TOYOTA's Activities towards SMART MOBILITY SOCIETY

Toyota aims to create a smart mobility society where people feel secure and happy in transport and everyday life.

COMFORT

The vehicle will become a trusted partner through close communication with the driver.
- The vehicle complies with the driver’s verbal and nonverbal commands.
- The vehicle predicts the driver’s actions in order to provide services.

SAFETY

Toward the realization of Toyota’s ultimate goal: zero casualties from traffic accidents.
- Vehicles exchange their locations and speeds at all times.
- Vehicles receive useful information from roadside infrastructure.

ECOLOGY

Optimizing the energy use of the entire community, achieving eco-friendly lifestyles with a high quality of life.
- Activating a low-carbon society where humans and vehicles share energy with each other.
- Promoting local energy production and consumption.
- Creating transportation that is strong enough to withstand natural disasters.

CONVENIENCE

Building a stress-free traffic environment where everyone can move around as they wish.
- Utilizing big data generated from vehicles to improve traffic control and disaster-related measures.
- Implementing an autonomous EV driving service integrated with public transportation.

Graphics from http://www.toyota-global.com/ unless otherwise specified
SMART MOBILITY SOCIETY

- Safety / Autonomy

- Ecological Powertrains
  - Internal Combustion
  - Hybrid Vehicle
  - Electric Vehicle
  - Plug-in Hybrid Vehicle
  - Fuel Cell Vehicle

- Intelligent Transportation Systems

- Smart Grid

- Research samples

Relevant but not discussed:

- Personal Mobility
- Partner Robot
Smart Mobility Society for Safety: Aiming for No Traffic Accidents
Vehicle Safety Technologies: Today
Automated Highway Driving Assist System: Tomorrow

Demonstrated on public roads in Detroit during the fourth annual Toyota Advanced Safety Seminar on Sept. 4, 2014

60 Sec ITS Video TOYOTA.wmv

http://corporatenews.pressroom.toyota.com/releases/toyota+advanced+automated+vehicle+technology+us+roads+sept4.htm
Autonomous Vehicles: Future

Toyota Research Institute (TRI)
DR. GILL PRATT at the Consumer Electronics Show 2016

“...the technologies we develop have to work not only at the Million-mile scale, but at the Trillion-mile scale. To address this problem and leverage AI for other uses, TRI has four initial mandates:

First, we wish to enhance the safety of automobiles with the ultimate goal of creating a car that is incapable of causing a crash, regardless of the skill or condition of the driver.

Second, we want to increase access to cars to those who otherwise cannot drive, including people with special needs and seniors.

Third, we plan to help translate Toyota’s expertise in creating products for outdoor mobility into products for indoor mobility. In other words, Toyota’s goal is to move people across the room...across town...and across the country.

Finally we hope to accelerate scientific discovery by applying techniques from artificial intelligence and machine learning particularly in the area of materials science. ...”

http://corporatenews.pressroom.toyota.com/releases/2016+ces+pratt.htm
Smart Mobility for Ecology

Three challenges regarding environmental and energy issues:
- finding alternative energy sources to oil
- reducing CO2 emissions
- preventing air pollution

Market considerations: cost, driving range, re-energizing, infrastructure
Smart Mobility for Ecology: Future

Efficient vehicles and alternative fuels key to achieve 2DS*

* 2DS: 2°C temperature rise scenario: Efficiency and Low-carbon fuels

https://www.iea.org/media/workshops/2013/egrdmobility/DULAC_23052013.pdf
Smart Mobility for Ecology: Efficiency

Development Areas:

- SI engine
- Discrete Variable Valve Lift
- Turbocharging & Downsizing
- Cooled EGR
- Transmission
- Aerodynamics
- Mass reduction
- Tire rolling resistance
- Accessories (e.g. air conditioning, power steering)

Smart Mobility for Ecology: Alternative Powertrains

Toward zero greenhouse gas emissions

- **Battery Electric**
- **Fuel Cell**
- **Internal Combustion**
- **Plug In Hybrid**

Smart Mobility for Ecology: Hybrid Technology is the Core

hybrid technologies are regarded as our key technology
Smart Mobility for Ecology: Market Position

Intelligent Transportation Systems

Smart communities and connected vehicles will provide new features that affect all aspects of human mobility.
Smart Grid

Smart use of renewable natural energy by connecting homes, people and cars

*1 G-Station : Charger for EVs and PHVs
*2 G-Book : G-BOOK/G-Link
* Home Energy Management System
Research samples

Clearly, Cyber-Physical Systems (CPS) technologies are vital to Smart Mobility advancement.

Our group at the Toyota Technical Center focuses on the application of Model Based Development to automotive powertrains:

- CPS modeling of powertrain and vehicle systems
  - Advanced control design
  - Simulation guided verification and validation
Research samples: Advanced control design

General automotive powertrain control problem characteristics:
- multi-input / multi-output nonlinear dynamics
- multiple performance objectives / tradeoffs
- constrained operation for reliability / high performance

→ Nonlinear Model Predictive Control as a systematic design method

Primary Challenge:
- Computation Cost

Approach:
- Apply Symbolic Computing

Application Demonstration:
- Diesel Air Path Control
  - $u$: EGR Valve, Throttle, VGT
  - $y$: Intake Pressure, EGR rate
Research samples: Advanced control design: Nonlinear MPC

Set-up and solution

\[ \dot{x}(t) = f(x(t), u(t)) \quad \text{On-line plant model} \]
\[ J = \int_0^T l(x(\tau), u(\tau))d\tau \quad \text{Cost function} \]
\[ g(x(t), u(t)) = 0 \quad \text{Constraints} \]
\[ h(x(t), u(t)) \leq 0 \]
\[ \bar{L} = l + \pi^T f + \bar{\mu}^T \bar{g} \quad \text{Lagrangian with modified constraints} \]

\[ \bar{\gamma} = [u_0^T, \bar{\mu}_0^T, x_1, p_1, u_1^T, \bar{\mu}_1^T, \ldots, u_{N-1}^T, \bar{\mu}_{N-1}^T, x_N, p_N]^T \]

Optimization variables

\[ F \left( \bar{\gamma}, x(t) \right) = \begin{bmatrix}
\tilde{L}_u (x_0, u_0, p_0, \bar{\mu}_0) \\
\tilde{g}(x_0, u_0) \\
\vdots \\
\tilde{L}_u (x_{N-1}, u_{N-1}, p_N, \bar{\mu}_{N-1}) \\
\tilde{g}(x_{N-1}, u_{N-1})
\end{bmatrix} \]

Off-line necessary conditions for optimality

Formulation requires symbolic differentiation

\[ F_{\bar{\gamma}}(\bar{\gamma}, x) \Delta \bar{\gamma} = -F(\bar{\gamma}, x) \quad \text{On-line Newton iteration to find the values of the optimization variables} \]

\[ \bar{\gamma}_{k+1} = \bar{\gamma}_k + \Delta \bar{\gamma}_k \]

On-line computation reductions due to offline symbolic analysis

① Formulation requires symbolic differentiation

② \( F_{U}(\bar{\gamma}_k, x) \) evaluation

③ Common terms between \( F(\bar{\gamma}_k, x) \) and \( F_{\bar{\gamma}}(\bar{\gamma}_k, x) \)

④ Sparse and structural Linear Solve

identify zero and constant elements off-line

Ken Butts, CPS Week 2016, Vienna
Research samples: V&V: Powertrain Control Design

- Dev. target
- Requirements and Design co-developed
- X-In-the-Loop-Simulators
- Legacy Code
- Hardware-in-the-loop testing
- New design
- System evaluation
- Integrated code
- Software-in-the-loop testing
- Prototype modeling and implementation
- Validate this!
- Controller Specification Model
- Auto-Code Generation

Lots and lots of testing, now by driving!

Ken Butts, CPS Week 2016, Vienna
Research samples: V&V: leverage engineering process and technology trends

Can apply to real designs? (scalability)

Software Testing
- Control Theory Techniques
  - Simulation
  - Linear Analysis (numerical)
  - Test Vector Generation for Model Coverage
  - Linear Analysis (symbolic)

Program Analysis
Formal Verification
- Ideal technique
  - Falsification
  - Concolic Testing
  - (Bounded) Model Checking
  - Stability Proofs
  - Reachability Analysis
  - Theorem Proving

Unexplored Frontier

Ken Butts, CPS Week 2016, Vienna
Search-Based Test (Falsification)

Search-Based Test Framework “Automatic harsh test machine”

Key elements:
1. Requirement Description Language
2. Robustness Computation
3. Input Design
4. Optimization (for hybrid dynamics)
5. Coverage

Now finding design flaws in production scale specifications

Ken Butts, CPS Week 2016, Vienna
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Ken Butts, CPS Week 2016, Vienna
Cyber Physical Systems $\iff$ Smart Mobility

An exciting future with great potential

Thank you!
Additional
Research Progress: Next Generation Secondary Batteries

**Figure 2** All-solid-state battery
Directly connected cells enables smaller package

**Figure 3** Lithium-air battery
Using oxygen in the air for the cathode and lithium metal for the anode allows for a smaller and lighter package.

Ken Butts, CPS Week 2016, Vienna
Smart Mobility for Ecology: Mirai Fuel Cell Electric Vehicle

- Hydrogen fuel derived from a variety of sources
- Zero tailpipe emissions
- Convenience on par with conventional gasoline engine vehicles:
  - Range of roughly 650 km
  - Refueling time of about three minutes
Research samples: V&V: how to leverage engineering process and technology trends?

- Cheaper data analysis
- Computation power
- Data Storage
- Cyber physical systems theory
- Plant modeling & simulator

\[ \Diamond P \land \Box (Q \rightarrow \Diamond_{[0,1]} R) \]