Automated Vehicles and Mobility Services

Alexander Carballo, Dr.Eng.

Autonomous vehicles and mobility solutions

- Levels of Autonomy
- Smart Cities
- Urban revolution
- Social impact
- Open source autonomous driving

Key Words in Today's Automotive Society

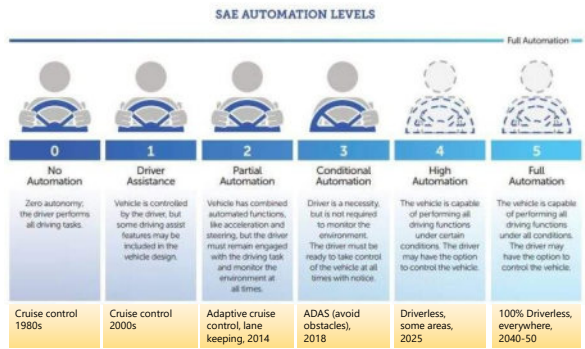
C Connected
A Automated
S Sharing & Service
E Electric Drive

Autonomous Vehicles

Vehicles capable of **perceiving** and **understanding** it's environment to **autonomously navigate** through it.

Uber self-driving car (2017)

Levels of Autonomy



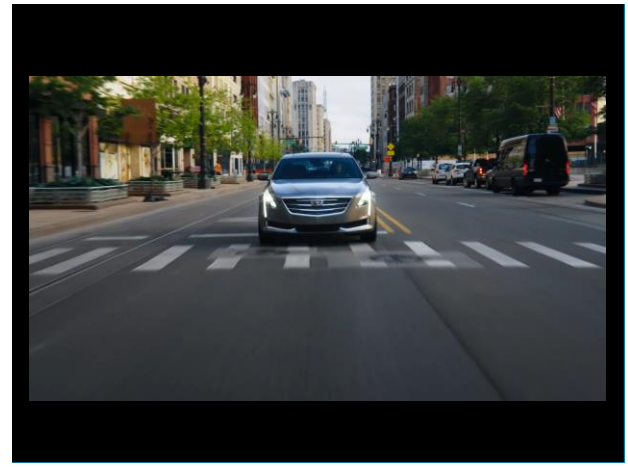
Levels of Autonomy

SAE Level	SAE Name	SAE Narrative Definition	Execution of Steering/ Acceleration/ Deceleration	Monitoring of Driving Environment	Fallback Performance of Dynamic Driving Task	System capability (driving modes)	BASt Level	NTHSA Level
Human Driver monitors the driving environment								
0	No Automation	the full-time performance by the human driver of all aspects of the dynamic driving task	Human Driver	Human Driver	Human Driver	N/A	Driver only	0
1	Driver Assistance	the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration	Human Driver and System	Human Driver	Human Driver	Some Driving Modes	Assisted	1
2	Partial Automation	Part-time or driving mode-dependent execution by one or more driver assistance systems of both steering and acceleration/deceleration. Human driver performs all other aspects of the dynamic driving task	System	Human Driver	Human Driver	Some Driving Modes	Partially Automated	2
Automated driving system ("system") monitors the driving environment								
3	Conditional Automation	driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task - human driver does respond appropriately to a request to intervene	System	System	Human Driver	Some Driving Modes	Highly Automated	3
4	High Automation	driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task - human driver does not respond appropriately to a request to intervene	System	System	System	Some Driving Modes	Fully Automated	3/4
5	Full Automation	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	Some Driving Modes		

Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles. SAE J3016, Sept. 2016.

Level 2: *Hands-off* autonomous driving

- Fully autonomous capabilities for extended periods of time, but requires full attention of the driver.
  - Example: fully autonomous highway driving with absolutely, no safety guarantees, the driver is still responsible.
- Tesla autopilot is certified **SAE-2**;
  - Can fully control the vehicle in some scenarios, i.e. highways.
  - Expects **full driver attention**, i.e. same reaction time as if they were driving the vehicle.



Level 3: Eyes-off autonomous driving

- Fully autonomous capabilities for extended periods of time, where full driver attention is not required.
  - Example: driver can read while the auto-pilot is active.
- 2018 Audi A8 has the first **claimed** level 3 functionality.
  - Traffic Jam Pilot can take over on one directional highways, traffic conditions below 60 km/h.
  - Safe to look away from the road when conditions are met, but must be ready to take over, e.g. when traffic dissolves.

Level 4 & 5: Fully Autonomous Driving

- **Level 4:** Fully autonomous capabilities for extended periods of time, any scenario in **geo-fenced** area.
- **Level 5:** Same as level 4, but any human drive-able area can be negotiated by the autopilot.

Level 4-capable vehicle claimed in testing;

- Tons of startups;
- *Uber, Waymo, nuTonomy, MobileEye* many more
- Tech companies, *Google*
- *Tesla, Toyota, Honda, GM,* most major car companies

apparently will be in the market by 2019/2020.

The Current State of Autonomous Driving

- Three different perspectives:

Marketers

"Level 4 autonomous driving is a solved problem and you can try it now*, level 5 is around the corner."

**safety* not guaranteed

The Current State of Autonomous Driving

- Three different perspectives:

Companies

"Level 4 capable vehicles are now in testing phase and should be available within a few years."

The Current State of Autonomous Driving

- Three different perspectives:

Researchers

"Significant advancements in technology and infrastructure are still required to make *safe* autonomous driving a reality."

Why Autonomous Vehicles and Smart Cities

RANK	CITY	COUNTRY	CONTINENT	PEAK HOURS SPENT IN CONGESTION	INRIX CONGESTION INDEX	AVERAGE CONGESTION RATE
1	Los Angeles; CA	USA	North America	102	18.3	12%
2	Moscow	Russia	Europe	91	20.1	26%
3	New York City; NY	USA	North America	91	17.4	13%
4	Sao Paulo	Brazil	South America	86	16.9	22%
5	San Francisco; CA	USA	North America	79	13.7	12%
6	Bogota	Colombia	South America	75	16.2	30%
7	London	UK	Europe	74	14.1	13%
8	Atlanta; GA	USA	North America	70	12.3	10%
9	Paris	France	Europe	69	13.1	13%
10	Miami; FL	USA	North America	64	11.8	9%
11	Bangkok	Thailand	Asia	64	12.5	23%
12	Jakarta	Indonesia	Asia	63	13.4	20%
13	Washington; DC	USA	North America	63	10.8	11%
14	Boston; MA	USA	North America	60	10.6	14%
15	Istanbul	Turkey	Europe	59	12.2	19%

Source: Numbeo (2017)

Self-Driving Vehicles Revolution

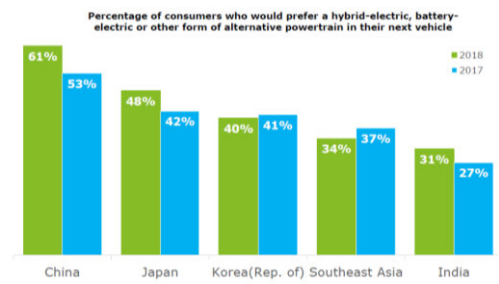
1. **Reducing car density in cities through MaaS**
   - More efficient and frequent public transit
   - Affordable driverless taxi and ride-sharing services
   - Increased availability of parking space
2. **Improve road safety**
   - Reduce number of crashes and fatalities
   - Improve response time
3. **Reduce environmental impact**
   - Increased efficiency of traffic
   - Electric vehicles more practical for self-driving applications

Smart Cities in ASEAN

- South East Asian countries have the worst traffic conditions in the world; test case for **smart cities**

Difficulties to Implementing New Transportation

- 4 important factors: technology, infrastructure, Policy and **consumer acceptance**



Transitioning to Smart Cities

- Lawmakers control policy

Overall rank	Country	Total score	Policy and legislation		Technology & innovation		Infrastructure		Consumer acceptance	
			Rank	Score	Rank	Score	Rank	Score	Rank	Score
1	The Netherlands	27.73	3	7.89	4	5.46	1	7.89	2	6.49
2	Singapore	26.08	1	8.49	8	4.26	2	6.72	1	6.63
3	United States	24.75	10	6.38	1	6.97	7	5.84	4	5.56
4	Sweden	24.73	8	6.83	2	6.44	6	6.04	6	5.41
5	United Kingdom	23.99	4	7.55	5	5.28	10	5.31	3	5.84
6	Germany	22.74	5	7.33	3	6.15	12	5.17	12	4.09
7	Canada	22.61	7	7.12	6	4.97	11	5.22	7	5.30
8	United Arab Emirates	20.89	6	7.26	14	2.71	5	6.12	8	4.79
9	New Zealand	20.75	2	7.92	12	3.26	16	4.14	5	5.43
10	South Korea	20.71	14	5.78	9	4.24	4	6.32	11	4.38
11	Japan	20.28	12	5.93	7	4.79	3	6.55	16	3.01
12	Austria	20.00	9	6.73	11	3.69	8	5.66	13	3.91
13	France	19.44	13	5.92	10	4.03	13	4.94	10	4.55
14	Australia	19.40	11	6.01	13	3.18	9	5.43	9	4.78
15	Spain	14.58	15	4.95	16	2.21	14	4.69	17	2.72
16	China	13.94	16	4.38	15	2.25	15	4.18	15	3.13
17	Brazil	7.17	20	0.93	18	0.86	19	1.89	14	3.49
18	Russia	7.09	17	2.58	20	0.52	20	1.64	18	2.35
19	Mexico	6.51	19	1.16	17	1.01	17	2.34	19	2.00
20	India	6.14	18	1.41	19	0.54	18	2.28	20	1.91

Transitioning to Smart Cities

- Infrastructure needs to be in place

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6	Germany	22.74	5	733	3	6.15	12	5.17	12	4.09
7	Canada	22.61	7	712	6	4.97	11	5.22	7	5.30
8	United Arab Emirates	20.89	6	726	14	2.71	5	6.12	8	4.79
9	New Zealand	20.75	2	792	12	3.26	16	4.14	5	5.43
10	South Korea	20.71	14	5.78	9	4.24	4	6.32	11	4.38
11	Japan	20.28	12	5.93	7	4.79	3	6.55	16	3.01
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Transitioning to Smart Cities

- **Our responsibility is technology and innovation**

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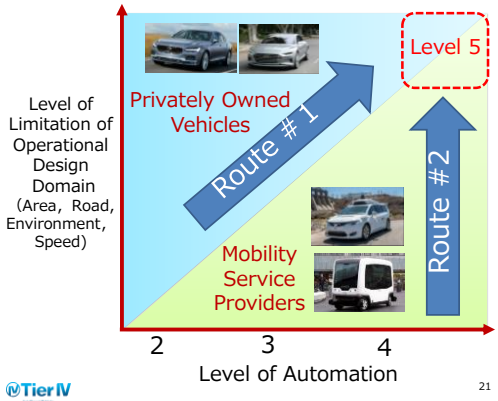
Achieving Level 5 : Two Routes



Current Status of Each Route

Route #1: Audi A-8

Vehicle with Level 3 Automation

Route #2 : Toyota e-Palette

TOYOTA will be Mobility Service Company.

Route #2: VolksWagen CEDRIC

As are VW, Daimler, GM, Ford‥

Route #2: Waymo's Robot Taxi

Driverless Autonomous Driving Trials

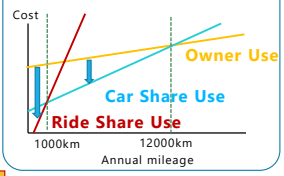
Urban Traffic Revolution through CASE

Efficiency

Traffic Efficiency
- No Traffic Jam,
- Small Emission,
- Reduced Collisions

Land & Vehicles utilization
- Higher Road Usage Efficiency
- Fewer Parking Area

Economy

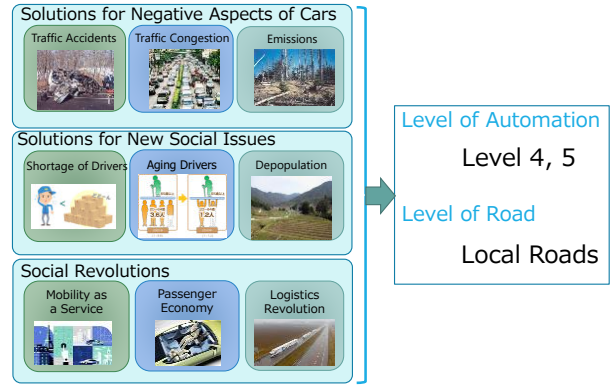


Source: "Mobility Revolution", Droit Tohmatsu

Ratio of Owner Vehicles to Shared Vehicles: 50/50 by 2030)
Mobility as a Service (MaaS)

Source: "Mobility Revolution", Droit Tohmatsu

Social Impacts of CASE Automated Vehicles



Issues for Developing Automated Vehicles

Wide Application Areas & Difference of Traffic Rules / Manners

Passenger Vehicles

Level.2→3→4
Highways, Main Roads

Logistics Vehicles

Level.2→3→4
Highways, Main Roads

MaaS Vehicles

Level.4 (Remote Level.3)
Urban, Local Area

Other Categories

Indoor Factory Agriculture Mine Construction Road Maintenance

Wide Technology Areas

AI & Data Science Robotics Sensors
Vehicular Technologies
Communications & Networks Computer Software & Hardware

Our Solution for Developing Automated Vehicles

Wide Application Areas & Difference of Traffic Rules / Manners

Wide Technology Areas

Even big OEMs, suppliers and IT companies find it difficult to develop whole systems by themselves.

How can universities and research institutes contribute to this development ?

Using an Open Platform is one possible solution:
To Accelerate Innovation
To Sustain Mutual Benefits

Sensors

GNSS

LIDAR

Cameras

RADAR

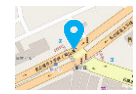
Autonomous driving - tasks

- Localization
  Where are we?
- Object detection
  What is around us?
- Driving control
  Path planning
  Physical driving of the vehicle

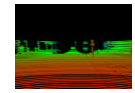
Sensor technologies

- GNSS – **G**lobal **N**avigation **S**atellite **S**ystem
  GPS, GLONASS, BeiDou, etc
  For localization
- LIDAR – **Li**ght **D**etection **A**nd **R**anging
  Perception, localization, object detection
- Cameras
  Perception, localization, object detection
- RADAR - **Ra**dio **D**etection **A**nd **R**anging
  Perception, object detection

Sensor data



GNSS
Single position estimate
~10Hz



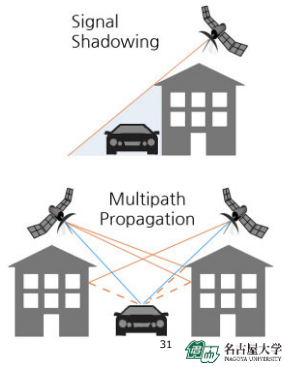
LIDAR
Semi-dense 3D point cloud
~10Hz

Camera
High resolution image
~30Hz

RADAR
Very sparse depth objects
~5Hz

GNSS positioning systems

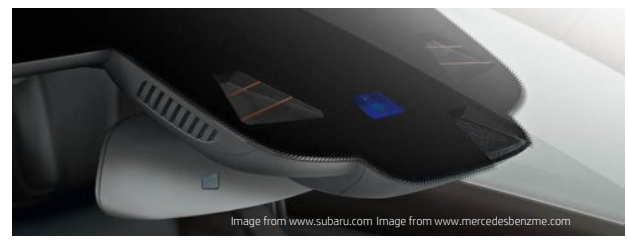
- Passive location estimation
  Relies on satellite signal
  Signal shadowing and multipath propagation
- Average errors often exceed 5 meters



LIDAR - Velodyne

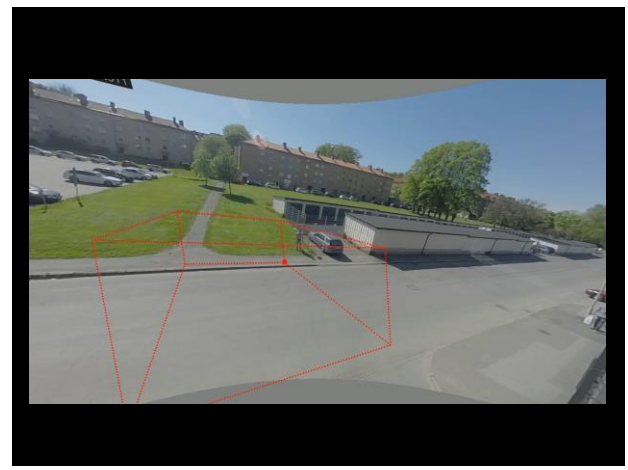
In-vehicle cameras

- Already in many production vehicles
- Used for drive recording, lane following, pedestrian detection systems
- Large amount of data



RADAR

- Already in many production vehicles
  Used for parking assistance, automated braking
- Low resolution, low range
- Also measure object speed from Doppler effect
- Unobtrusive (bumper mounted)



Which sensors for which tasks?

Localization

GNSS	LIDAR	RADAR? Camera?
- Initialization - Rural localization	- Precise (~10cm) positioning	

Perception

LIDAR	Camera	RADAR
- Object detection - 3D tracking	- Object detection - Classification	- 3D tracking

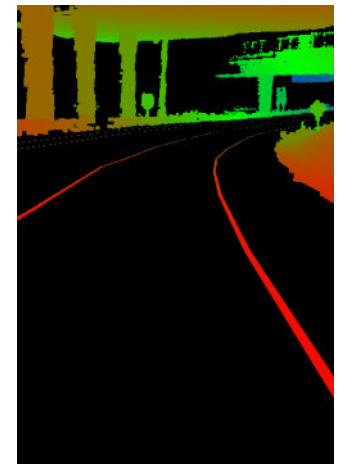
Fusion?

Open source autonomous driving

ROS

Autoware

Apollo



Why open source?

Development by the community
Progress for everybody!

Removing the need to reinvent the wheel

Common tasks such as device drivers don't require re-implementation

Cutting-edge methods can be quickly added and tested by everyone

Research on a specific element of autonomous driving can be carried out without building a whole framework

Pre-requisites

1. Linux operating system
   - Nearly all development on Ubuntu 16.04
2. Robotic Operating System (ROS)
   - Tools an libraries for robotics applications
   - An ecosystem which provides a backbone for various modules to connect and communicate to one another

Robotic Operating System (ROS)

- Currently on 12th official release (ROS Melodic Morenia)
- Created to encourage *collaborative* robotics projects
- Provides a **core** for different modules to pass information

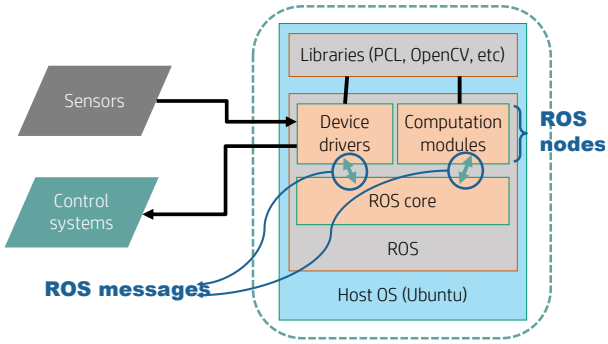
Getting started with ROS

- Huge amount of documentation and tutorials

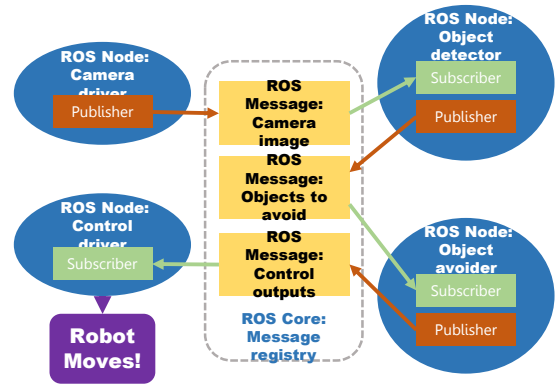
  http://www.ros.org

- Pre-built Debian packages make install simple
- C++ and Python for making new modules

ROS system overview



ROS messaging system



Autonomous driving frameworks

AutoWare

Nagoya University TierIV
Current release: 1.10
https://autoware.ai/

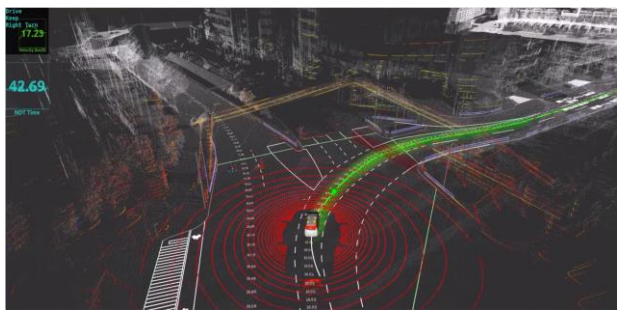
apollo

Baidu
Current release: 3.5
http://apollo.auto

Platform comparison

AutoWare	apollo
Uses standard ROS Kinetic	Custom ROS (Apollo Platform)
Docker or native build/install	Docker only
Runtime manager + RViz	Web interface - Dreamview

Autoware : Open-Source Software for Automated Driving



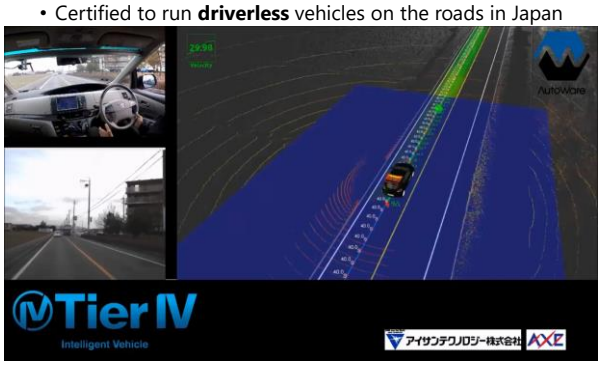
Autoware Community

Autoware.AI, GitHub project has 2400+ stars, 1100+ forks,
60+ contributers; Slack group has 500+ members.

- **International**: 20+ different countries
- **Widespread adoption**: used in 100+ companies
- **Flexible**: used on 30+ different types of vehicles
- **Used in Education**: *Autoware Academy* currently offering courses in 5 countries and expanding
- Used by OEMs for mobility as a service development

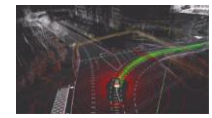
Autoware Projects

- Certified to run **driverless** vehicles on the roads in Japan



Autoware Projects

- **Autoware.AI**
  - Original, fully open-source project on GitHub built on ROS1.
  - Platform for any and all researchers to implement and test.
- **Autoware.IO**
  - Project interfacing Autoware with third-party hardware.
  - Includes sensor drivers, drive-by-wire controllers, SoC support.
- **Autoware.Auto**
  - Autoware.AI *best-of* project, supported by software managers implemented to industry standards.



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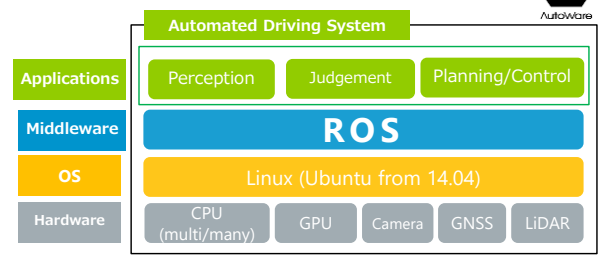
https://github.com/CPFL/Autoware



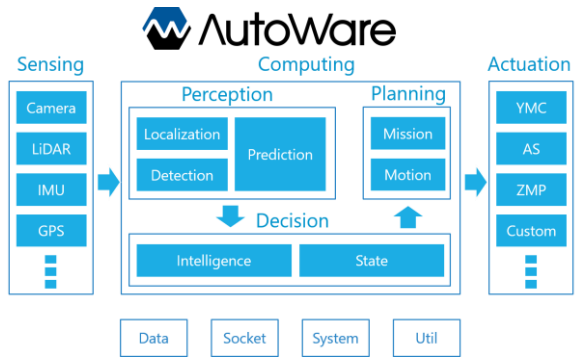
Autoware : Open-Source Software for Automated Driving

https://github.com/cpfl/autoware

⇒ **800 Users** Industries>100, Universities>30



Autoware : Open-Source Software for Automated Driving



Autoware demo

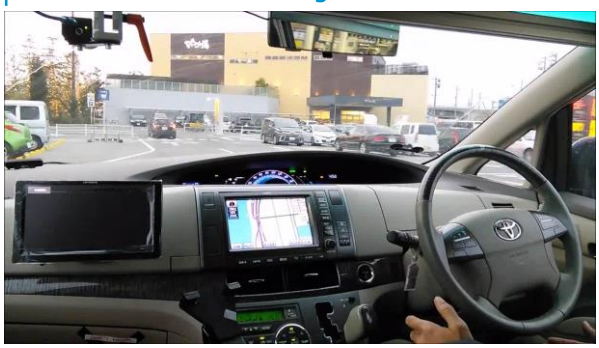
2015: First Automated Driving Trial on Public Roads

Jan. 2015: First Autonomous Driving Trial on a Public Road in Nagoya Japan

In Dec. 2015. Asoc. Prof. Kato and 3 other Professors founded Tier IV, Inc.

2016 : Automated Driving Trial on Public Roads

2017 : Automated Driving Trial on Public Roads



2018: Automated Driving Trial on Public Roads

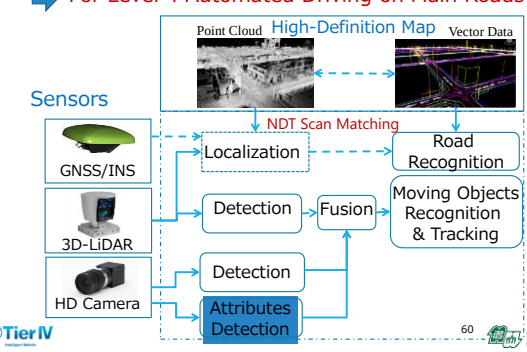
Collaboration with Japan Post

Autoware Automated Driving Target

	Tesla Autopilot / Nissan Propilot	Yamaha Cart / IMTS	Low speed / EasyMile	Autoware / Google(Waymo)
Level of Automation	SAE Level 2 Driver Assist	SAE Level 4~ Driverless		
Level of road	Highways	Main roads		
Infrastructure Physical Infra Digital Infra	None	Induction cable Magnetic markers	(Magnetic Markers) 2D Map	3D HD Map
Sensors Localization Obstacle Detection	Camera	RF/Magnet Sensor Camera LiDAR	GNSS/INS Camera LiDAR	3D-LiDAR Camera GNSS/INS

Standard Perception Flow of Autoware

- ○Sensor Fusion (3D-LiDARs, Cameras)
- ○High-Precision Map
  - For Level 4 Automated Driving on Main Roads



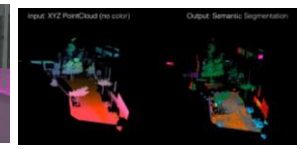
Digital Infrastructure (High Definition Road Map)

Supports State-of-the-Arts DNN-based Recognition

Image Recognition (YOLO2)

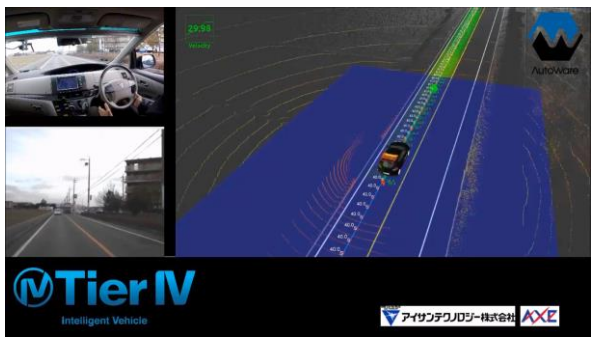
Image Recognition (SSD)

Image based Semantic Segmentation

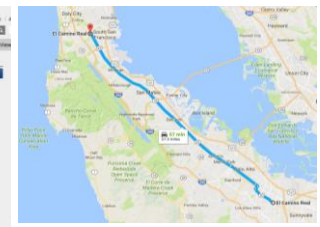


LiDAR based Semantic Segmentation

Supports Several Path Planning Algorithms



World-Wide Collaboration

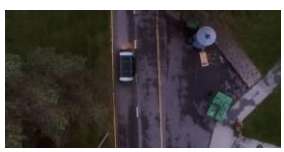


A TierIV autonomous vehicle traveled 31 miles along the Bay Area's El Camino Real, through 140 traffic signals and crosswalks during regular traffic over a period of an hour and a half.

World-wide Collaboration

USA (Silicon Valley)

China（Guiyang）



EU (Estonia)

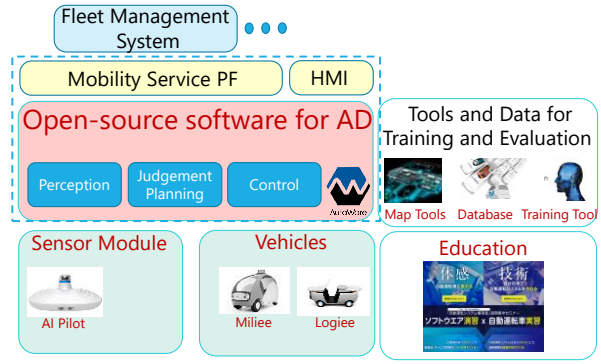
Taiwan（NCK）

Supports Remote Surveillance and Control

Supports Wide Variety of Computer Hardware

Automotive Spec. PC : NVIDIA DrivePX2

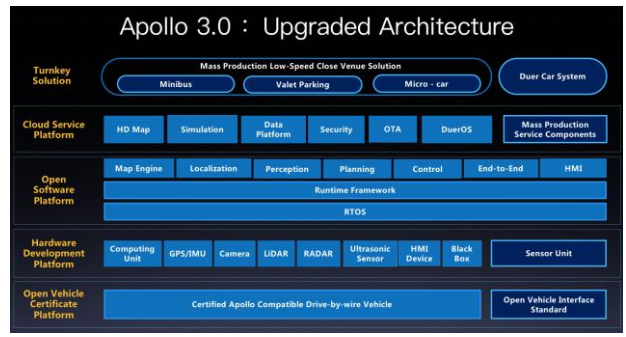
Open Platform for Automated Driving



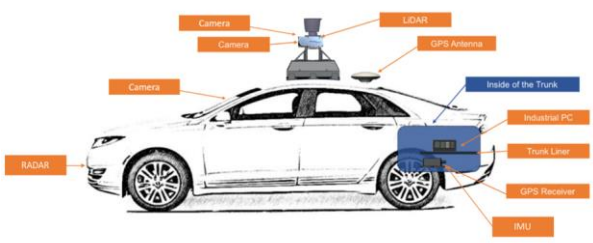
Baidu's Apollo

- A project started by the Chinese company Baidu
- Industry support still offered by Baidu
- Is supplied as a docker with custom ROS:
  - Drivers for (some) sensors used in autonomous driving
  - 3D mapping and localization with LIDAR
  - LIDAR and camera-based object detection and tracking
  - Traffic light recognition
  - Vehicle control

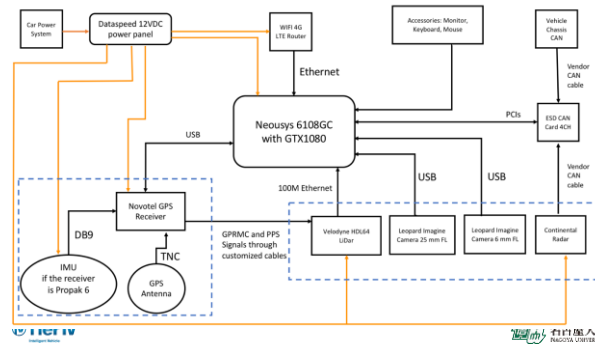
Baidu's Apollo



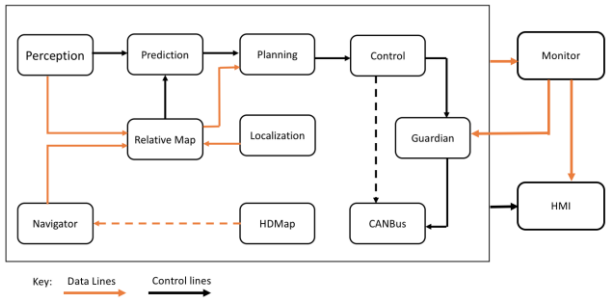
Baidu's Apollo



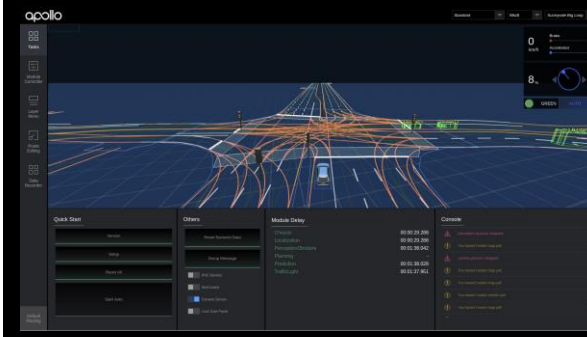
Baidu's Apollo



Baidu's Apollo



Apollo demo



Closing

Autoware or Apollo?

Conclusion

Autoware or Apollo?

Autoware

- Closer to standard ROS, giving flexibility and ease of extension
- Wider variety of supported hardware
- Less polished in some areas i.e. web interface

Apollo

- Designed for specific hardware
- Much steeper learning curve for development and extension
- Fairly complete and solid implementation (on specific hardware)

Conclusion

- Autonomous driving
  True driverless cars are on their way!
- Open source software for autonomous driving
  Allows open development and contribution
  Collaboration helps foster research
- Autoware or Apollo?
  Choose based on your available hardware and goals

Thanks you for kind attention!