Innovation of automotive software development

Masahiro Goto
Director
ePF R&D Division
DENSO CORPORATION
Corporate Profile

December 16, 1949

Established

Capital
187.4 billion yen (US$1.8 billion)

Net sales

<table>
<thead>
<tr>
<th></th>
<th>Consolidated basis</th>
<th>Non-consolidated basis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4,095.9 billion yen (US$39.8 billion)</td>
<td>2,490.8 billion yen (US$24.2 billion)</td>
</tr>
</tbody>
</table>

Operating Income

<table>
<thead>
<tr>
<th></th>
<th>Consolidated basis</th>
<th>Non-consolidated basis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>377.7 billion yen (US$3.7 billion)</td>
<td>223.3 billion yen (US$2.2 billion)</td>
</tr>
</tbody>
</table>

Employees

<table>
<thead>
<tr>
<th></th>
<th>Consolidated basis</th>
<th>Non-consolidated basis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>139,842</td>
<td>38,581</td>
</tr>
</tbody>
</table>

Consolidated subsidiaries

185
(Japan 62, North America 26, Europe 35, Asia/Oceania 56, South America/Others 6)

Affiliates under the equity method

33
(Japan 13, North America 4, Europe 3, Asia/Oceania 11, South America/Others 2)

Notes:

U.S. dollar amounts have been translated, for convenience only, at the rate of 102.92 yen = US$1, the approximate exchange rate prevailing on March 31, 2014. Billion is used in the American sense of one thousand million.

*/ as of March 31, 2014
Automotive Fields

**Environment**
Hybrid and electric vehicle components,
gasoline engine management system,
diesel engine management system,
starter, alternator, radiator, etc.

**Safety**
Sensing technologies for driving assist systems,
actuator & computer for antilock brake system (ABS) /
electronic stability control (ESC),
adaptive front-lighting system (AFS),
airbag sensors & electronic control units,
periphery monitoring system, instrument cluster,
rain sensor for automatic windshield wiper, etc.

**Comfort & Convenience**
Car air-conditioning system,
air conditioner for buses, air purifier,

Car navigation system,
electronic toll collection system (ETC),
remote security system,
remote touch controller, smart key,
advanced vehicle operation system (AVOS), etc.
Challenges surrounding Mobility Society

**Global Environment**
- Contribution to developing an environment friendly to the earth
- CO₂ reduction, fuel efficiency improvement and diversification of energy sources to prevent global warming
- More electric (Hybrid, PHV, EV) Change from Engine to Motor

**Traffic Safety**
- Realize Zero-traffic accident society
- Pre-crash safety ~ Active safety ~ Drive assist
- Make existing products low cost for wider spread and develop further advanced safety device

**Future Society**
- Energy collaboration with homes and local communities
  - PHV, EV to Smart grid, Micro grid
- Semi-automatic drive by coordination with infrastructure (Vehicle-vehicle, Road-vehicle)
- Utilization of IT • Cloud by broadband connection
- Change of the usage style of the car
  - Car sharing, Multi modal

*PHV: Plug-in Hybrid
EV: Electric Vehicle*
**Global environment** : Global warming and counter measures

### Forecast of CO₂ emission

- **Forecast**
- **New Policies Scenario** *1
- **Stay in CO₂ = 450ppm**

- **[Source]** World Energy Outlook 2012, IEA.

### Powertrain Mix (450ppm scenario)

- **Share**
- **Forecast**
- **CO₂ of new car**:
  - **Conventional**
  - **ISS**
  - **HV**
  - **EV**

- **CO₂ free / Low CO₂ emission vehicle will expand**

*1 assuming most energy consuming countries implement new policies of energy efficiency

**[Source]**  Share forecast : DENSO
CO₂ of new car: Ricaldo

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Safety - traffic accident fatalities in global and Japan

Traffic fatalities in global (thousand)

<table>
<thead>
<tr>
<th></th>
<th>1996</th>
<th>2010</th>
<th>trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Japan</td>
<td>9.9</td>
<td>4.9</td>
<td>↓</td>
</tr>
<tr>
<td>U.S</td>
<td>42.1</td>
<td>35.5</td>
<td>→</td>
</tr>
<tr>
<td>EU 25 *1</td>
<td>55.5</td>
<td>30.4</td>
<td>→</td>
</tr>
<tr>
<td>China (PRC)</td>
<td>73.7</td>
<td>276.0</td>
<td>→</td>
</tr>
<tr>
<td>India</td>
<td>74.7</td>
<td>231.0</td>
<td>→</td>
</tr>
<tr>
<td>SE Asia *2</td>
<td>32.2</td>
<td>84.6</td>
<td>→</td>
</tr>
<tr>
<td>Brazil</td>
<td>5.3 (’98)</td>
<td>43.9</td>
<td>→</td>
</tr>
<tr>
<td>World</td>
<td>1170.7 (’98)</td>
<td>1225.9</td>
<td>→</td>
</tr>
</tbody>
</table>

Traffic fatalities in Japan

- stronger crackdown, safety education
- Infrastructure improvements
- seatbelt obligated
- front-crash test obligated
- Airbag, ABS 100% installed

Emerging country is similar to 1960s Japan
Airbag, ABS/ESC already spread in JP,US,EU

⇒ Demanding Airbag, Seatbelt, ABS/ESC
⇒ Demanding ADAS (Advanced Driver Assistant)
Anyone, Anytime, Anywhere: enjoy various services through network without any stress.

Widespread use of IT services

- Permanent connection
- Cloud
- Smart phone

Smart grid

- Generation
- Transmission
- Management
- Operation & management center
- Charging spot
- Monitoring
- Smart meter
- PLC or radio
- BATT

Ubiquitous Society

Automated driving

- Distance control
- Crash avoidance
- Pedestrian detection
- V2V
- DSRC
- WiFi

Social control

- Park & Ride
- Car sharing
- Transit fee
- Multi-modal mobility

New mobility society in cooperation with social infrastructure
Automotive Electronic System Development

Why does Automotive systems become complex?

System requirements are developed through iteration of prototyping and evaluation

- Spec. becoming too detailed and complex.
- Intent getting harder to understand

- Driving Context
- Physical Phenomena
- Human Operation
Automotive embedded software development

Increasing number of versions due to functional improvements

Increasing variations due to car line

A large number of similar but different software is developed
ADAS (Advanced Driving Assistance System)

“We are developing driving support systems to reduce the danger in an emergency (safety when needed) and to take away drivers’ worries (peace of mind always).”


Vehicle
- Pre-Crash
  - Low-speed → High-speed
  - Pedestrian
  - Lane-keeping → Off-lane
  - Reduce driver’s load
  - Reduce human error
- Damage reduction in case of car crash

Infrastructure / Crowd
- Intersection accident avoidance
- Automatic driving

Driver

Society
- Reduce Traffic Accidents

Technology Expansion

Influence for Society

source: ITS World Congress @Oct. 2013

Prevention mistake of gas pedal (Nissan)
Pedestrian PCS (Toyota)
City brake active system (Honda)
ADAS as a complex system

Integrating sensors and actuators to provide various services

- MMW RADAR
- LIDAR
- Camera
- Ultra sonic
- Wireless com.
- Driver Monitor

Service
- Adaptive Cruise Control
- Collision Mitigation
- Prevent misacceleration
- Auto Parking
- Auto Lighting Control
- Lane Departure Warning
- Collision Warning
- ...

ECU
- Engine
- ESC
- EPS
- Light Control

Safety Manager

Sensor Manager

Vehicle Motion Control

HMI Manager

Instrument Cluster

Center Display

Driver

Engine

Brake

Steering

Light
Context of ADAS

Various road environment over the world

depending on traffic situations, customs, and cultures
## Cybersecurity

### Evolving Services
- Connected vehicles
- ADAS

### Negative aspect: Cybersecurity
- Demonstration of carjack (DEFCON)

*source: DEF CON 21 @Aug. 2013*

<table>
<thead>
<tr>
<th>Target</th>
<th>Demonstration</th>
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</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Unintended acceleration</td>
</tr>
<tr>
<td>Brake</td>
<td>Unintended deceleration</td>
</tr>
<tr>
<td>Steering</td>
<td>Unintended steering</td>
</tr>
<tr>
<td>Indicator</td>
<td>Indicating 100mph even when stationary</td>
</tr>
<tr>
<td>Horn</td>
<td>Sudden beeping</td>
</tr>
<tr>
<td>Seat belt</td>
<td>Sudden tightening of seatbelts</td>
</tr>
<tr>
<td>Gas gauge</td>
<td>Inaccurate indication of gas</td>
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</table>
Evolving Automotive Electronics getting more critical

Influence for Society

Connected Systems

Target System

In-Vehicle Systems

Safety

Asset

Property / Privacy

Multimedia

Information Security

Functional Safety

Powertrain Chassis

ADAS

Body

Car Security

Reprograming Security

Quality

DENSO

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Major following observations

- Growing complexity of the systems
- Diversifying the system contexts

indicate the importance of

Getting higher confidence of automotive electronic systems

Confidence is the source of both:
- responsibility to provide high quality of the products, and
- accountability to promise peace of mind to the society
Existing Solution

Model-based development
Simulation technologies promote automation of development

Specification development & Verification
Control model description tool

Verification

Implementation
Code generation & test

Calibration & Validation
Calibration DB
Automatic calibrator
Calibration tool

Design

Automatic code generation tool

Control model
C program

Automated test bench
Why “Testing” is important

It is very important to verify “it works on-specification”

“It works on-specification” does not only mean the system satisfy the performance written in the document,

but also includes the system will not do any behavior other than written in the document.

Thus, it is much important to consider various conditions and environment (even when it is un clear),

and check if the system actually works using various test case.
Typical example

- unit testing in software creation
- Integration testing in system development
- System testing on early prototype phase
Testing in software unit level

Back-to-back test between Model and Software
- Compare behavior based on the structural coverage

```c
void untitled_obs_step(void)
{
    int16_T rtb_Switch;
    if (In2) {
        rtb_Switch = In1;
    } else {
        rtb_Switch = In3;
    }
    if (In4 < rtb_Switch) {
        rtb_Switch = In4;
    }
    Out1 = rtb_Switch;
}
```
Testing in software unit level

High automation is available

- Test Execution can be automated
- Test Vector can be automatically generated

But effect is limited

- Less possibility to find bugs
- High confidence against coverage

Measures to prevent creating bugs like restricted coding rules and auto code generation are more effective. Peer review is more efficient to find coding bugs.

Bugs of compilers are only found by testing.
Testing for integration* and functionality

Requirement based testing
- Compare Implementation and Requirement

* SW Integration, HW/SW Integration, System Integration

Abstract model (Observer)

Implementation Model

Test cases

Conditions to cover Requirement

Map to Implementation

Expected Behavior
Testing for integration and functionality

Modeling is intensive
- More work than test case design

Automation is limited
- Test Execution can be automated
- Automated Test Generation does not scale

Simulink models used for product development contain more than ten thousands of blocks and take several thousands of simulation steps
System testing on early prototype

How testing technology assist early phase?

Prototype Evaluation

Collect data

Control Design

Revise control using simulation

Plant Modeling

Revise model to fit required accuracy
Testing Strategy

Test as “Evidence” of verification

Ideal Proof
“Fundamental” Formal Method

Asset management
Regression, …

Combinational method
All-pair, HAYST method, …

MBT

Requirement-based Verification

Monkey
No strategy

Test to find Bugs

Control trade-off in accordance with development phase and purpose
Findings So Far

• Simulation technologies are widely used
• Test generation technology is available but effect is limited
• System is getting more complex, which causes:
  ✓ Scalability is crucial for the tools
  ✓ Modeling is required as engineers’ work
How Technologies impacts Organization

Technologies require engineers’ skills

- Introducing Automation → Understanding both Technologies and Process
- System Design → Modeling domain specific requirements
Management of diverse human resources

Clarify “What an employee wants to do”, “What an employee can do”, and globally implement “right person in a right place”
Conclusion

• Automotive technology is evolving rapidly and brings various influence on the society.
• It is a key to get higher confidence of automotive electronic systems.

Many excellent ideas and technologies are proposed from academia, but it looks like only a few of them have been applied as industrial solutions because of various constraints and issues.

I would like to emphasize the importance of academia-industry collaborations
• to see and to understand what is happening in gemba, or the actual place, and
• to find out the essence of the issues and to improve appropriate technologies for the solution!