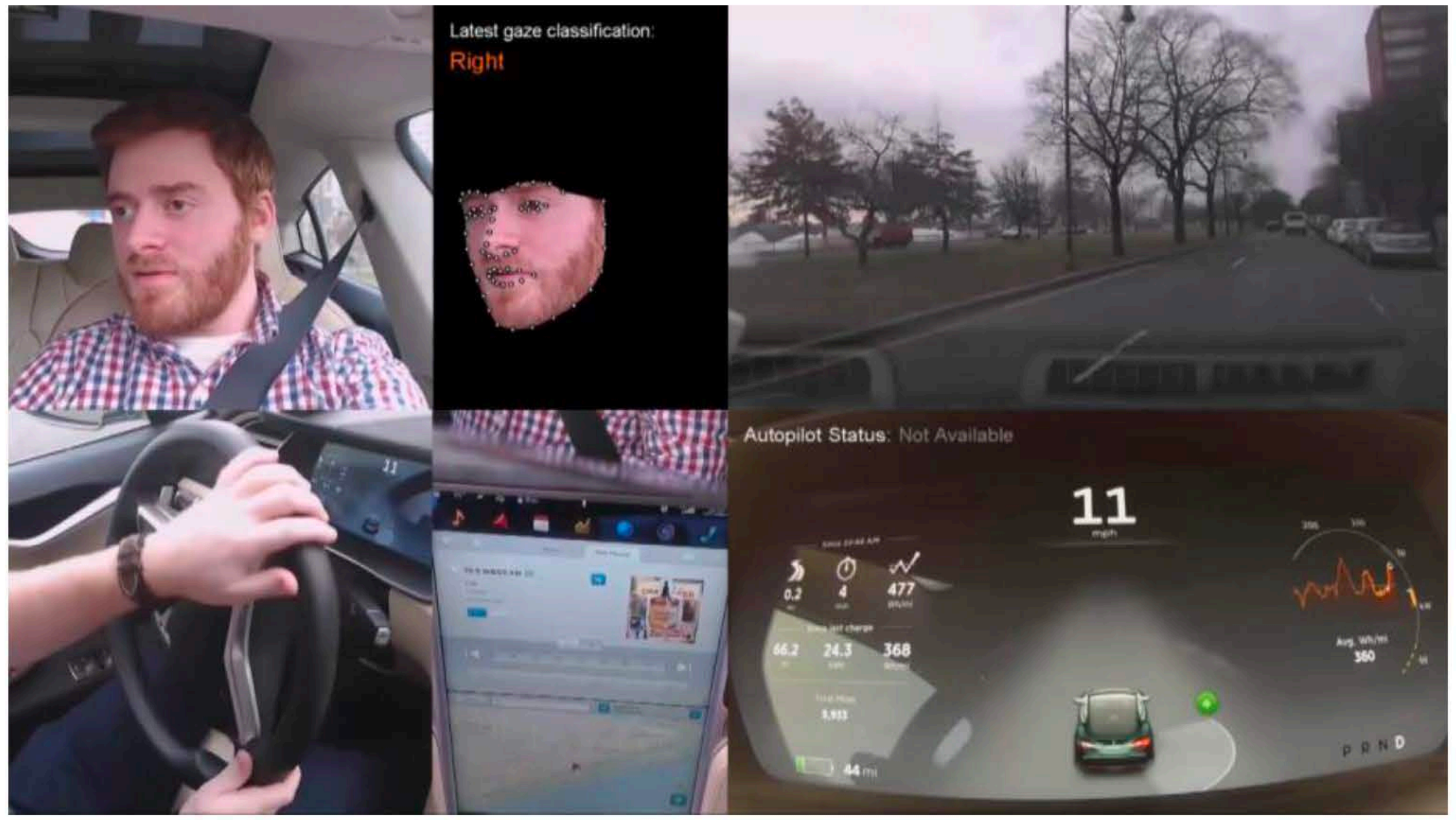
Resolution: LIDAR vs Radar

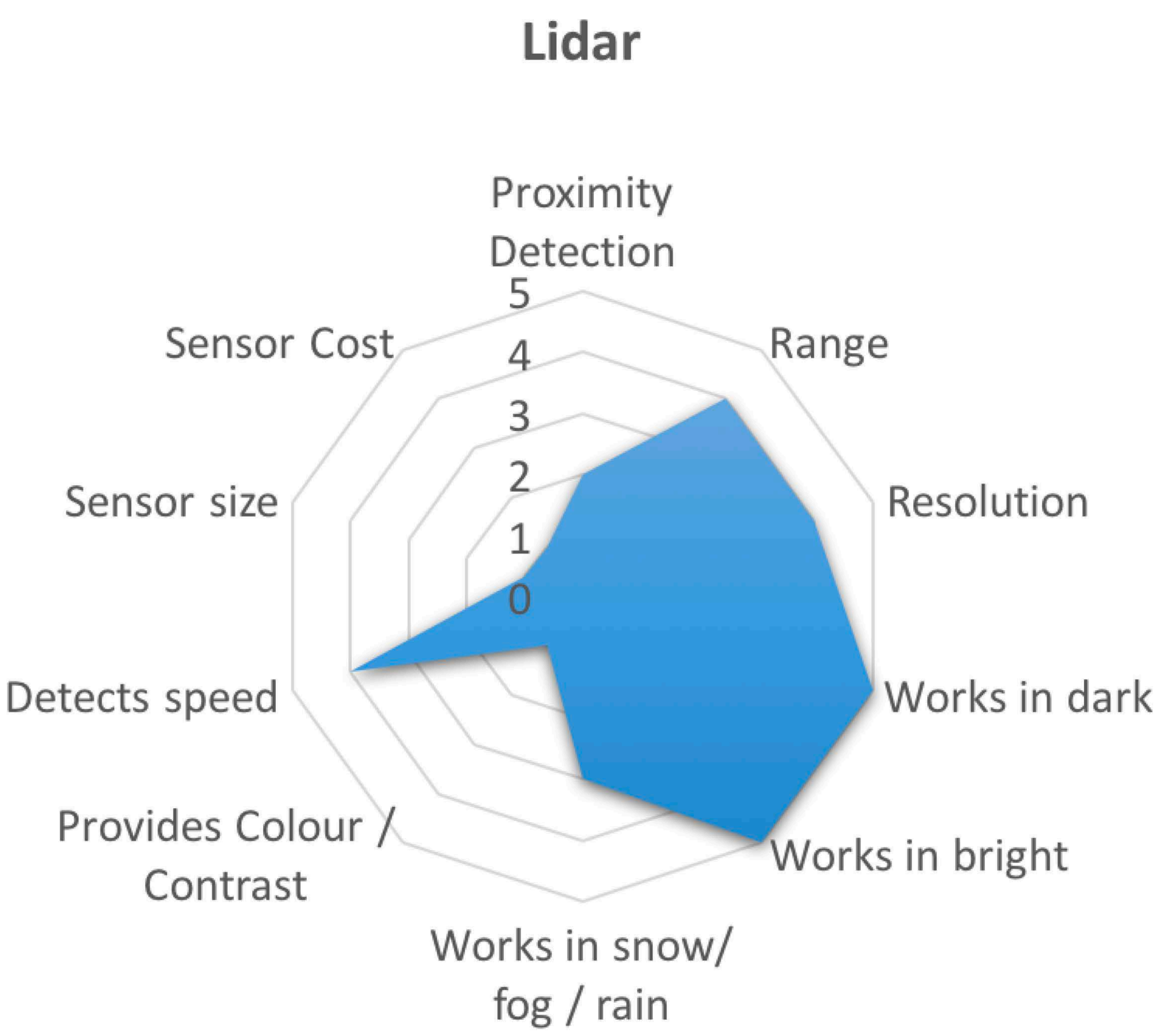




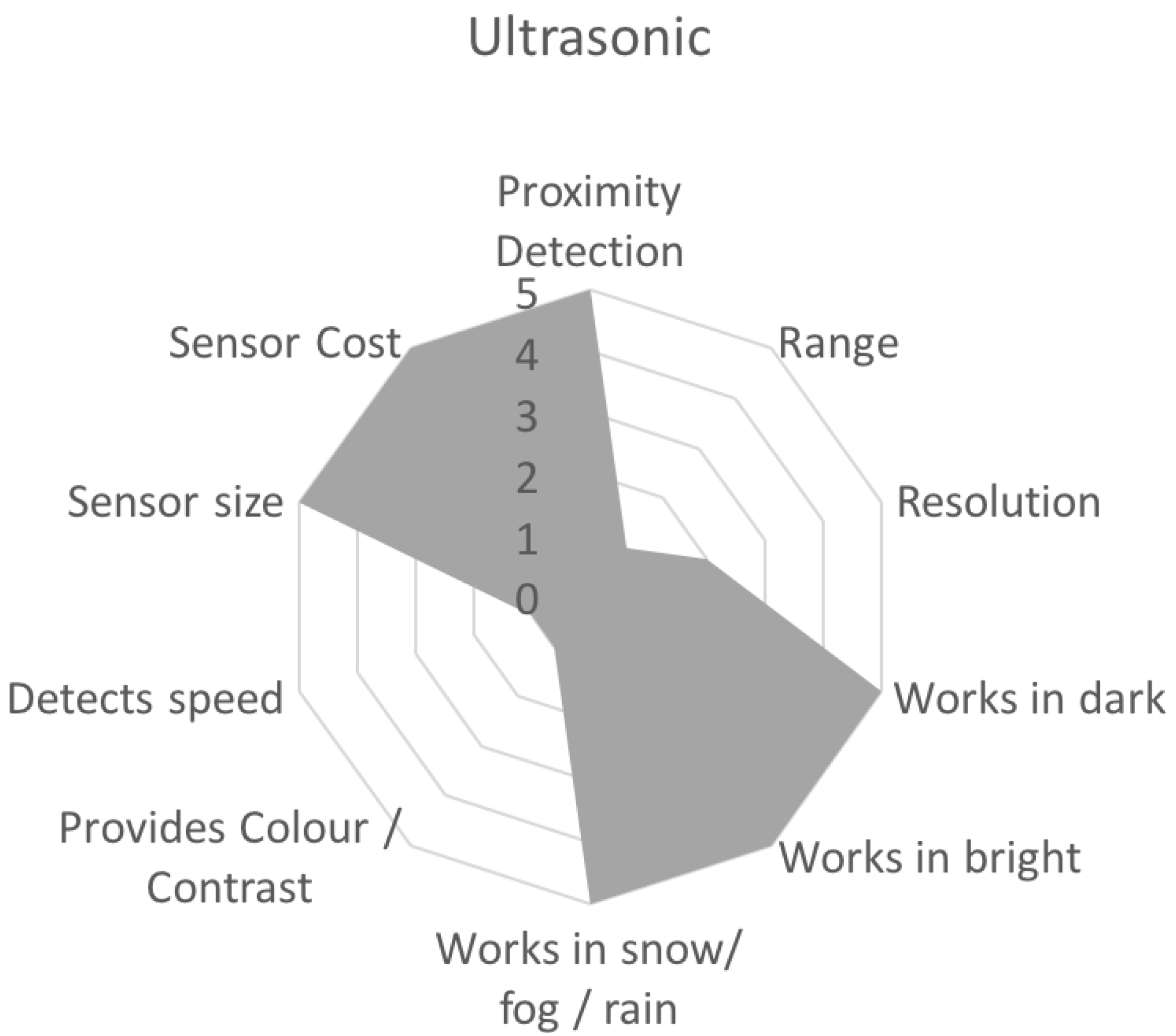
Camera

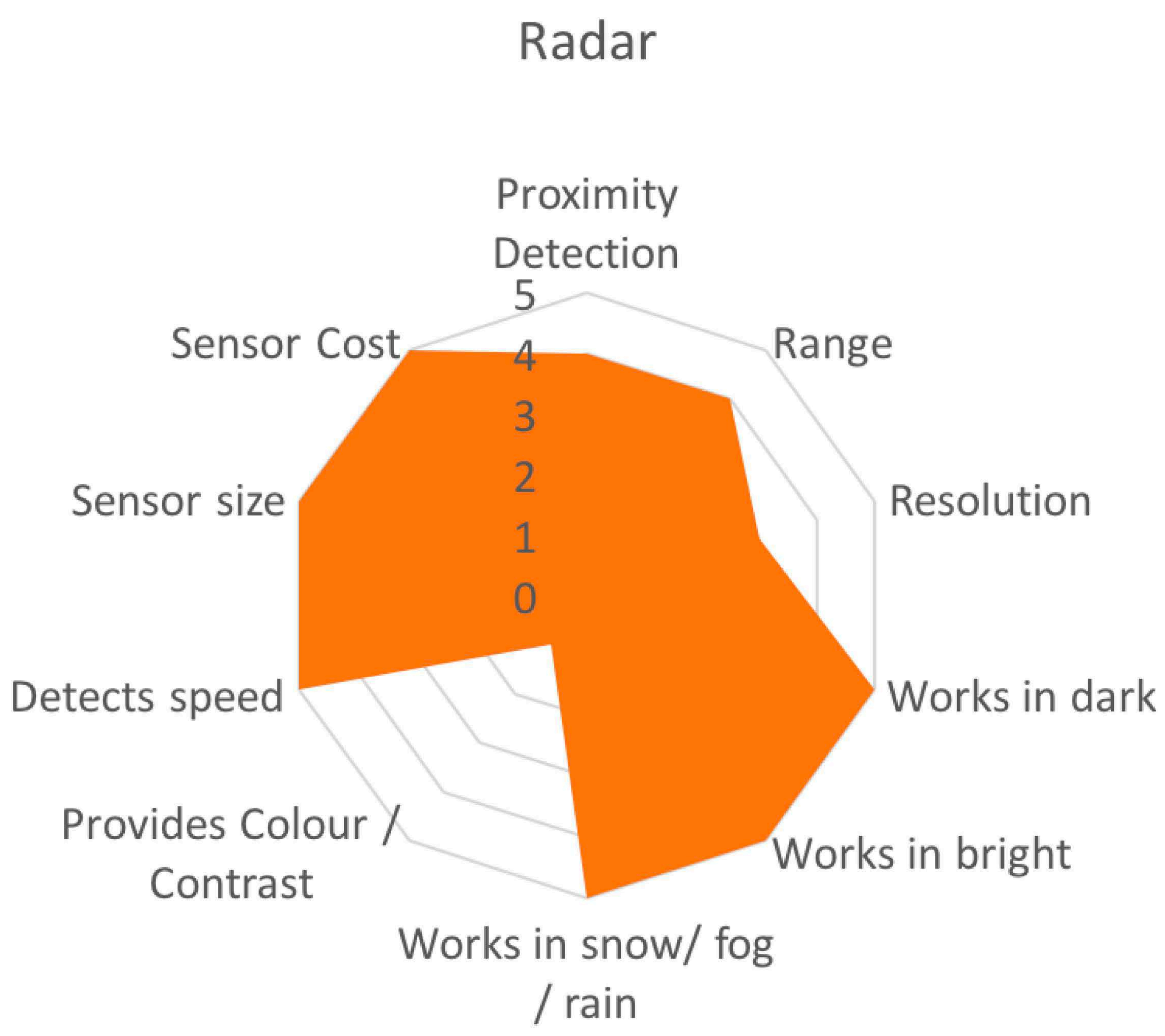
- Cheap
- Highest resolution
- Huge data = deep learning
- Human brains use similar sensor technology for driving
- Bad at depth estimation
- Not good in extreme weather

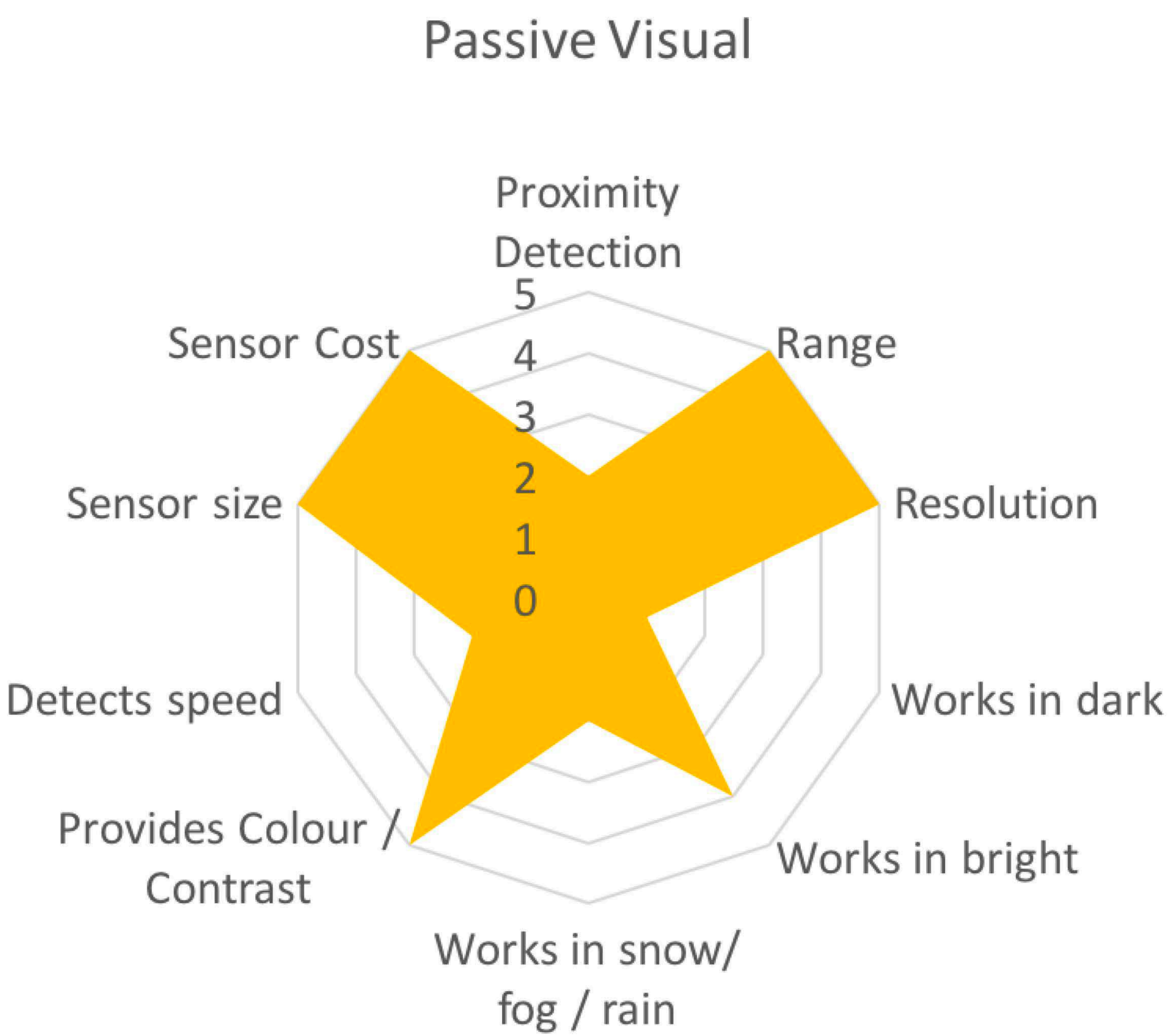




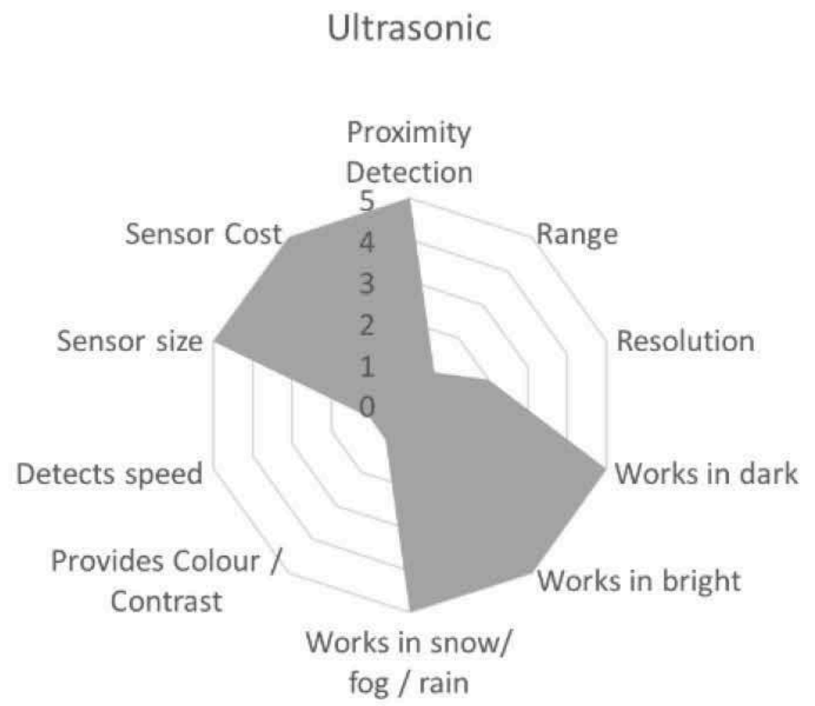
Lidar
Proximity Detection
Range
Resolution
Works in dark
Works in bright
Works in snow/ fog / rain
Provides Colour / Contrast
Detects speed
Sensor size
Sensor Cost
5
4
3
2
1
0

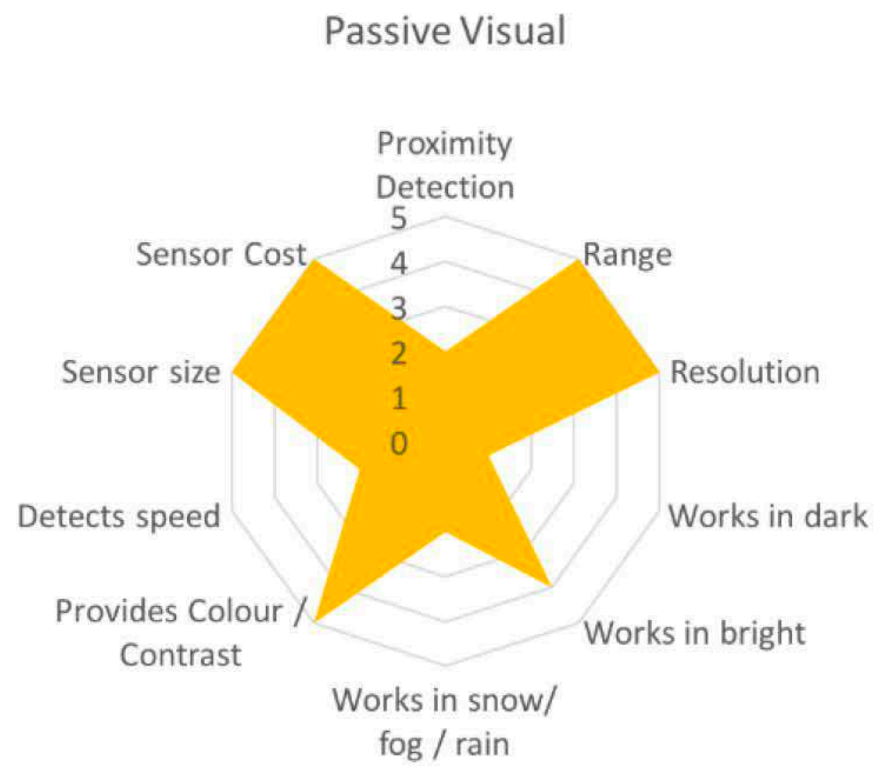

Ultrasonic
Proximity Detection
Range
Resolution
Works in dark
Works in bright
Works in snow/ fog / rain
Provides Colour / Contrast
Detects speed
Sensor size
Sensor Cost
5
4
3
2
1
0

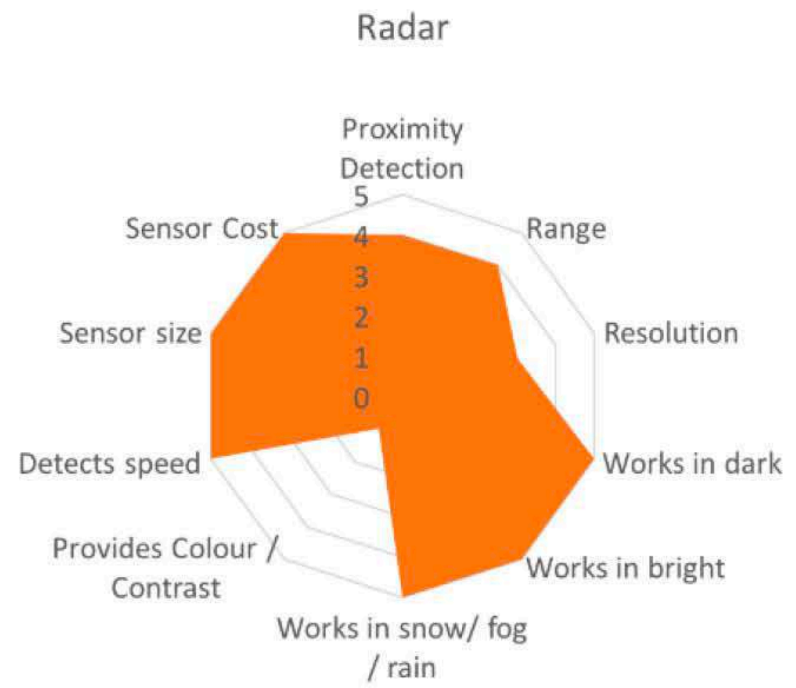

Radar
Proximity Detection
Range
Resolution
Works in dark
Works in bright
Works in snow/ fog / rain
Provides Colour / Contrast
Detects speed
Sensor size
Sensor Cost
5
4
3
2
1
0

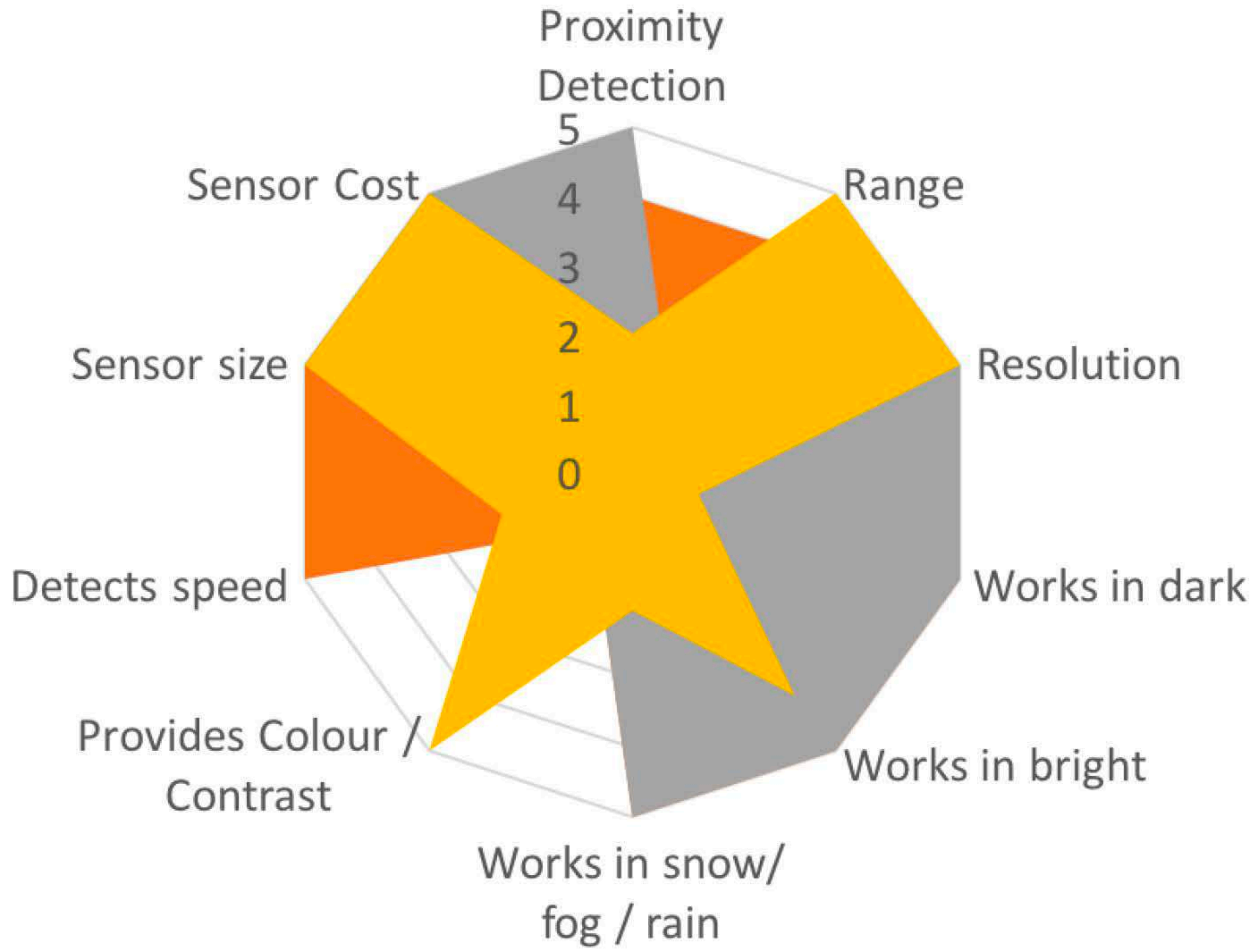

Passive Visual
Proximity Detection
Range
Resolution
Works in dark
Works in bright
Works in snow/ fog / rain
Provides Colour / Contrast
Detects speed
Sensor size
Sensor Cost
5
4
3
2
1
0

Sensor Fusion



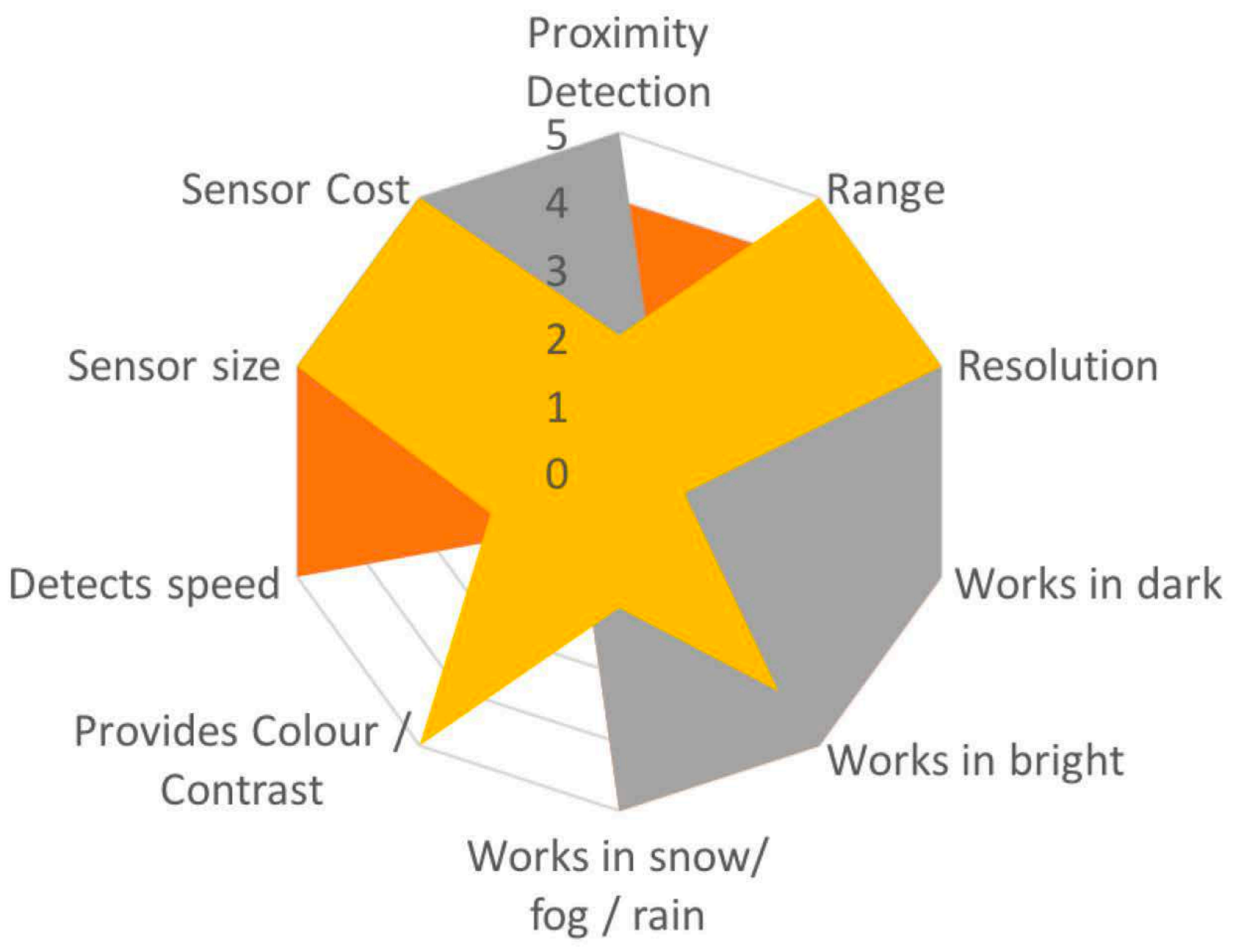


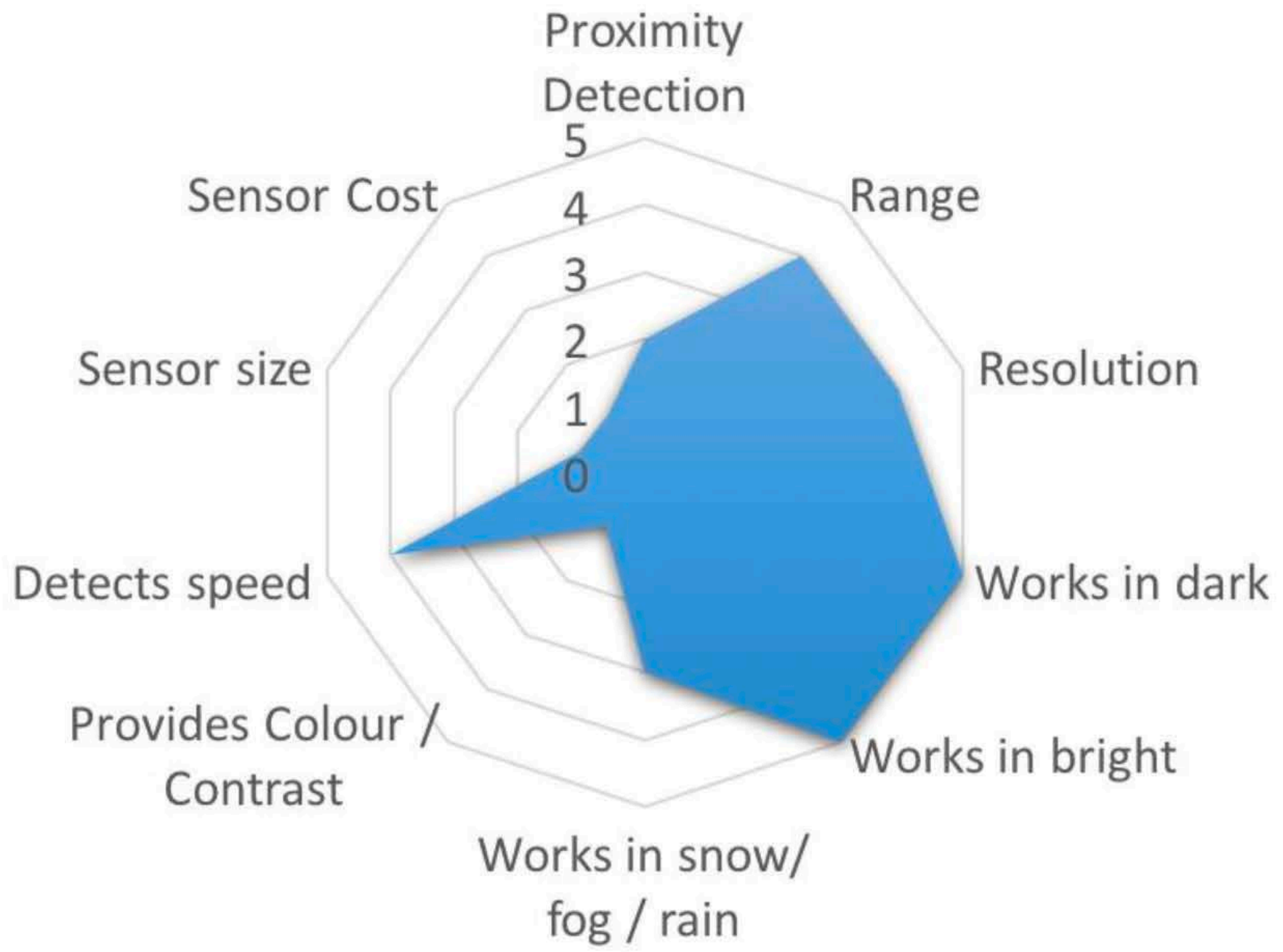




Future of Sensor Technology: Camera vs LIDAR

- **Radar and Ultrasonic:**
  - Always there to help
- **Camera:**
  - Annotated driving data grows
  - Deep learning algorithms improve
- **LIDAR:**
  - Range increases
  - Cost drops (solid-state LIDAR)





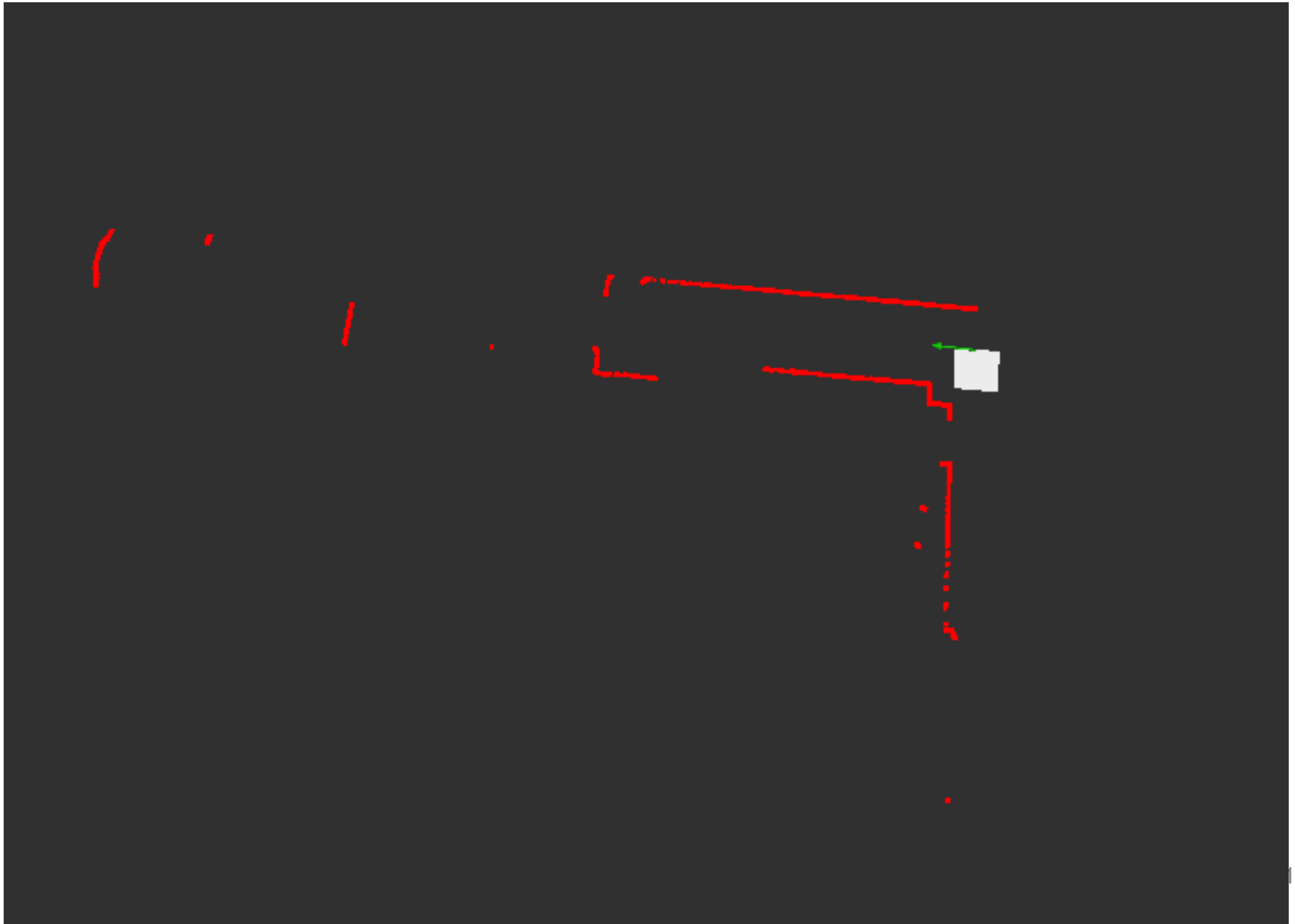
Planning


LiDAR
Camera
IMU
STRUCTURE
SENSOR
Filters
Map generation
Computer vision
Localization
Path planning
Steering
Motor Controller
Drive

Planning

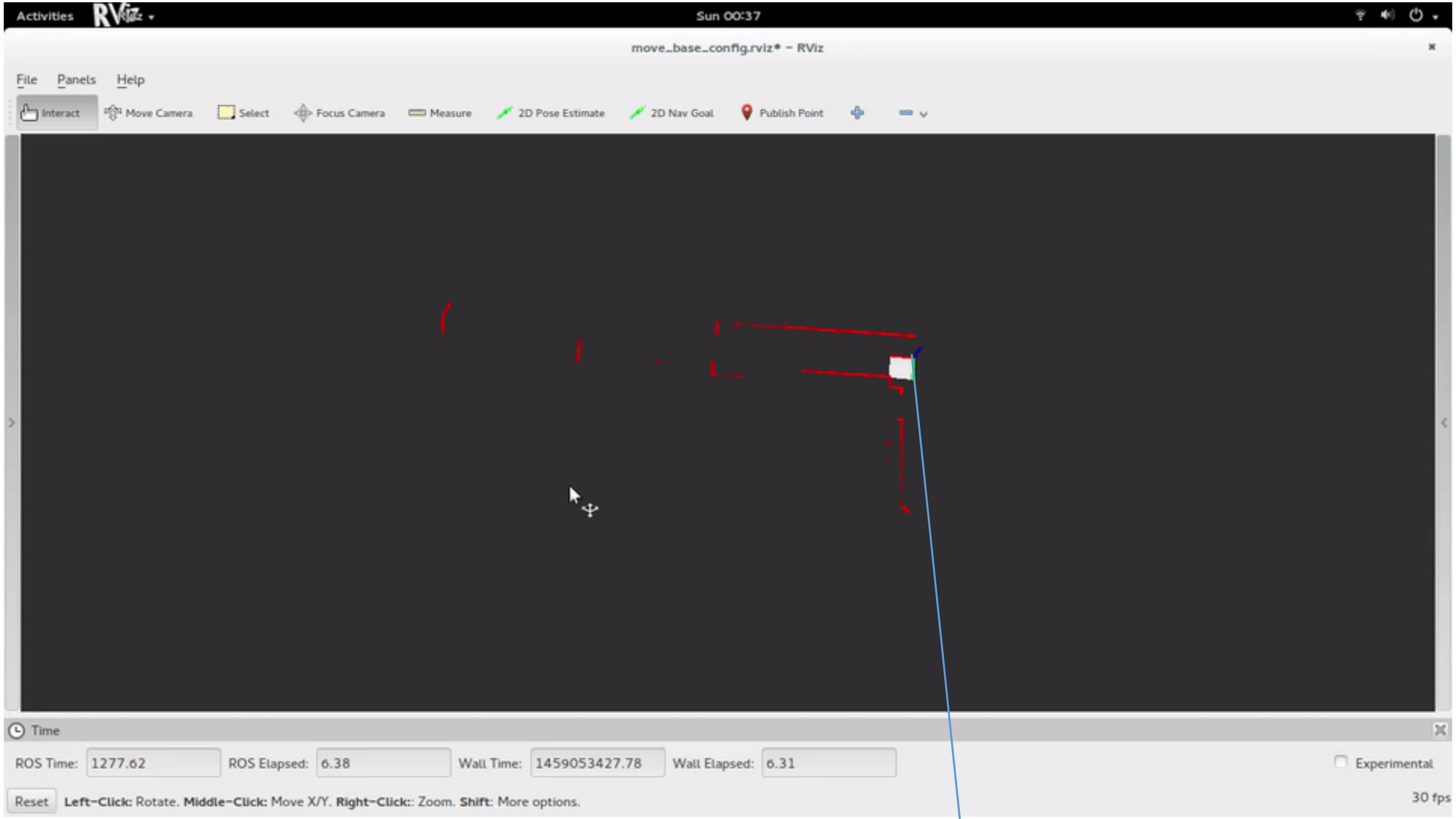

Cost Maps path planning
Time
ROS Time: 1453072851.57
ROS Elapsed: 30.29
Wall Time: 1454341978.42
Wall Elapsed: 68.81
Experimental
Reset
Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click:: Move Z. Shift: More options.
30 fps

Registering a LIDAR Scan



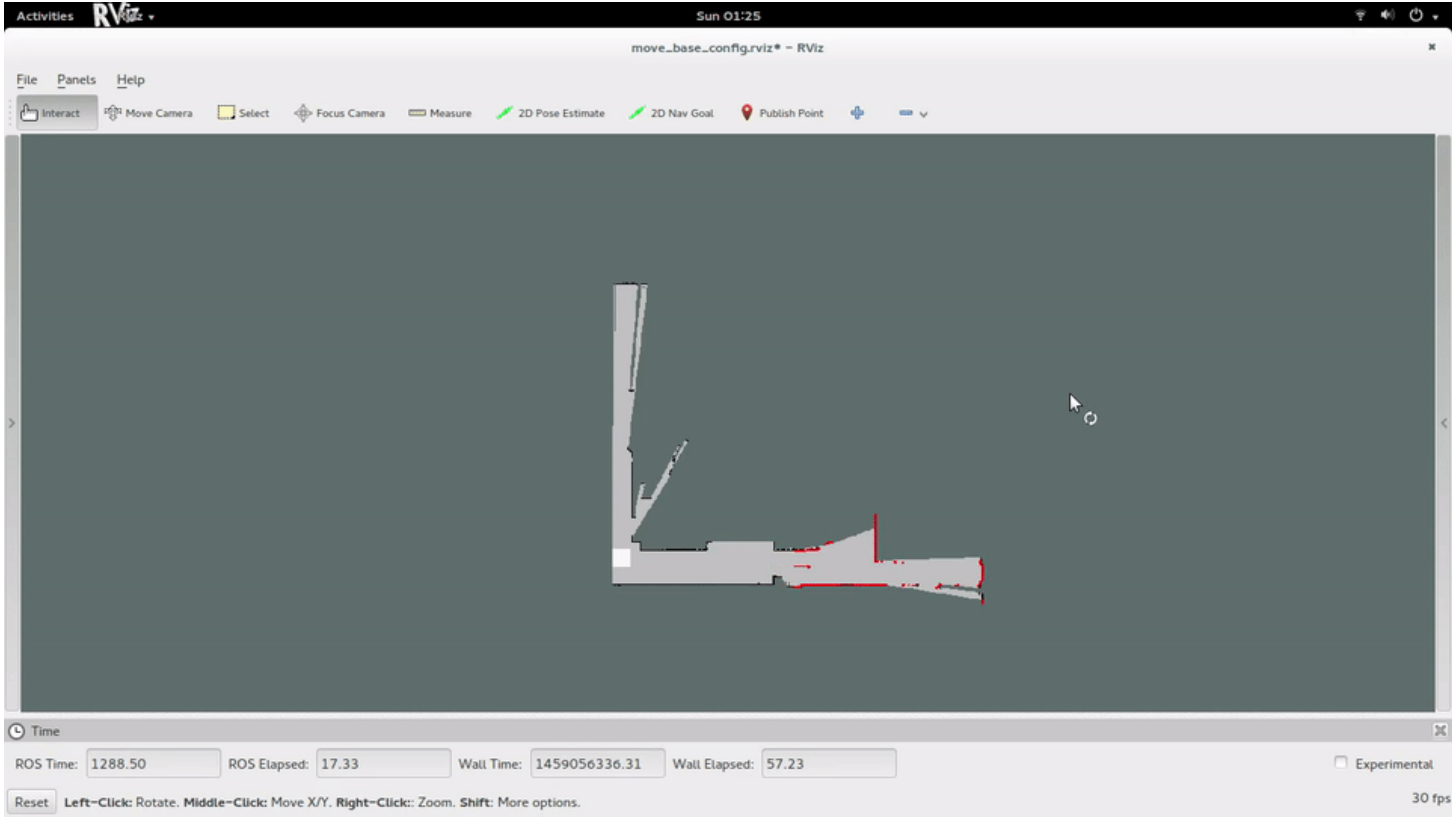
Registering a LIDAR Scan

What the car sees..



Baseframe Axes

What can we infer..




Activities
Wed 19:48
mapping_demo.rviz* – RViz
File
se Estimate
2D Nav Goal
Publish Point
Hector
SLAM
Topic
/map
Alpha
0.7
Color Scheme
map
Draw Behind
Resolution
0.05
Width
2048
Height
2048
Position
-51.225; -51.225; 0
Orientation
0; 0; 0; 1
Path
Status: Ok
Add
Remove
Rename
Time
ROS Time:
1458504023.35
ROS Elapsed:
2.01
Wall Time:
1460591289.42
Wall Elapsed:
22.83
Experimental
Reset
Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click:: Zoom. Shift: More options.
30 fps

Control

LiDAR
Camera
IMU
STRUCTURE
SENSOR
Filters
Map generation
Computer vision
Localization
Path planning
Steering
Motor Controller
Drive

Control

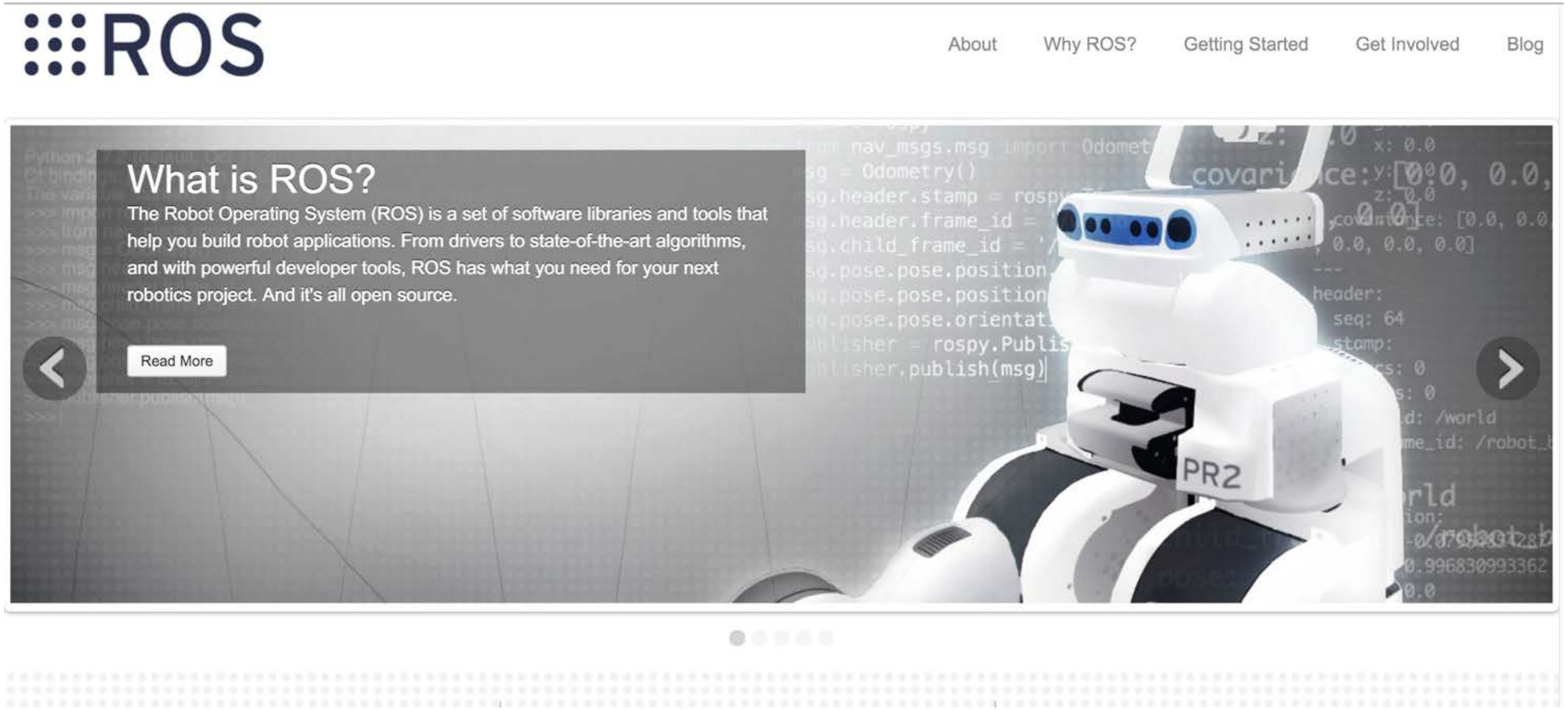
Proportional, **I**ntegral, **D**erivative control

Nominal gains

Smaller Kp

AMCL- Adaptive Monte Carlo Localization

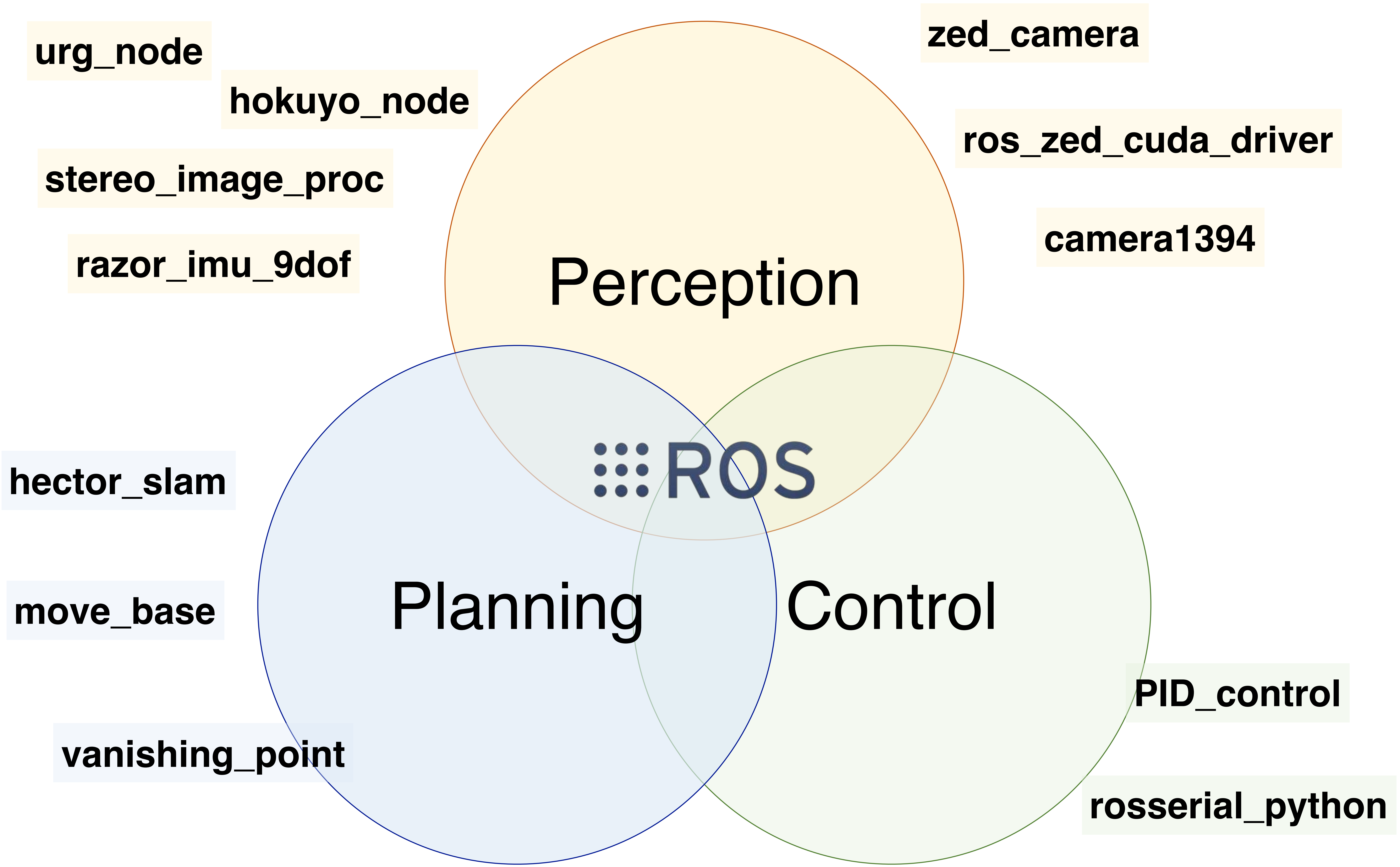
ROS: Robot Operating System



ROS.org

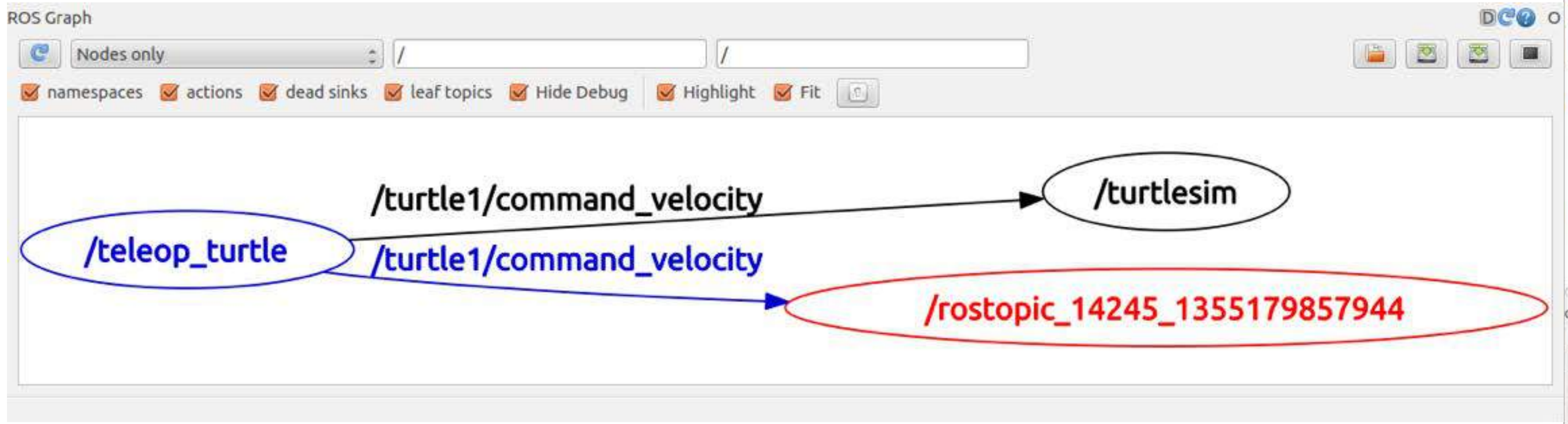
Open Source Robotics Foundation

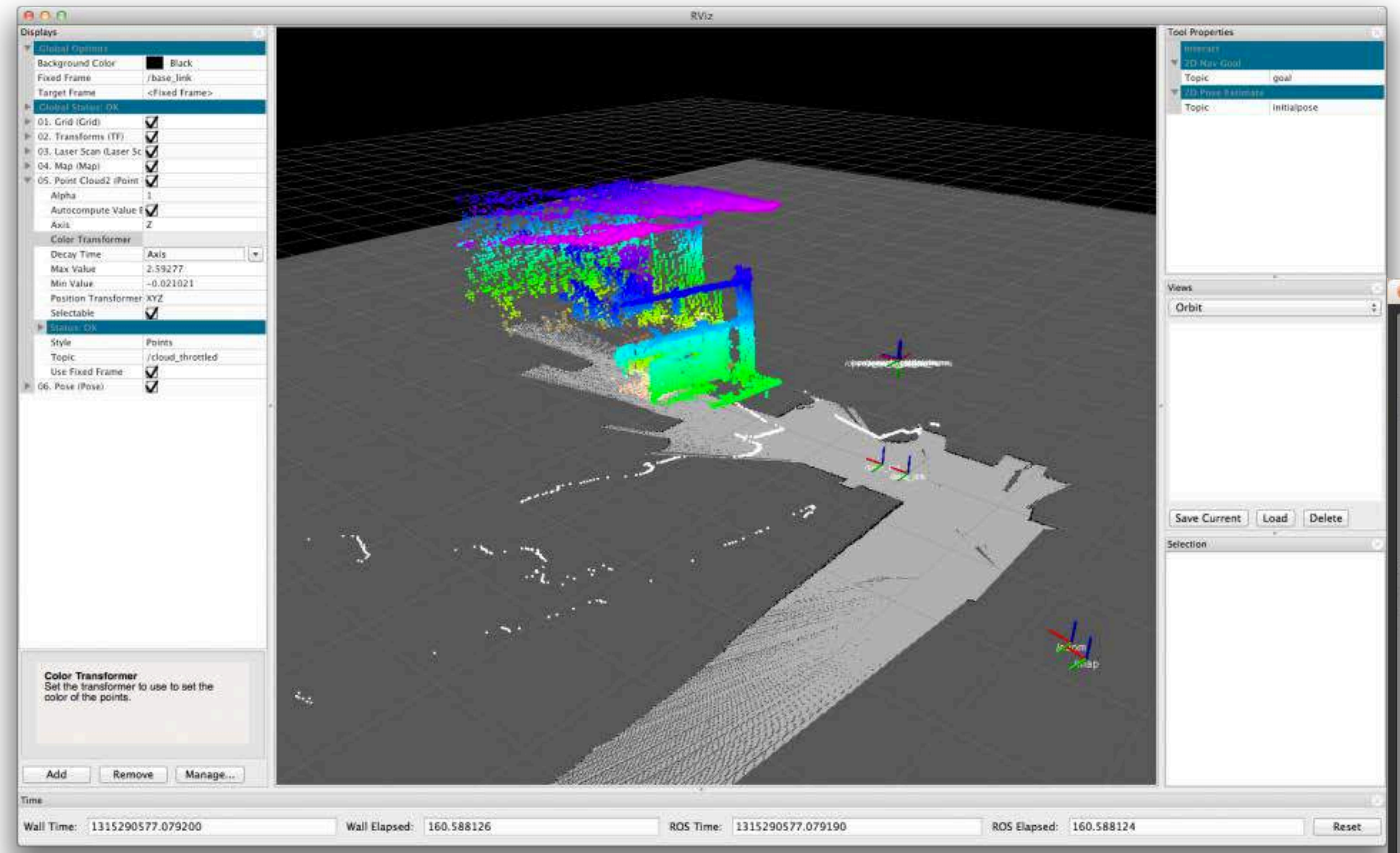
ROS Capabilities

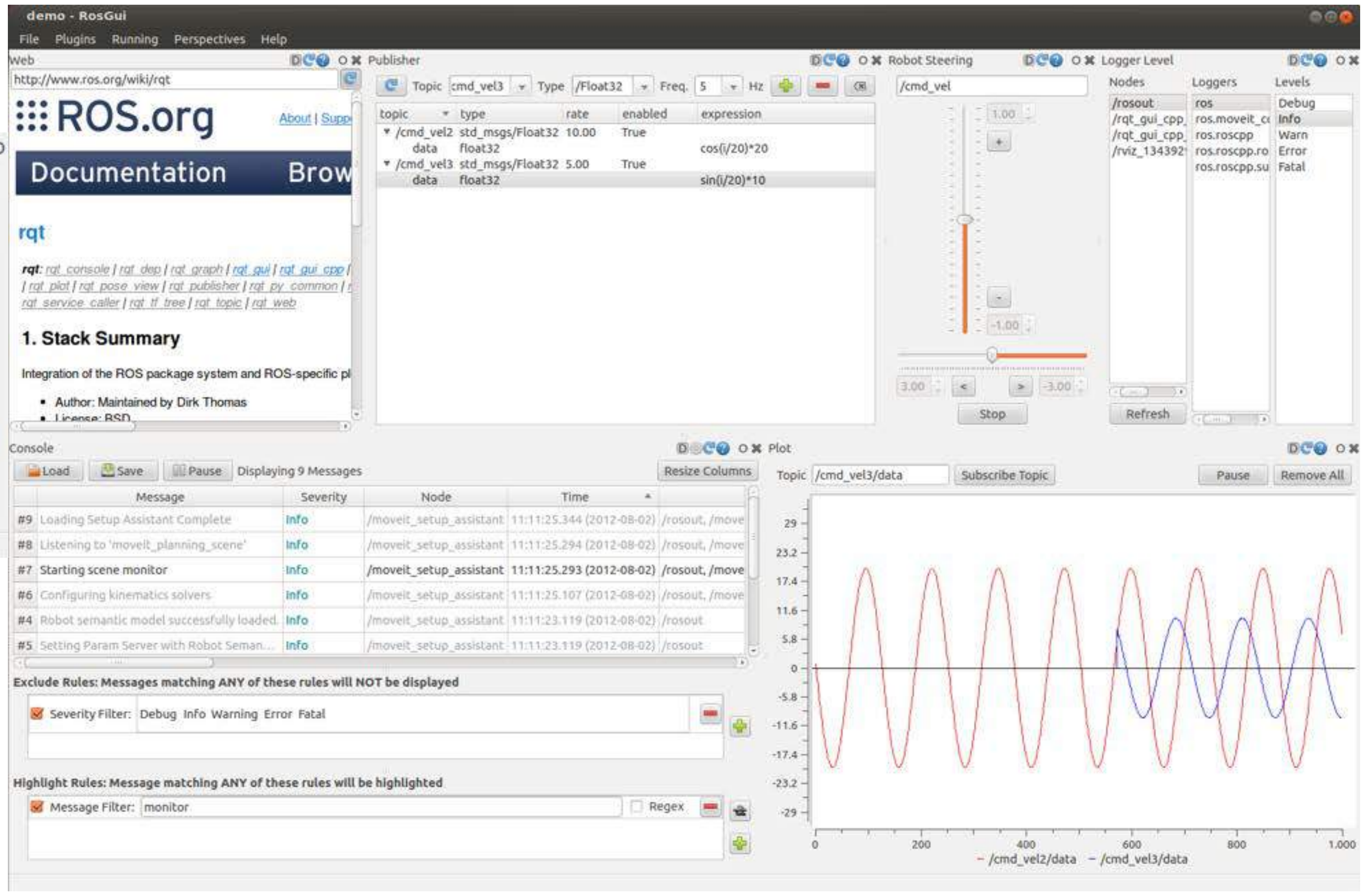


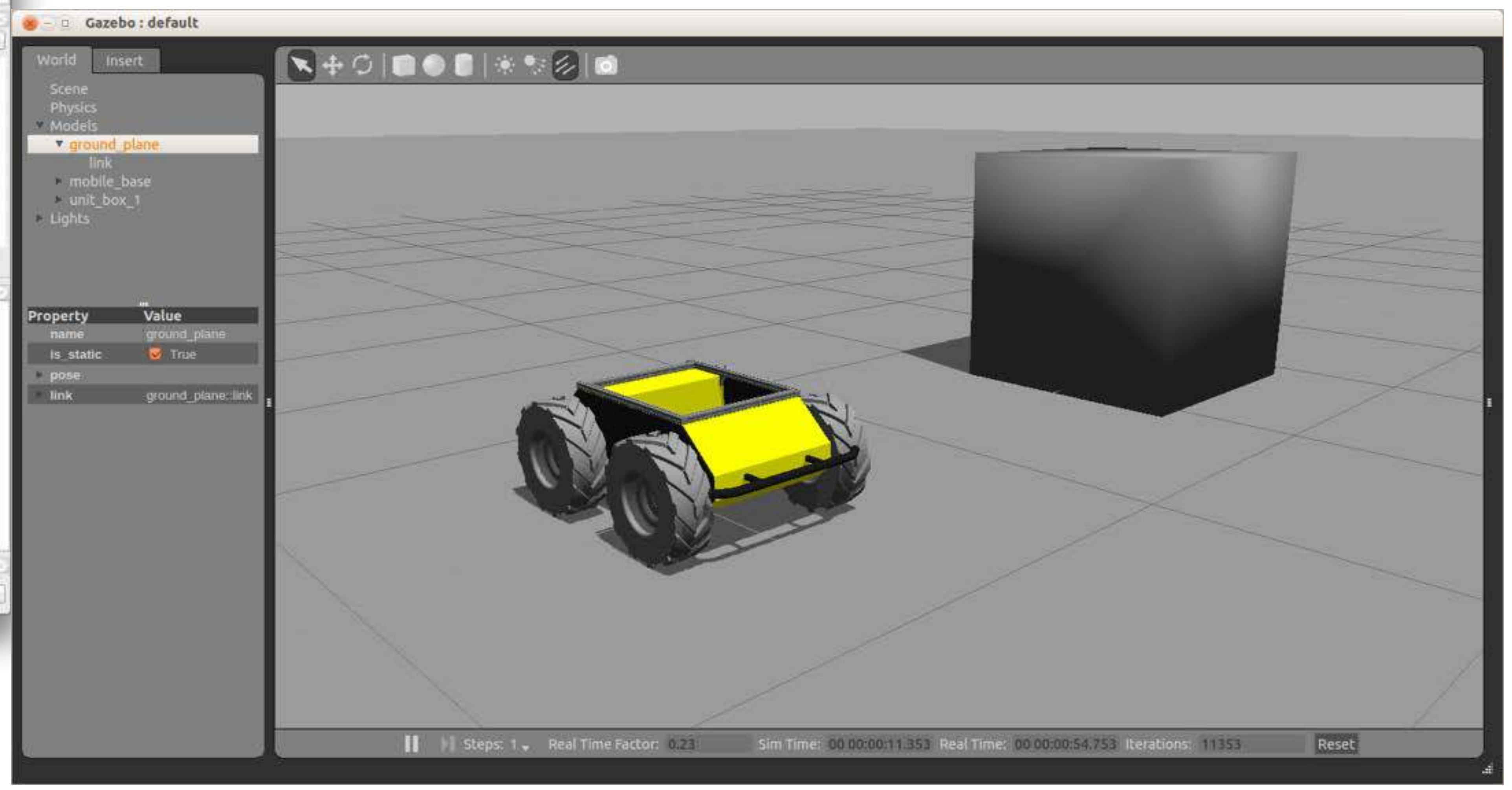
ROS Tools

Visualization, debugging and diagnostics, logging, and simulation









ROS: Topics

Topics are channels over which nodes exchange messages.

They are for **streaming data**

Publishes on topic: Scan

Scan [Topic]

Mapping Node

hokuyo_node

Subscribes to topic: Scan

Publisher Node

Subscriber Node


Activities
Terminal
Gazebo
File Edit Camera View Window Help
World Insert Layers
GUI
Scene
Spherical Coordinates
Physics
Atmosphere
Wind
Models
ground_plane
LINKS
link
jersey_barrier_1
SimpleScreenRecorder
Recording
Pause recording
Enable recording hotkey
Enable sound notifications
Hotkey: Ctrl + Shift + Alt + Super + R
Information
Total time:
FPS in:
FPS out: 30.00
Size in: 1920x1080
Size out: 1920x1080
File name: teleop.mp4
Preview
Preview frame rate: 10
Note: Previewing requires extra CPU time (especially at high frame rates).
Start preview
Log
Cancel recording
Save recording
File Edit View Search Terminal Help
Loading controller: left_rear_wheel_velocity_controller
Loading controller: right_rear_wheel_velocity_controller
Loading controller: left_front_wheel_velocity_controller
Loading controller: right_front_wheel_velocity_controller
Loading controller: left_steering_hinge_position_controller
Loading controller: right_steering_hinge_position_controller
Loading controller: joint_state_controller
Controller Spawner: Loaded controllers: left_rear_wheel_velocity_controller, right_rear_wheel_velocity_controller, left_front_wheel_velocity_controller, right_front_wheel_velocity_controller, left_steering_hinge_position_controller, right_steering_hinge_position_controller, joint_state_controller
Started controllers: left_rear_wheel_velocity_controller, right_rear_wheel_velocity_controller, left_front_wheel_velocity_controller, right_front_wheel_velocity_controller, left_steering_hinge_position_controller, right_steering_hinge_position_controller, joint_state_controller
Real Time Factor
Sim Time
Real Time
Iterations
FPS
Reset Time

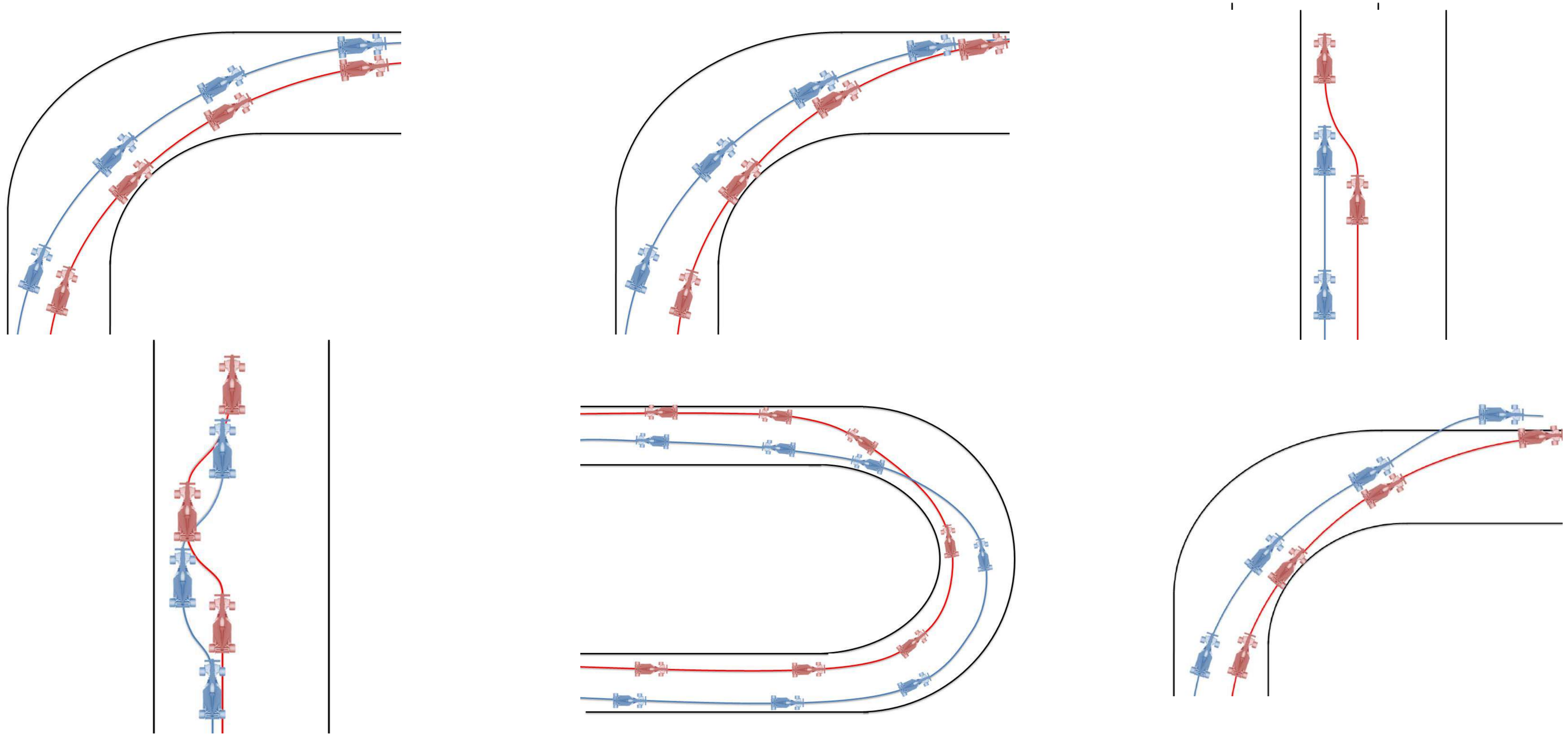

Activities
Terminal
Gazebo
File Edit Camera View Window Help
World Insert Layers
GUI
Scene
Spherical Coordinates
Physics
Atmosphere
Wind
Models
Lights
SimpleScreenRecorder
Recording
Pause recording
Enable recording hotkey
Enable sound notifications
Hotkey: Ctrl + Shift + Alt + Super + R
Information
Total time: 0:00:01
FPS in: 30.97
FPS out: 0.00
Size in: 1920x1080
Size out: 1920x1080
File name: mapping.mp4
File size: 263 KiB
Bit rate: 0 bit/s
Preview
Preview frame rate: 10
Note: Previewing requires extra CPU time (especially at high frame rates).
Start preview
Log
[PulseAudioInput::InputThread] Stream is a monitor.
[PageRecord::StartInput] Started input.
[PulseAudioInput::InputThread] Input thread started.
[FastResampler::Resample] Resample ratio is 1.0000 (was 0.0000).
Cancel recording
Save recording
File Edit View Search Terminal Help
Loading controller: left_front_wheel_velocity_controller
Loading controller: right_front_wheel_velocity_controller
Loading controller: left_steering_hinge_position_controller
Loading controller: right_steering_hinge_position_controller
Loading controller: joint_state_controller
Controller Spawner: Loaded controllers: left_rear_wheel_velocity_controller, right_rear_wheel_velocity_controller, left_front_wheel_velocity_controller, right_front_wheel_velocity_controller, left_steering_hinge_position_controller, right_steering_hinge_position_controller, joint_state_controller
Started controllers: left_rear_wheel_velocity_controller, right_rear_wheel_velocity_controller, left_front_wheel_velocity_controller, right_front_wheel_velocity_controller, left_steering_hinge_position_controller, right_steering_hinge_position_controller, joint_state_controller
Interact
Move Camera
Select
Focus Camera
Measure
2D Pose Estimate
Time
ROS Time:
ROS Elapsed:
Wall Time:
Wall Elapsed:
Experimental

Activities
Terminal
Gazebo
File Edit Camera View Window Help
World Insert Layers
GUI
Scene
Spherical Coordinates
Physics
Atmosphere
Wind
Models
ground_plane
LINKS
link
asphalt_plane
jersey_barrier_1
Property Value
name ground_plane
is_static True
self_coll... False
enable_... False
pose
link
File Edit View Search Terminal Help
navigation.rviz* - RViz
File Panels Help
Interact Move Camera Select Focus Camera Measure 2D Pose Estimate 2D Nav Goal
Time
ROS Time: ROS Elapsed: Wall Time: Wall Elapsed: Experimental
Reset Left-Click: Rotate. Middle-Click: Move X/Y. Right-Click/Mouse Wheel: Zoom. Shift: More options.

Research

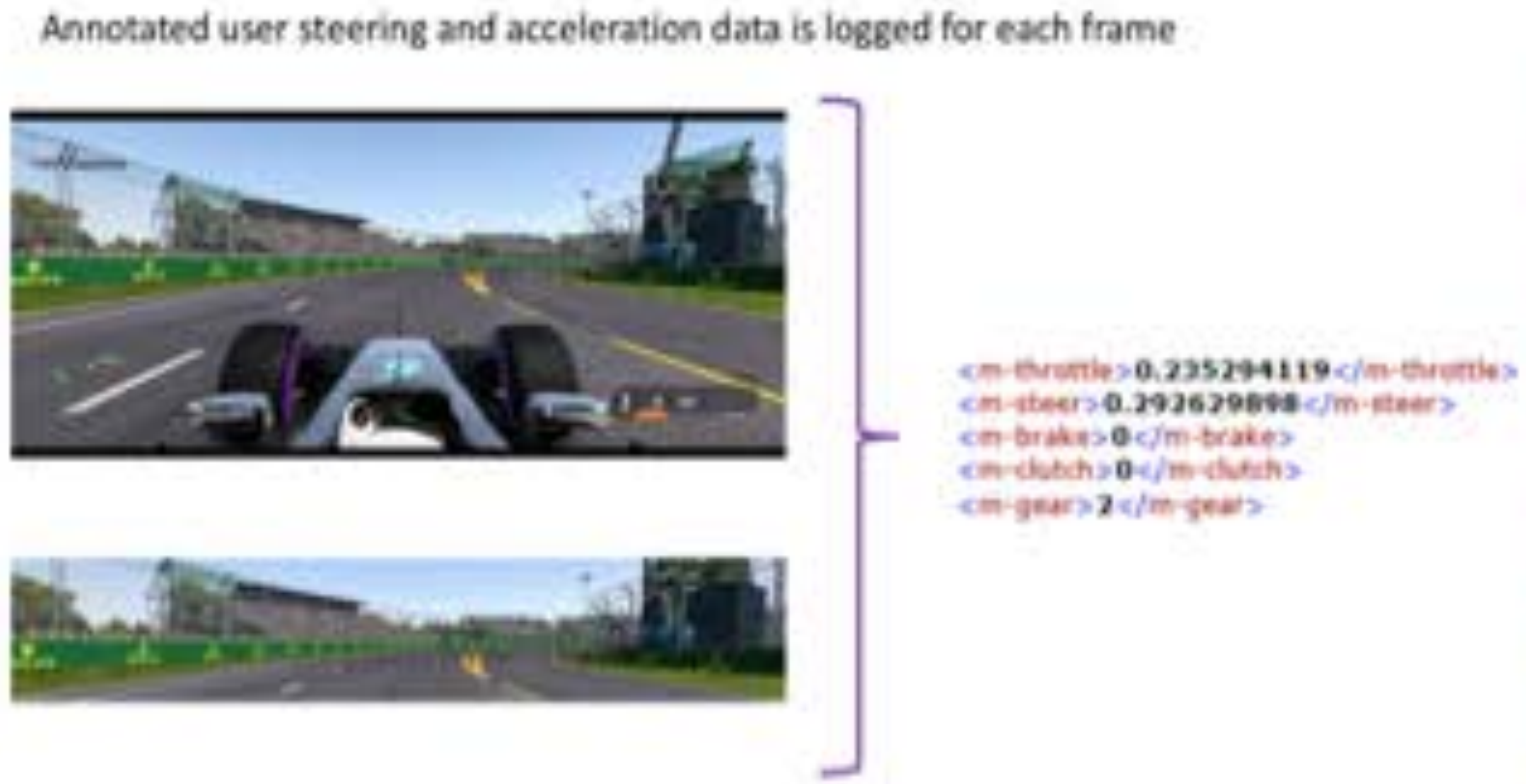

Overtaking
Algorithms ?
PIRELLI

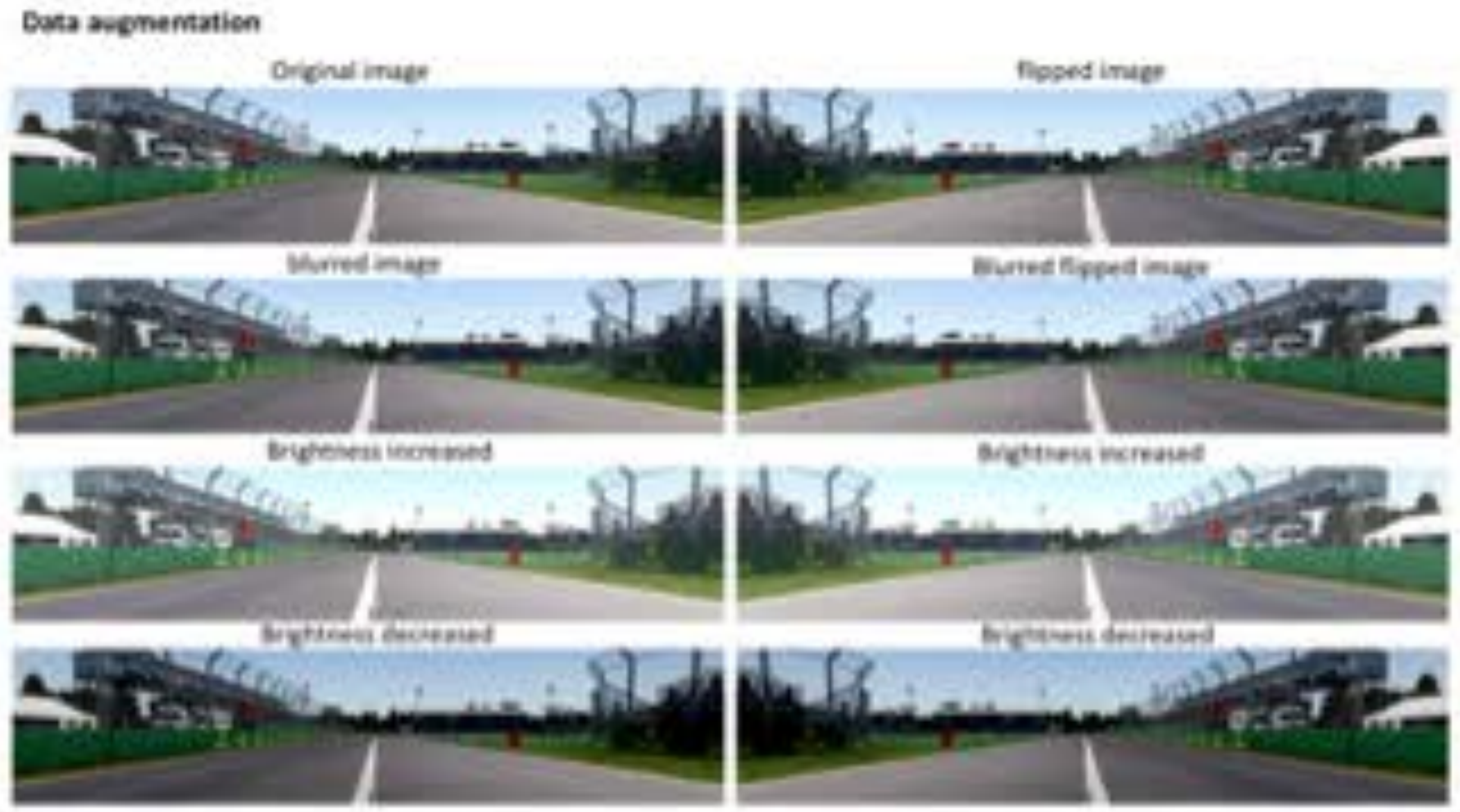
Overtaking Algorithms



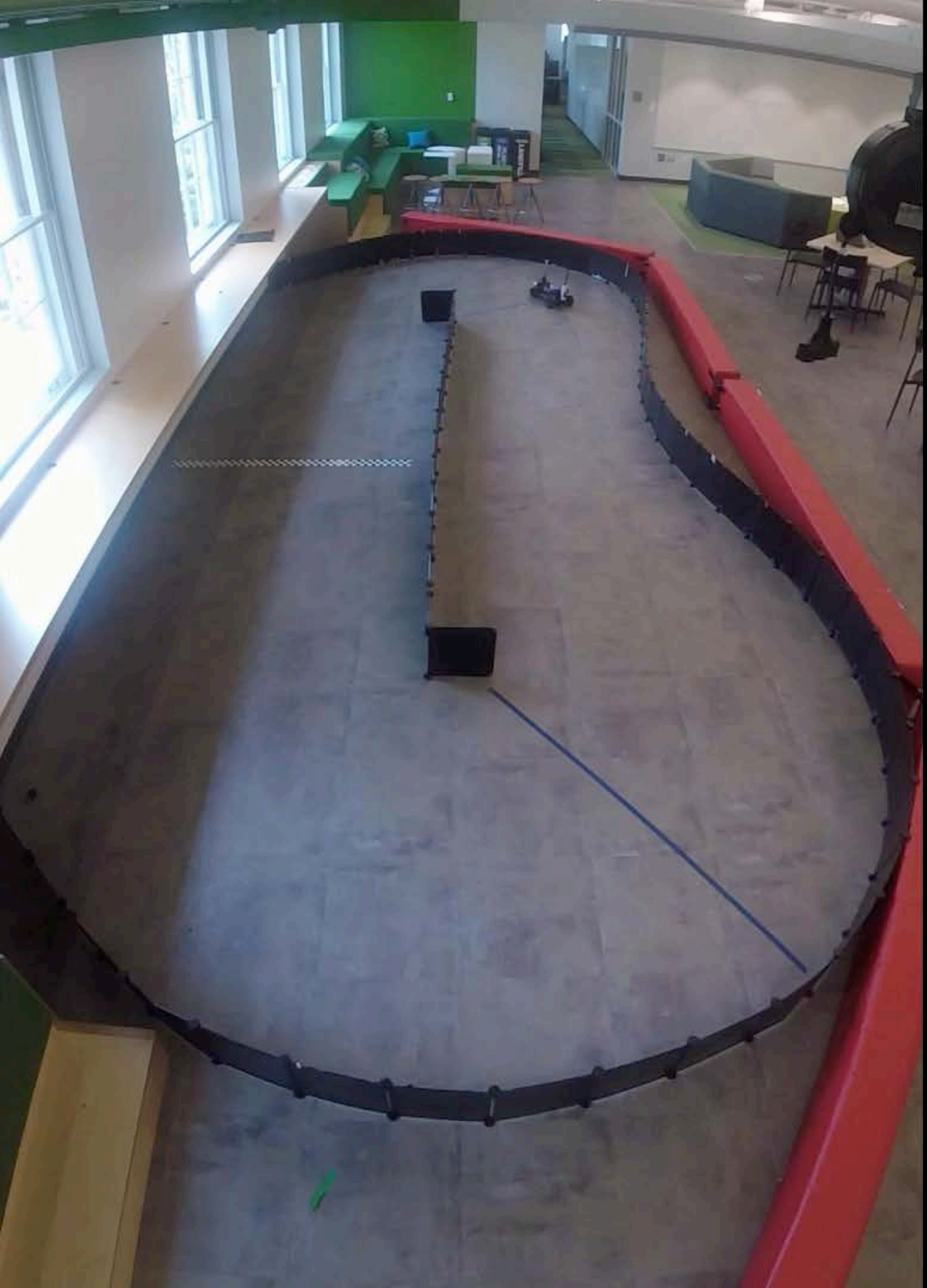

GAME
REAL LIFE
MOTOGAMESTV
Gulf Air
Gulf Air
BOTTAS
SUPER
ROLEX
59.0
8

F1 Game
Steering
Acceleration + Braking
Manual Driving Inputs
GAME
REAL LIFE
MOTOGAMESTV
Racing creates frequent edge cases at high speeds
F1 2017
codemasters
Photorealistic + Accurate Physics
Autonomous Driving Inputs
vjoy virtual joystick
Closed Loop Testing
UDP
UDP stream to log Steering + Accl. i/p
CPP
Synchronized screen capture
Each image is labeled with steering and acceleration data
end-to-end learning
DeepRacing Agile Controller
predicted steering + acceleration





CNN + LSTM – End-to-end driving



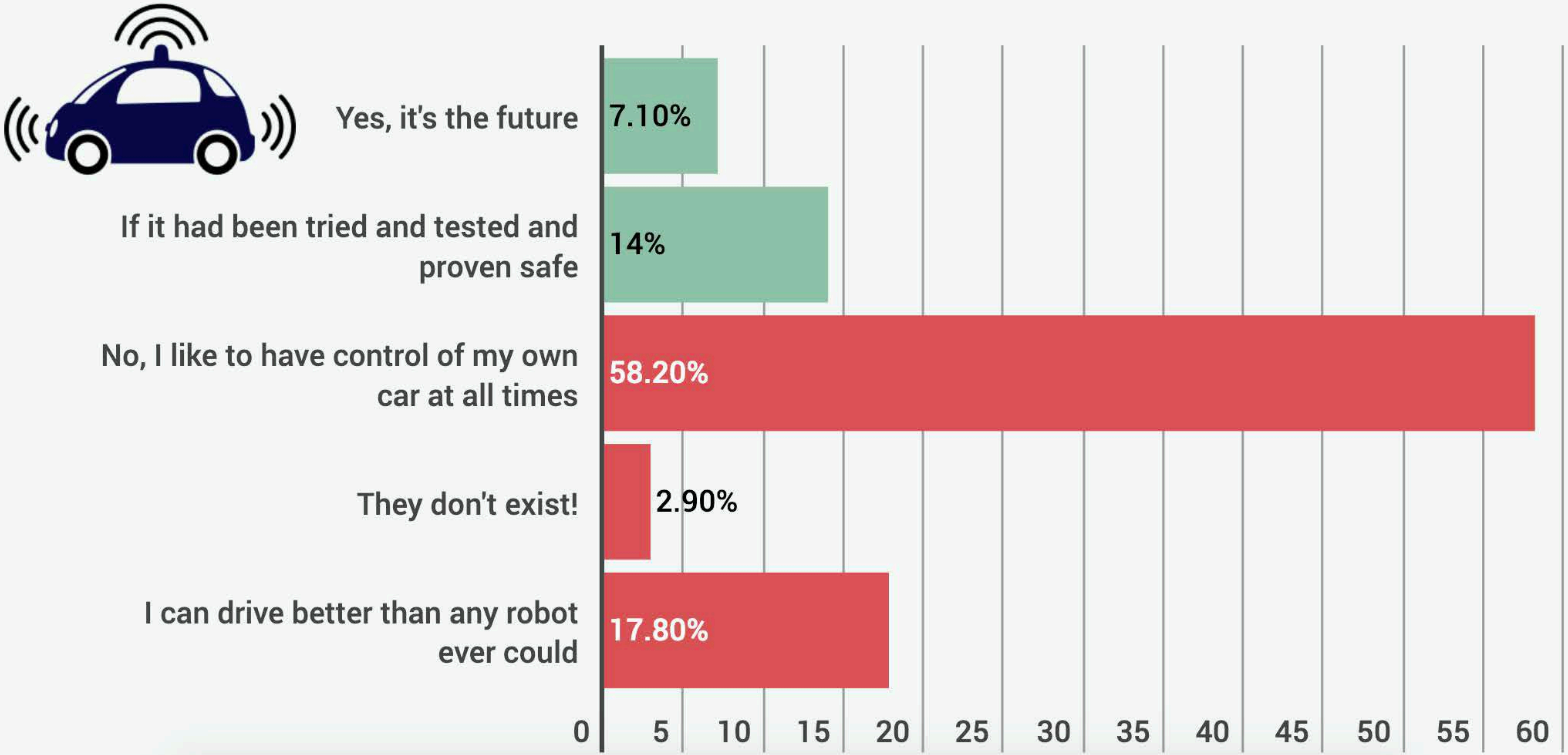
F1/10
FPV
Driving


Autonomous racing in progress !
F1/10
CAUTION


Formula 1
@carlosmsegarra
Predicted:−0.03

980 respondents Jan-June 2018

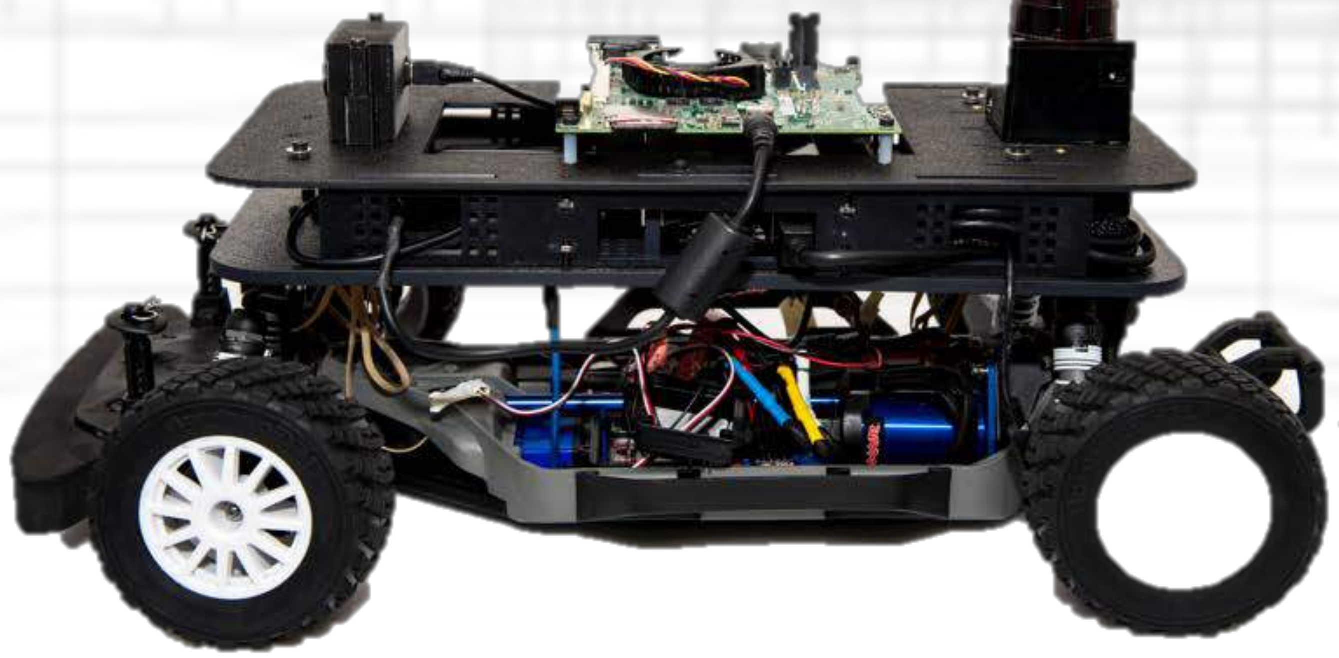
Question: Would you trust an autonomous car? (Self-driving car).

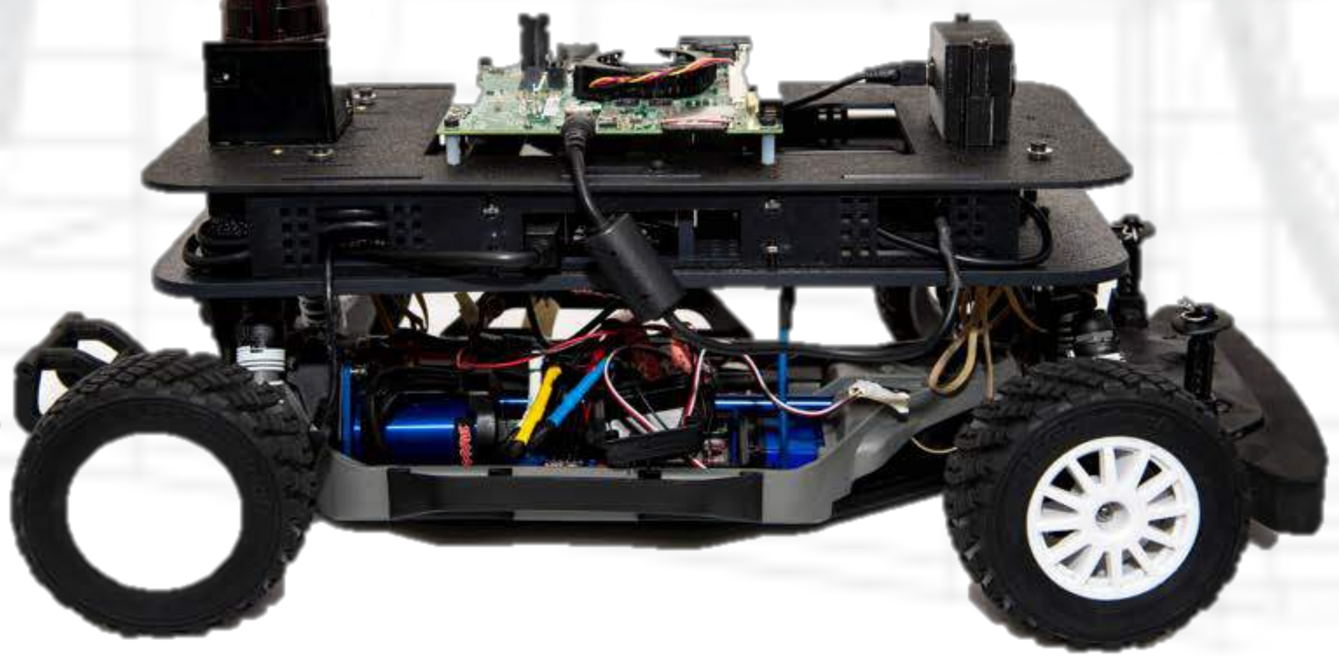


Fun!

F1/10

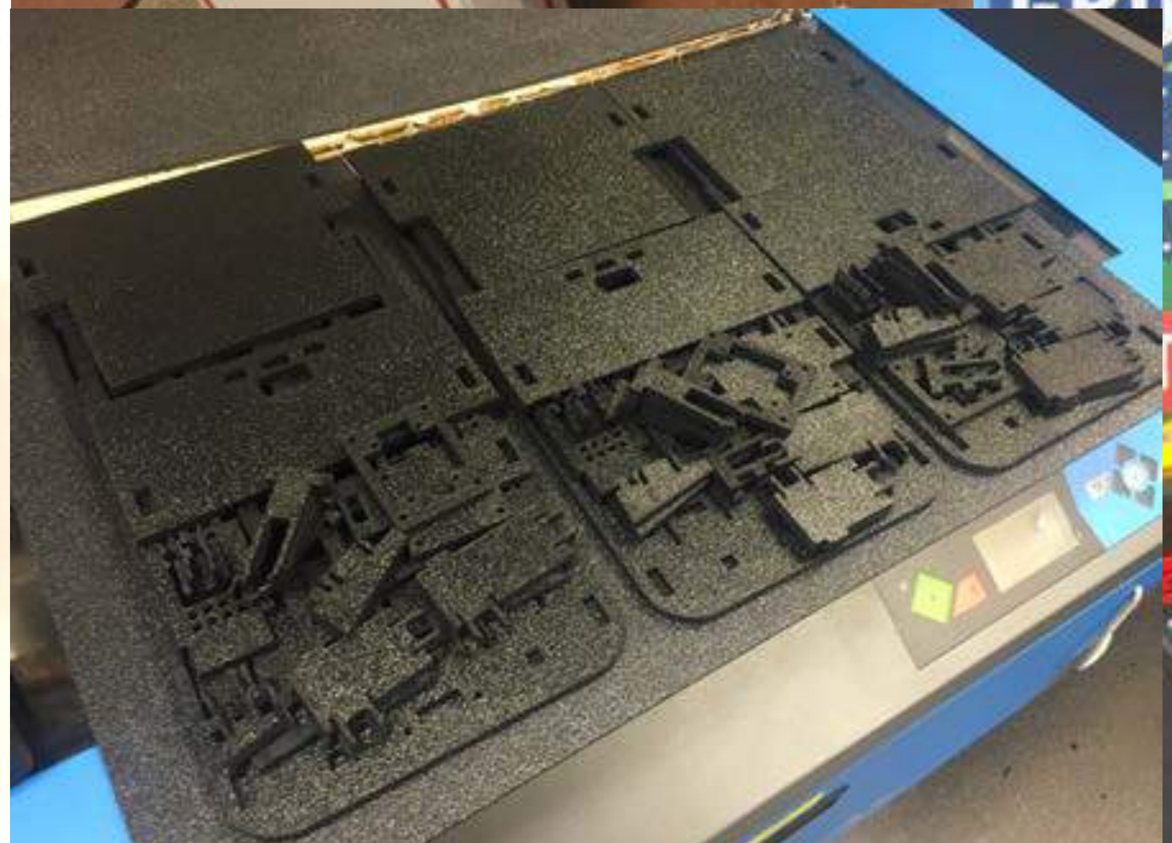
1/10th the scale. 10 times the fun!






Energizer.



GROSSER PREIS VON
PROJEKT-SPIELBERG.COM
TOTAL
Red Bull
TOTAL

2017 Formula One United States GP, October, Austin, TX

No drivers were harmed
during the making of this video.

Questions ?