MEMS Approach for the Automotive Industry

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TOYOTA CENTRAL R&D LABS., Inc.

1. TOYOTA CRDL, INC
Company Outline

- **Established:** November 1960
- **Location:** Nagakute, Aichi, Japan
- **Capital:** 3 billion yen
- **Number of Employees:** 1,045
- **Ground Area:** About 300,000 m²
- **Floor Space:** About 98,000 m² (July 2013)

Stockholder Companies & Technical Collaboration Contractor Companies

**Stockholder Companies**
- Toyota Industries Corporation
- Toyota Motor Corporation
- Aichi Steel Corporation
- JTEKT Corporation
- Toyota Auto Body Co., Int.
- Toyota Tsusho Corporation
- Aisin Seiki Co., Ltd.
- Denso Corporation
- Toyota Boshoku Corporation

**Technical Collaboration Contractor Companies**
- Toyota Motor East Japan, Inc.
- Toyoda Gosei Co., Ltd.
- Hino Motors, Ltd.
- Daihatsu Motor Co., Ltd.
- Other 39 companies
  (July 2013)
2. Sensing Technology for Automobiles

Configuration of VDIM

VDIM: Vehicle Dynamics Integrated Management

- Brake actuator
- Suspension control computer
- Steering sensor
- Yaw rate sensor and linear G sensor
- Skid control computer
- Steering torque sensor
- Electric power steering computer
- Rear wheel speed sensor and rotor
- Engine control computer
- Brake pedal stroke sensor
- Front wheel speed sensor and rotor

CAN: Control Area Network
Sensor application comparison

<table>
<thead>
<tr>
<th></th>
<th>Automobile</th>
<th>Home Electronics</th>
<th>Industry</th>
<th>Airplane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>1 to 5 %</td>
<td>5 to 20 %</td>
<td>0.1 to 1 %</td>
<td>0.1 to 1 %</td>
</tr>
<tr>
<td>Temperature</td>
<td>-40 to 120 °C</td>
<td>-10 to 50 °C</td>
<td>0 to 60 °C</td>
<td>-55 to 70 °C</td>
</tr>
<tr>
<td>Vibration</td>
<td>2 to 25 G</td>
<td>1 to 5 G</td>
<td>0 to 5 G</td>
<td>0.5 to 10 G</td>
</tr>
<tr>
<td>Power Fluctuation</td>
<td>+/- 50 %</td>
<td>+/- 10 %</td>
<td>+/- 10 %</td>
<td>+/- 10 G</td>
</tr>
<tr>
<td>EMC</td>
<td>Large</td>
<td>Small</td>
<td>Medium</td>
<td>Small</td>
</tr>
<tr>
<td>Ambient</td>
<td>Water, Salt, Dirt, Erosion</td>
<td>Water</td>
<td>Water, Oil, Erosion</td>
<td>Water, Salt</td>
</tr>
<tr>
<td>Sensor Cost</td>
<td>1 to 10 $</td>
<td>1 to 10 $</td>
<td>10 to 100 $</td>
<td>100 to 1000 $</td>
</tr>
<tr>
<td>Whole Cost</td>
<td>0.01 to 0.1 M$</td>
<td>0.001 to 0.01 M$</td>
<td>0.001 to 1 M$</td>
<td>0.1 to 100 M$</td>
</tr>
<tr>
<td>Cost Ratio</td>
<td>10^2 to 10^5</td>
<td>10^4 to 10^5</td>
<td>10^1 to 10^5</td>
<td>10^2 to 10^5</td>
</tr>
<tr>
<td>Mass Production</td>
<td>Good</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Public, Professional</td>
<td>Public, Professional</td>
<td>Professional</td>
<td>Professional</td>
</tr>
</tbody>
</table>

EMC: electromagnetic compatibility

Accuracy: Middle
Working range: Wide
Life: Long

Kind of automotive sensor

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Water, Oil, Intake, Exhaust air, Fuel, Cabin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>Oxygen, Lean, NO_x, HC, H_2</td>
</tr>
<tr>
<td>Pressure</td>
<td>Intake air, Air flow, Combustion, Supercharging, Brake, Tire, Compressor</td>
</tr>
<tr>
<td>Position</td>
<td>Fuel level, Cam, Vehicle height, Seat</td>
</tr>
<tr>
<td>Angle</td>
<td>Crankshaft, rotation, Throttle, Steering, Direction</td>
</tr>
<tr>
<td>Speed</td>
<td>Engine, Vehicle, Transmission, Wheel</td>
</tr>
<tr>
<td>Angular rate</td>
<td>Yaw rate, Rollover</td>
</tr>
<tr>
<td>Acceleration</td>
<td>Airbag, Chassis, Suspension</td>
</tr>
<tr>
<td>Force, Load</td>
<td>Brake pedal, Steering torque, Loading</td>
</tr>
<tr>
<td>Vibration</td>
<td>Knocking</td>
</tr>
<tr>
<td>Light, Electric wave, Sound</td>
<td>Laser, Microwave, Visible light, IR light, Solar irradiation, Headlight, Voice, Ultrasound</td>
</tr>
<tr>
<td>Others</td>
<td>Glow plug, Particle, Rain drop, Humidity, Antenna, Fingerprint, Current</td>
</tr>
</tbody>
</table>

Inner sensor: Pressure, Acceleration, Angular rate,
Outer sensor: Sonar, Rader, Vision
Automotive sensor & MEMS technology


Pressure Sensor
- Bulk Gauge
- Diffusion Gauge
- Gas Pressure Sensor
- Air-intake Pressure
- Air Conditioner Sensor
- Magnetic IC Sensor

Combustion Sensor
- Cross Gauge
- Magnetic Sensor
- Acceleration Sensor

Yaw Rate Sensor
- Quartz Yaw Rate Sensor
- SOI Yaw Rate Sensor
- Tactile Sensor
- Magnetic Impedance Sensor
- Jerk Sensor
- 3G Sensor
- Scanner

On Board Description today

Element Shape
- Wafer Process
- IC Sensor
- SOI
- 3D Process

IC Sensor
- Poly Si, Film

Actuator

TOYOTA CRDL., INC.

Prize of “One Step on Electro-Technology” from IEE Japan in 2013 (電気の礎)
The Institute of Electrical Engineers of Japan

Piezoresistive Semiconductor Pressure Sensor
Toyota Central R&D Labs., Inc.

- Si Diaphragm with Semiconductor Strain Gauge with MEMS Technology (1970s)
- Gas Pressure Monitoring Sensor (Toyota Machine Works 1980)
- Intake Pressure Sensor for Automobile (Denso 1981)
3. Sensors for Automobiles

3.1 Combustion Pressure Sensor
Combustion Pressure Sensor

- Low exhaust emission
- Low-fuel consumption

Lean Burn Engine (TOYOTA) 1993

Installed on TOYOTA Lean Burn engine in 1993

Cross Section View

Cross Gauge Type
3. Sensors for Automobiles

3.2 Quartz Yaw Rate Sensor

Structure of Quartz Sensor

PIEZOELECTRIC EFFECT
(Intrinsic Polarization)

Coriolis Force
\[ F_c = 2 \text{ mV} \times \dot{\Omega} \]

CROSSSECTION of VIBRATOR

(15 x 3.5 x 0.3 mm³)
Quartz Yaw Rate Sensor

Installed on TOYOTA VSC System in 1998
VSC: Vehicle Stability Control

SENSOR ELEMENT
15 x 3.5 x 0.3 mm³

IC PACKAGE SIZE
25 x 25 x 5 mm³

HOUSING
107 x 48 x 37 mm³

4. Sensors for Robots

4.1 Robot Use of Automotive Sensors
Role of the Artificial Three Semicircular Canal

- Walk on stilts with keeping balance
- Ride on wheel with keeping balance

Robots with the Inertial Force Sensing System
Parson Carrier Biped-type Robot

- Biped-type Robot (Plays the Trumpet)
- Biped-type Robot with Wire Drive
- Rolling Type (2 + 1 wheels) Robot
  
Rolling Type (2 wheels) Robot (Inverted Pendulum)
4. Sensors for Robots

4.2 Tactile Sensor with Nerve Network

Nerve Net Type Tactile Sensor

<POINTS>
Serial bus, Event driven against congestion
Sensor chip on signal processor
Signal outputs when force changes
Nerve like relay node

Transducers2011

Robina, TOYOTA
5. Summary

- The sensors for the automobiles have been advanced with the MEMS technology.

- New sensors and devices are created with new MEMS technology, and that will continue to grow.

- The needs and applications of the sensors and devices are expanding.

- The sensors and devices of the automobiles should be integrated with LSI for high performance and communication systems.