Self-driving (Autonomous) Cars
When we should trust them

Information, Decisions & Networks
DemosFest
Ann Arbor, MI
July 28-29, 2016
Manju Hegde,
CEO, Uhnder
Why should we trust self-driving cars?

Whew!
When?

- CEO of Nissan: driverless cars would be in showrooms by 2020

- Jaguar Land Rover: fully-autonomous driving modes in its cars in the next decade

- Elon Musk: fully autonomous Teslas to be on the roads by 2023

- Daimler: autonomous trucks available to purchase around 2025

- Chris Urmson, head of Google’s self-driving car: “My older son is 12 years old. In four years, he gets a driver’s license. We don’t want him to have to.”
Autonomous < = > NHTSA Level 4 Driving

• **Level 0**: The driver completely controls the vehicle at all times

• **Level 1**: Individual vehicle controls are automated, such as electronic stability control or automatic braking

• **Level 2**: At least two controls can be automated in unison, such as adaptive cruise control and lane keeping

• **Level 3**: The driver can fully cede control of all safety-critical functions in certain conditions. The car senses when conditions require the driver to retake control and provides a "sufficiently comfortable transition time" for the driver to do so.

• **Level 4**: The vehicle performs all safety-critical functions for the entire trip, with the driver not expected to control the vehicle at any time. As this vehicle would control all functions from start to stop, including all parking functions, it could include unoccupied cars.
Advanced Driver Assistance Systems (ADAS)

- Systems *incrementally* approaching self-driving (autonomous) cars
Benefits and Functionality

• Reduction of driver errors
• Comfort to the drivers
• Efficiency in traffic & transport
• Economical cost & pollution
Antilock Braking System (ABS)

- Antilock braking system mainly known as ABS. Basically it allows the wheels to maintain traction control with the road surface while braking (emergency braking) and prevents the wheels from locking up and avoid uncontrolled skidding.
Adaptive Cruise Control (ACC) uses forward looking radar and maintains the safe distance from the car ahead. It is designed to avoid accidents by keeping your vehicle at a safe distance from the traffic ahead.
A blind spot monitor detects other vehicles located in the blind spot areas such as side and rear, however it detects other areas as well. Also the system provides audible and visual sign to backing out of a parking space.
Driver drowsiness detection is another car safety technology that designed to prevent accidents when the driver is getting drowsy and often fails to recognize early enough.
Electronic Stability Control

Electronic stability control (known as ESC) improves a vehicle stability control by reducing loss of traction or skidding. When ESC detects loss of steering control, automatically applies the brakes to help steer the vehicle.
Hill Descent Control

- Hill descent control allows a smooth and controlled hill descent without the driver needing to touch the brake pedal. It works with the ABS to control each wheel speed and automatically applies brakes to avoid skidding.
The Intelligent speed assistance system constantly monitors vehicle speed and local speed limits on the road and control the speed if the vehicle is detected to exceeding the speed limit.
Lane Departure Warning/Lane Assist systems

- Lane departure warning system is designed to warn a driver when the vehicle begins to move out of its lane especially on 70mph motorways.
If the pedestrian and car are in the same lane then the car warns driver or automatically start braking to avoid collision and minimize the accident.
Traffic sign recognition (TSR) system detects the road signs such as school, turn ahead, speed limit etc., and notify or warn the driver by displaying them.
Rear Cross Traffic Alert

- Rear Cross Traffic uses the same senses of blind spot detect system, designed to reduce the chance of accident and injury happened while the reversing out of a parking space.
Automatic Emergency Braking (AEB)  
*Killer Application*

• 33,000 people die each year in the US in automotive fatalities; worldwide 1.2 million per year
  • Estimated that around 93% of those are caused by human error

• AEB *required* by NCAP in Europe for five-star rating

• In March 2016, U.S. DOT announced historic commitment of 20 automakers to make automatic emergency braking standard on new vehicles
Multiple Sensors

Sensor Cocoon
To enable ADAS features
Global Advanced Driver Assistance Systems (ADAS) Market to Exceed US$90 Billion by 2020-- ABI Research

Global Advanced Driver Assistance Systems Market

Global Advanced Driver Assistance Systems Market is expected to reach $50.14 Billion by 2020

Growing at a CAGR of 22.8% (2014-2020)

Global Advanced Driver Assistance Systems Market By Sensor Type

- Ultrasonic Sensor
- Infrared (IR) Sensor
- Radar Sensor
- Image Sensor
- LiDAR Sensor
- LASER Sensor

Global Advanced Driver Assistance Systems Market By Geography

- North America
- Europe
- APAC
- LAMEA

Europe is expected to be highest revenue generating region by 2020

Top Impacting Factors

- Increasing focus on safety
- Increasing Demand for comfort driving
- Multifunctional system
- Safety regulations
- Increasing per capita income

Top Impacting Factors: Complexity and cost pressure

2013 2020

For More Details See Table of Contents

July 28, 2016
% Electronics in a Car is increasing

“80% percent of innovation is electronic”

“Impossible to comply with regulation without electronic systems”

-Automotive OEM

Advanced Driver Assistance
Active-Passive Safety
Green Powertrain
Radar / Vision
Telematics
Infotainment

Electronic cost as % of total car cost

2.5% 5% 10% 15% 22% 30% 35% 50%

Fuel Injection
Electronic

July 28, 2016
# Self-driving cars: benefits and costs

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Reduced driver stress.</em> Reduce the stress of driving and allow motorists to rest and work while traveling.</td>
<td><em>Increases costs.</em> Additional equipment, services and maintenance, and possibly roadway infrastructure</td>
</tr>
<tr>
<td><em>Reduced driver costs.</em> Reduce costs of paid drivers for taxis and commercial transport</td>
<td><em>Additional risks.</em> May introduce new system failures, be less safe under certain conditions, and encourage road users to take additional risks</td>
</tr>
<tr>
<td><em>Mobility for non-drivers.</em> Provide independent mobility for non-drivers, and therefore reduce the need for motorists to chauffeur non-drivers, and to subsidize public transit</td>
<td><em>Security and Privacy concerns.</em> May be used for criminal and terrorist activities (such as bomb delivery), vulnerable to information abuse (hacking), and GPS tracking and data sharing may raise privacy concerns</td>
</tr>
<tr>
<td><em>Increased safety.</em> May reduce many common accident risks and therefore crash costs and insurance premiums. May reduce high-risk driving, such as when impaired.</td>
<td><em>Induced vehicle travel and increased external costs.</em> Autonomous vehicles may induce additional vehicle travel, increasing external costs of parking, crashes and pollution.</td>
</tr>
<tr>
<td><em>Increased road capacity, reduced costs.</em> May allow platooning (vehicle groups traveling close together), narrower lanes, and reduced intersection stops, reducing congestion and roadway costs</td>
<td><em>Social equity concerns.</em> May have unfair impacts, for example, by reducing other modes’ convenience and safety.</td>
</tr>
<tr>
<td><em>More efficient parking, reduced costs.</em> Can drop off passengers and find a parking space, increasing motorist convenience and reducing total parking costs.</td>
<td><em>Reduced employment and business activity.</em> Jobs for drivers should decline, and there may be less demand for vehicle repairs due to reduced crash rates.</td>
</tr>
<tr>
<td><em>Supports shared vehicles.</em> Could facilitate carsharing (vehicle rental services that substitute for personal vehicle ownership), which can provide various savings</td>
<td><em>Misplaced planning emphasis.</em> May discourage communities from implementing conventional but cost-effective transport projects such as pedestrian and transit improvements, pricing reforms</td>
</tr>
</tbody>
</table>
Google

• Going straight to Level 4 autonomous driving

• Use of 1 Lidar, 1 GPS, 4-Radar (3 in front and 1 in the rear), 1 forward facing camera, tire rotation monitor, IMU, Internet and high resolution map data

• Currently has 1.5 million miles of autonomous test driving
  • ~50 cars that are registered to drive
  • Typically doing about 8800 miles per year per car

• Have announced a collaboration with FCA
Incumbents -- Incremental

- **Bosch**
  - 1 Lidar, stereo cameras, 2 radars, 1 forward and and 1 rear LR Radar/MR Radar, IMU, GPS, and ultrasonics

- **Delphi**
  - 6 Lidars, 6 LR Radars, 4 SR Radars, 3 vision cameras, and GPS
  - Drove across the US last year

- **Nissan**
  - 12 cameras, 5 Radars, a Lidar

- **Ford**
  - 4 Lidar, 5 Radar, Camera(s), GPS, and ultrasonics

- **Audi**
  - Multiple cameras, 3 radars, 2 long-range radar sensors in the headlights, and !midrange radar doing blindspot detection, ultrasonic sensors around the car
Incumbents -- Incremental

• GM
  • One camera, three radars, multiple ultrasonics
  • Collaborating with and invested in Lyft, bought Cruise Automation

• Daimler
  • Have tested self driving trucks and cars
  • Radar, Lidar, Vision, Ultrasonics

• Volvo
  • A number of Laser scanners, Radar, ultrasonics
  • Announced to be available on the XC70 in 2017
Tesla: Incremental

- Small internal fleet of cars 6 months prior to integrating into Model S in September 2014
- Integrated HW functionality in all Model S -- customers to pay an upgrade fee to enable autopilot
  - Autopilot was released in October 2015
  - Prior to the enablement of the Autopilot, system was gathering data for training
  - 1.5 million miles being collected per day have been mentioned and a total of 140 million driving miles
- HW: 1 Vision camera, 12 Ultrasonics (specced at 5 meters & 50 miles an hour, Elon has said its 15 meters and unlimited speed), 1 LRR radar, differential GPS over cell phone towers with IMU, Mobileye processor, Domain controller with Deep Learning, internet, optional map to help lane keeping in inclement weather
- Next generation HW functionality will be included in 2016
  - Will include 8 cameras (3 forward, 4 corner & 1 rear), 12 ultrasonics, 1 LRR radar, differential GPS over cell phone towers with IMU, redundant processing and networking (no LIDAR)
Uber

- Going straight to Level 4 to eliminate the driver from the loop
- Has ~105 employees in the advanced development team in Pittsburg
- Has been seen driving around Pittsburg with multiple cameras and spinning Lidar
  - Closely interwoven with CMU
Tesla’s Self Driving Car

' 2016 TESLA Model S P90D ' Test Drive & Review /// Autobahn / City / Country /// - TheGetaways
Google’s Self Driving Car
Bosch’s Self Driving Car

BMW Self Driving Car by Bosch! BMW Driverless Car BMW Autonomous Car CARJAM TV 2016
Ford’s Self Driving Car

Ford’s Self-Driving Car Takes To The Road
Audi’s Self Driving Car

Audi Self Driving Car A9 Highway Demo A7 Audi Piloted Driving How It Works CARJAM TV HD 2016
Audi’s Self Driving Car
Delphi’s Self Driving Car

Delphi’s self-driving car is boring in the best way possible – CES 2016
Volvo’s Self Driving Car

Here's an early look at Volvo's self-driving car, due to hit the streets in 2017.

AUTONOMOUS PARKING
GM’s Self Driving Car

General Motors: Super Cruise press kit
Mercedes’ Self Driving Truck
Nissan’s Self Driving Car
Nissan’s Self Driving Car
Audi’s Self Driving RACE Car
Trusting “self-driving cars”

• People trust technology very quickly

• Google drivers sign contracts that they will stay engaged 100%
  • Quickly distracted

• Tesla drivers with Autopilot do amazingly foolish things

• Level 3: The car senses when conditions require the driver to retake control and provides a "sufficiently comfortable transition time" for the driver to do so.
  • Difficult for human drivers to switch context
Reality of Autonomous

- Google self-driving cars disengage every 5318 miles (year before, it was every 785 miles), Delphi had disengagement every 40 miles, Nissan had disengagement every 14 miles, Mercedes every 1.5 miles, Bosch every .75 miles!

- Tesla is the most advanced for Level 3
  - Collecting millions of miles daily – Just announced that they have 780 M miles of sensor data!

  - Property + Injury Crash rate: 488,120 miles per incident
  - Injury crash rate: 1,668,000 miles per incident
  - Fatality crash rate: 88,500,000 miles per incident

- So for maintaining just property/injury crash rate, autonomous cars will need a disengagement of no more than every 500,000 miles and perhaps a larger margin than just the same (say) 10X. That is 3 orders of magnitude off (~2,500x -- 5,000x)

- Amount of driving data will be a gate in rolling out functionality
Danger of Rush to Self-Driving

• First fatal “self-driving” accident (Tesla with Autopilot on)
Self-driving tasks

Self-driving cars constantly need to answer these questions

• **Where am I?**
  • The car processes both map and sensor information to determine where it is in the world. Knows what street it's on and which lane it's in

• **What’s around me?**
  • Sensors help detect objects all around. The software classifies objects based on their size, shape and movement pattern

• **What will happen next?**
  • The software predicts what all the objects around might do next

• **What should I do?**
  • The software then chooses a safe speed and trajectory for the car
Self-driving Technologies

• **Where am I?**
  • Mapping, calibration, localization, registration, data management

• **What’s around me?**
  • Sensing, detection, classification, data association, sensor fusion, data management

• **What will happen next?**
  • Tracking, filtering, prediction, sensor fusion

• **What should I do?**
  • Policy learning, deep learning, control, actuation

All with Functional safety, robustness, security........
Multi-Level Fusion
Multi-Level Fusion Benefits

• Improves reliability and safety
  • Major reduction in false-positive rate, as compared to single sensor only

• Improves detection performance
  • Better range & radial velocity
  • Poor visibility performance

• Reduces computation load

• Improves security
Multi-Level Fusion Synergies

• Between Radar and Vision
  • Speed, efficiency, robustness and inference

• Between Lidar and Vision
  • Speed, inference

• Between Radar and Lidar
  • Speed, efficiency, robustness
Multi-Level Fusion: Radar and Vision

- Radar is naturally better at identifying presence of potential targets, range determination and resolution, at radial velocity determination and resolution, in robustness to weather and in field of view.
- Vision is better at classification of objects, in angle resolution, tangential velocity, in lane detection, sign identification.
- Following key example scenarios show benefit of Multi-Level Fusion:
  - **Radar** identifies a group of potential targets at a distance and **Vision** then classifies them into pedestrian separation.
  - **Vision** identifies a traffic sign (“School”), **Radar** enters a mode to identify small objects rapidly (kids on bicycles) and the Vision system is brought to bear to classify.
  - **Vision/Radar** identifies bad weather and more work is handed off to **Radar** in all fusion algorithms.
  - **Radar** uses micro-Doppler to sense slow moving targets and improve **Vision** acquisition of hard to see targets for Vulnerable Road Users.
  - **Radar** uses ranging to accurately determine distance to targets detected by **Vision** system for Vulnerable Road Users.
Multi Level Fusion: Radar and Lidar

- Radar is naturally better at identifying presence of potential targets, at longer range determination, at radial velocity accuracy and resolution, in robustness to weather and in field of view
- Lidar is better at classification of objects, in angle accuracy and resolution, at range accuracy and resolution, in lane detection, and in obtaining a point cloud representation of the field of view
- Low Level Fusion helps as the following key scenarios show:
  - Radar identifies a group of potential targets at a distance and Lidar then classifies them into pedestrians and with separation
  - Lidar/Radar identifies bad weather and more work is handed off to Radar in fusion algorithms
  - Radar uses micro-Doppler to sense slow moving targets and improve Lidar acquisition of hard to see targets for Vulnerable Road Users
  - Radar provides radial velocity measurement and Lidar improves tracking on curves to improve performance on and reduce false alarms for ACC/FSACC
Multi Level Fusion: Vision and Lidar

• Lidar is naturally better at identifying presence of potential targets, at range accuracy and resolution, at radial velocity accuracy and resolution, and vertical angular accuracy

• Vision is better at classification of objects, at azimuthal angular accuracy and resolution, and tangential velocity accuracy and resolution, in lane detection, and in sign identification

• Low Level Fusion helps as the following key scenarios show:

  • **Lidar** identifies a group of potential targets at a distance and **Vision** then classifies them into pedestrian separation
  
  • **Lidar** uses ranging to accurately determine distance to targets detected by **Vision** system for Vulnerable Road Users
  
  • **Lidar** measure range to identify cross traffic cars of interest, and **Vision** measures angle and tangential velocity to implement Front /Rear Cross Traffic Alert
### ADAS scenarios: Radar, Vision and Lidar and Multi-Level Fusion

<table>
<thead>
<tr>
<th></th>
<th>Radar</th>
<th>Lidar</th>
<th>Vision</th>
<th>Radar + Lidar</th>
<th>Radar + Vision</th>
<th>Lidar + Vision</th>
<th>R + L + V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection Range</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Range Quality</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Radial Velocity Quality</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Tangential Velocity Quality</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Adverse Weather</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Object Classification</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Object Contours</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Host Lane Position</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Host Path Determination</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Sign Identification</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
<tr>
<td>Compute Efficiency</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
<td>⭐⭐⭐⭐⭐⭐⭐⭐</td>
</tr>
</tbody>
</table>

- ⭐ Poor
- ⭐⭐ Marginal
- ⭐⭐⭐ Good
- ⭐⭐⭐⭐⭐⭐⭐ Good to Excellent
Sensor Fusion Techniques used in Automotive
Types of Sensor Fusion

Based on relations between input data sources

Based on input-output data types and their nature

Based on different data fusion levels

Based on architecture type: (a) centralized (b) decentralized, or (c) distributed.
Data Association

Determine the set of measurements that correspond to each target.

In frame-to-frame association and assume that $M$ possible points could be detected in all $n$ frames, then the number of possible sets is $(M)^{n-1}$.

- Nearest Neighbour and K-means
- Probabilistic Data Association methods
- Multiple Hypothesis Test methods
Example: Fusion for detection

- Input: Radar and camera sensors at the front of the car, monochrome camera with a resolution of 752 x 404 pixel and 43.5°/23.5° horizontal/vertical field of view is mounted behind the rear-view mirror. The camera resolution enables an object detection up to a distance of approximately 60 meters.

- Region of interest: rectangular area of five meter width and four meter height around the projected radar reflex.

- Vehicle rear views are used as training images subject to feature extraction (Haar Features) after contrast or variance normalization. Contrast normalization:

\[ I'(x_i, y_j) = \frac{I(x_i, y_j) - \min\{I(x, y)\}}{\max\{I(x, y)\} - \min\{I(x, y)\}} \]

- Apply filters just to certain sampling points and use all points for calculation of the filter response.
Example: Fusion for detection

- Each strong classifier within the cascade is trained with Adaboost

\[ H(x) = \begin{cases} 1, & \sum_{t=1}^{T} \alpha_t h_t(x) \geq \frac{1}{2} \sum_{t=1}^{T} \alpha_t \\ 0, & \text{otherwise} \end{cases} \]

- where \( x \) is the feature vector of an image, \( h_t \in \{0, 1\} \) is a weak classifier, \( \alpha_t \) is the weight of the \( t \)th weak classifier and \( T \) is the number of features selected

- Each time a new weak classifier is selected the maximal Mutual Information (MI) to one of the previously selected is determined. The classifier with smallest weighted error is accepted, if a certain value of MI is not exceeded

- For each sub-window the classifier gives a vote whether a vehicle is present or not

- Since the classifier is invariant against small changes in translation and scale, generally more than one detection occurs around a target vehicle

- After detection, the width in meter and accurate position can be estimated by fusing radar and vision data.

RADAR-VISION FUSION FOR VEHICLE DETECTION BY MEANS OF IMPROVED HAAR-LIKE FEATURE AND ADABOOST APPROACH

Anselm Haselhoff 1, Anton Kummert 1, and Georg Schneider 2
Example: Fusion for detection

<table>
<thead>
<tr>
<th>Classifier</th>
<th>TP</th>
<th>FP</th>
<th>AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>VN, unbounded MI</td>
<td>88.54%</td>
<td>0.32%</td>
<td>97.35%</td>
</tr>
<tr>
<td>CN, unbounded MI</td>
<td>89.81%</td>
<td>0.16%</td>
<td>97.81%</td>
</tr>
<tr>
<td>CN, MI&lt;0.5</td>
<td>93.63%</td>
<td>0.0%</td>
<td>98.76%</td>
</tr>
<tr>
<td>CN, MI&lt;0.25</td>
<td>88.54%</td>
<td>0.0%</td>
<td>97.68%</td>
</tr>
</tbody>
</table>
## Previous Deployment Cycles

<table>
<thead>
<tr>
<th>Product</th>
<th>Deployment Cycle</th>
<th>Typical Cost Premium</th>
<th>Market Saturation Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air bags</td>
<td>25 years (1973-98)</td>
<td>A few hundred dollars</td>
<td>100%, due to federal mandate</td>
</tr>
<tr>
<td>Automatic transmissions</td>
<td>50 years (1940s-90s)</td>
<td>$1,500</td>
<td>90% U.S., 50% worldwide</td>
</tr>
<tr>
<td>Navigation systems</td>
<td>30+ years (1985-2015+)</td>
<td>$500 and rapidly declining</td>
<td>Uncertain; probably over 80%.</td>
</tr>
<tr>
<td>Optional GPS services</td>
<td>15 years</td>
<td>$250 annual</td>
<td>2-5%</td>
</tr>
<tr>
<td>Hybrid vehicles</td>
<td>25+ years (1990s-2016+)</td>
<td>$5,000</td>
<td>Uncertain. Currently about 4%</td>
</tr>
</tbody>
</table>

*Victoria Transport Policy Institute*
### Deployment cycle for self-driving

<table>
<thead>
<tr>
<th>Stage</th>
<th>Decade</th>
<th>Vehicle Sales</th>
<th>Veh. Fleet</th>
<th>Veh. Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available with large price premium</td>
<td>2020s</td>
<td>2-5%</td>
<td>1-2%</td>
<td>1-4%</td>
</tr>
<tr>
<td>Available with moderate price premium</td>
<td>2030s</td>
<td>20-40%</td>
<td>10-20%</td>
<td>10-30%</td>
</tr>
<tr>
<td>Available with minimal price premium</td>
<td>2040s</td>
<td>40-60%</td>
<td>20-40%</td>
<td>30-50%</td>
</tr>
<tr>
<td>Standard feature included on most new vehicles</td>
<td>2050s</td>
<td>80-100%</td>
<td>40-60%</td>
<td>50-80%</td>
</tr>
<tr>
<td>Saturation (everybody who wants it has it)</td>
<td>2060s</td>
<td>?</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>Required for all new and operating vehicles</td>
<td>???</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Victoria Transport Policy Institute
65 or Not, Demos, continue to keep it up
And, Thank You!