Driverless Urban Mobility: The Path Towards an Autonomous Future

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Chief Technology Officer

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The Robotics Institute
Adjunct Associate Professor
Humanoid Motion Planning

- Stanford University
  1995 - 1999
- University of Tokyo
  1999 - 2001
- Carnegie Mellon University
  The Robotics Institute
  2001 - 2009
- Digital Human Research Center (AIST Japan)
  2001 - 2009
• Google Self-Driving Car Team  
  2009 – 2011  
• 3D Objects Project Co-Founder  
  2011 – 2013  
• Robotics Project Co-Founder  
  2013 – 2015
• **Established:** Jan 2016 - **CEO:** Dr. Gill Pratt
• Initial $1B investment
Key R&D Focus Areas

- Automotive Safety & Advanced Autonomy
- Mobility: Outdoor & Indoor (robotics)
- Scientific Discovery (Materials Science)
Talk Overview

• Historical Innovation
• Autonomous Vehicles and Future Cities
• Cloud-Enabled Robots
• Challenges and Future Prospects
The Computer
The Data Center
The Robot
Cloud-Connected Intelligent Vehicles and Robots
Historical Precedence: The Automobile

• 1885-1886
  Gottlieb Daimler and Karl Benz develop first gas-powered cars

• 1890-1915
  Rapid advancement in engine/transmission design and manufacturing technology

• 1910-1915
  Ford Model-T becomes first widely affordable automobile
Historical Precedence: The Computer

- 1945-60
  Early computer prototypes

- 1960-75
  Rapid advances in hardware (transistors, storage, displays)

- 1980-90
  Personal Computers (PCs) become widely affordable
Historical Precedence: The Mobile Phone

- **1983**
  Motorola DynaTAC cellular phone sold publicly for $4000

- **1985-2000**
  Rapid technology advances (size, transmission speed, reliability, network coverage, cost)

- **2000-2015**
  Mobile phones evolve into “smartphones” and overtake desktops worldwide
Intelligent Robotics Timeline

- **1996**
  Honda P2
  (first fully self-contained walking humanoid)

- **2000-20**
  Rapid advancement in *hardware*
  (actuators, power, sensors)
  and *software*
  (control, planning, learning)

- **2020-30?**
  Home robots become ubiquitous and affordable
Autonomous Cars Timeline:
DARPA Grand Challenges

2004

- No winner
- CMU Sandstorm traveled furthest (~7 miles completed)

2005

- $1M Cash Prize
- Stanford Racing (Stanley)

2007

- $2M Cash Prize
- CMU Tartan Racing
Google/Waymo Self-Driving Car Project (2009)
TODAY = An Explosion of R&D Activity

33 Corporations Working On Autonomous Vehicles

- Apple
- Audi
- Baidu 百度
- BMW
- Bosch
- DAF
- Daimler
- Delphi
- FCA
- Ford
- GM
- Google
- Honda
- Hyundai
- Intel
- Iveco
- Jaguar
- Land-Rover
- Lyft
- MAN
- Mercedes-Benz
- Microsoft
- Mobileye
- Nissan
- Renault
- PSA
- Scania
- Tata
- ELXSI engineering creativity
- Tesla
- Toyota
- Volkswagen
- Volvo
- Scania
- Yutong
- CB Insights
Ingredients for Disruption and Transformative Technology

- Strong Partnerships
- Critical Mass of Talent
- Investment

Academia
Industry
Government

[Diagram showing the combination of ingredients for disruption and transformative technology]
How might intelligent vehicle technology impact the design of future cities?

• Enable true “driverless cities”:
  – Transportation on demand / mobility as a service (MaaS)
  – Dramatic reduction in:
    • Traffic
    • Noise
    • Pollution
  – Land dedicated to parking lots converted into:
    • Residential
    • Commercial
PARKING: Today’s Reality

• The average car is parked 95% of the time, with only 5% on-the-road time.

• Worldwide, urban drivers spend an average of 20 minutes per trip looking for parking.

• The United States has ~1 billion parking spots for only 253 million cars and trucks (4x more parking spaces than vehicles).

PARKING: Today’s Reality

2015 study of Los Angeles County:

- 200 sq. miles of land dedicated to parking
- 18.6 million spaces
- 14% of all land area
• Driverless cars will enable:
  – Relocation of parking structures away from urban centers
  – More dense, efficient, packed parking spaces managed robotically
  – No requirement for parking structures to contain stairs, elevators, or wide alleyways for vehicle access
  – Data-driven dispatch of on-demand transportation and dynamic load-balancing of vehicle supply according to demand patterns

Source: http://www.roboticparking.com/
PARKING: Tomorrow’s Future

• Parking lots will double as **charging stations** and replace traditional gas stations
• Car cleaning, repairs and **maintenance** can all be performed at centralized parking lot facilities
• Parking lots full of connected cars will serve as **logistics hubs** – new shipping ports for the on-demand economy

Urban Center Re-design

- Convert parking lots and gas stations to green spaces
- Curbside parking spaces become bike lanes and/or expanded sidewalks
Radical Urban Center Re-design

- Move all vehicle traffic underground

- Convert all above-ground streets and roads to Fußgängerzone (pedestrian-only zones)
  - Less noise
  - Better air quality
  - Safer
Personal Mobility: New Vehicle Platforms

Toyota iRoad

- Zero-emissions electric vehicle
- Compact, three-wheel design
- Active balance and stability control
- Strong, lightweight, composite frame
- Powered by lithium-ion batteries that average 50km on a single charge

http://www.toyota-global.com/innovation/personal_mobility/i-road/
Fuel-Cell Vehicle: Toyota Mirai

Toyota Making 5,600 Hydrogen Fuel Cell Patents Free To Use
January 8th, 2015 by James Ayre

Toyota will be making more than 5,600 of its hydrogen fuel-cell technologies patents free to use for a large number of companies in the industry/sector — absolutely no charges, including no royalty payments — according to recent reports.

Seemingly taking a move from Tesla's recent playbook, the move is certainly an interesting one — but you can't help but wonder if the primary reason for it is simply as a means of generating good PR.

- Zero-emissions hydrogen fuel-cell vehicle
- 312 EPA-rated miles per tank
- 5 Minutes to refuel
- $8000 federal tax credit + $5000 CA rebate + 3 years' worth of complimentary fuel

https://ssl.toyota.com/mirai/
Search-based Artificial Intelligence

Moore’s Law

Planning = “Reasoning about the consequences of actions”
Conquering “Go”

Google’s AI Masters the Game of Go a Decade Earlier Than Expected
MIT Technology Review - Jan 27, 2016
AlphaGo was developed by a team known as Google DeepMind, a group created after Google acquired a small AI U.K. startup called DeepMind in 2014. The researchers built AlphaGo using an extremely popular and successful machine-learning method ...

In a Huge Breakthrough, Google’s AI Beats a Top Player at the Game of Go
WIRED - Jan 27, 2016
The DeepMind system, dubbed AlphaGo, matched its artificial wits against Fan Hui, Europe's reigning Go champion, and the AI system went undefeated in five games witnessed by an editor from the journal Nature and an arbiter representing the British Go ...

Cloud Robotics

- Build your own “cellbot”
  - http://www.cellbots.com/
  - http://www.cloudrobotics.com/
- ROS on Android
- Cloud Robotics Keynote at Google I/O (2011)
- “RoboEarth” EC project (2011-2014)
- IoT / Industry 4.0
Enabling Factors

- Wireless networking:
  - Fast
  - Reliable
  - Ubiquitous
  - Sufficient bandwidth

Peak Mobile Broadband speed growth:
64 kbps to 100 Mbps in 10 years = 1600x
Benefits of “Cloud Robotics”

• Provides a shared knowledge database
  – Organizes and unifies information about the world in a format usable by robots

• Offloads heavy computing tasks to the cloud
  – Cheaper, lighter, easier-to-maintain hardware (akin to desktop PC vs. a thin-client “netbook”)
  – Longer battery life
  – Less need for software pushes/updates
  – CPU hardware upgrades are invisible & hassle-free

• Skill / Behavior Database
  – reusable library of “skills” or behaviors that map to perceived task requirements / complex situations.
  – Data-mining the history of all cloud-enabled robots
Speech-to-Speech

- Recognition
- Translation
- Synthesis

Conversation Mode on Android
Example: Perception

- Cloud-enabled Object Recognition
  - e.g. “Google Goggles”
“Robot” Goggles

• Upload image(s) → Download Semantics
  – Object name
  – 3D model, mass, materials, friction properties
  – Usage instructions (function, how to grasp, operate)
  – Context / Domain knowledge

HSR - Human Support Robot (Toyota)
Enabling “Robotsourcing”

- Human crowdsourcing can scale hard semantic and quality control problems globally
  - Google MapMaker

- Large-scale deployment of data-sharing robots
  - Offers similar advantages to human crowdsourcing
Connected Cars and Vehicle Intelligence

- Big Data and Deep Learning
  - Powering tremendous advances:
    - Speech / NLU / Translation
    - Object recognition (ImageNet)

- Connected cars will:
  - gather novel data
  - upload new exemplars
  - train updated models in the cloud
  - download / broadcast updates to the entire vehicle fleet
Toyota Vehicle-sourced Maps

Jan 4, 2016
CES announcement

Toyota develops high-precision map generation system ...
www.roadtraffic-technology.com/.../newstoyota-develops-high-precision...

Jan 4, 2016 - Toyota has developed a high-precision map generation system that will make use of data from on-board cameras and GPS devices installed in ...

https://www.youtube.com/watch?v=56RNDP3hD-8
Toyota Distributed Map Generation
Robotics Going Forward:
Broad diversification and rapid growth of new application areas

- Transportation
- Manufacturing
- Defense
- Medical
- Space Exploration
- Logistics
- Security
- Consumer
Closing Thoughts

• The next generation of intelligent autonomous vehicles will enable a complete rethinking of how our urban centers are designed and built.

• Cloud Computing, Big Data, and Ubiquitous Connectivity will dramatically advance vehicle autonomy for improved safety and accessibility.

• Cloud Robotics enables cheaper, lighter, and “smarter” robots with a “shared knowledgebase”.

• Strong government, industry, and academic partnerships are key.
Thank you!

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