MEMS Approach for Automobiles and Robots

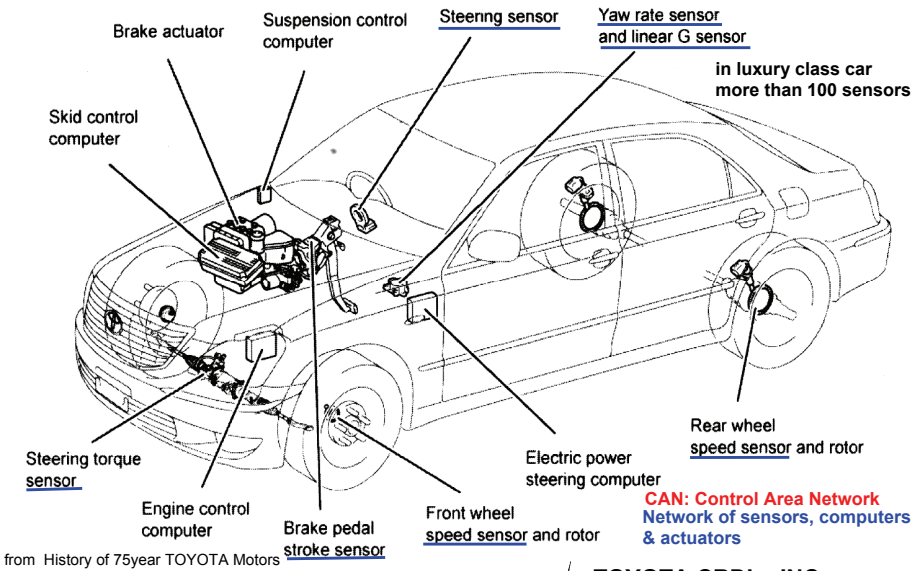
Yutaka NONOMURA
Professor
Department of Mechatronics Engineering
Faculty of Science and Technology
Meijyo University
Former Principal Researcher
System & Electronics Engineering Dept. III
TOYOTA CENTRAL R&D LABS., Inc.

Outline

1. Sensing Technology for Automobiles

Configuration of VDIM

VDIM : Vehicle Dynamics Integrated Management



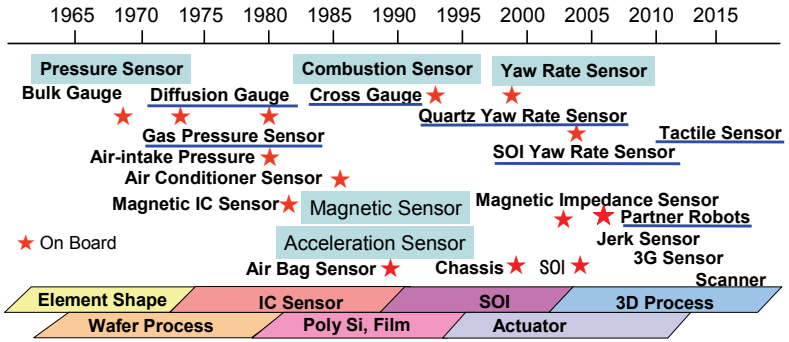
from History of 75year TOYOTA Motors

Kinds of Automotive Sensors

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

Inside Sensor: Pressure, Acceleration, Angular rate (very important to control vehicle)
Outside Sensor: Sonar, Rader, Vision (expecting advanced safety)

Automotive Sensor & MEMS Technology



Bulk Micro Machining
Integrated Micro Machining
Surface Micro Machining
SOI Micro Machining
3D Micro Machining

2. Sensors for Automobiles

2. Sensors for Automobiles

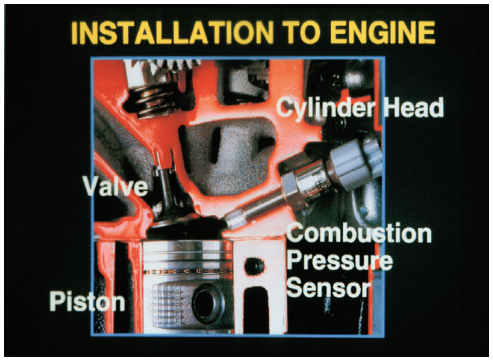
2.1 Piezoresistive effect Sensors

Combustion Pressure Sensor

for Low Exhaust Emission

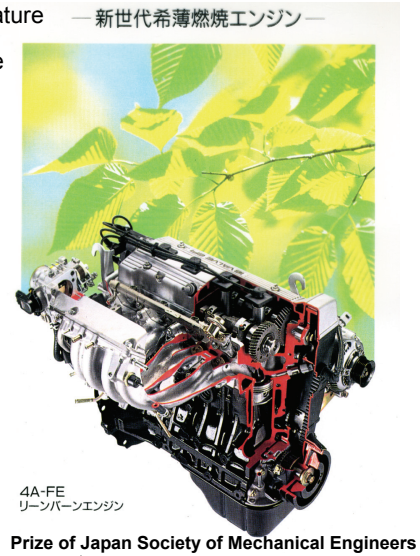
for Low-fuel Consumption

at High Temperature
700-1200degC
at High Pressure
1-2MPa



Lean Burn Engine (TOYOTA)

1993

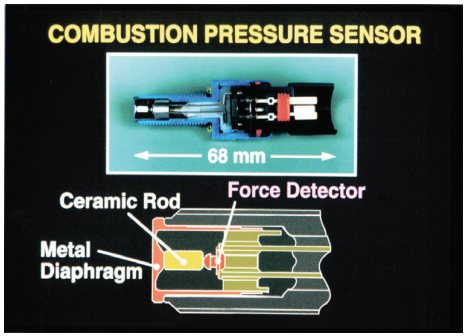


Prize of Japan Society of Mechanical Engineers

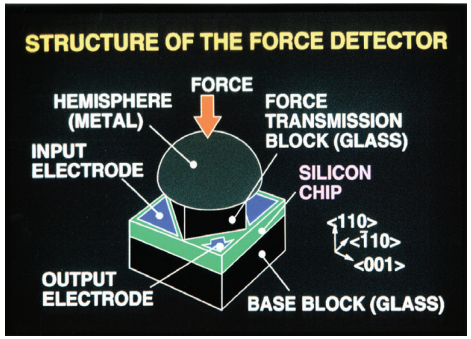
from Y. Nonomura et. al., IMechE (1994)

Combustion Pressure Sensor

Installed on TOYOTA Lean Burn Engine in 1993



Cross Section View

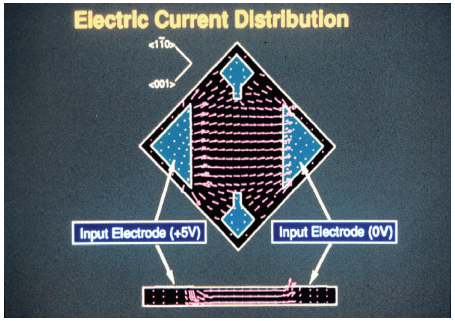


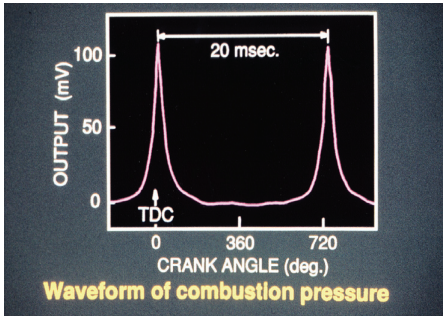
Cross Gauge Type

Piezoresistive effect of Semiconductor single crystal Si

from Y. Nonomura et. al., IMechE (1994)

Combustion Pressure Sensor





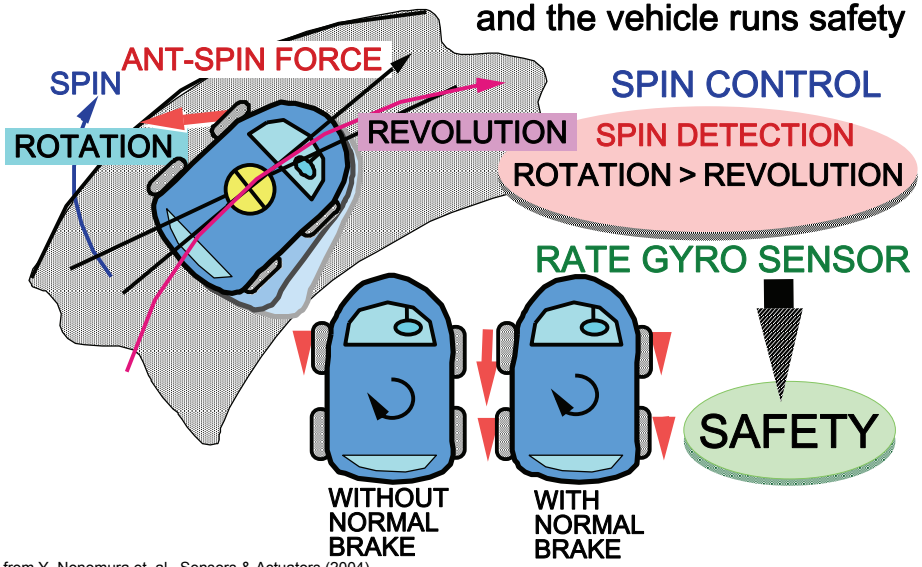
from Y. Nonomura et. al., IMechE (1994)

2. Sensors for Automobiles

2.2 Quartz Yaw Rate Sensor

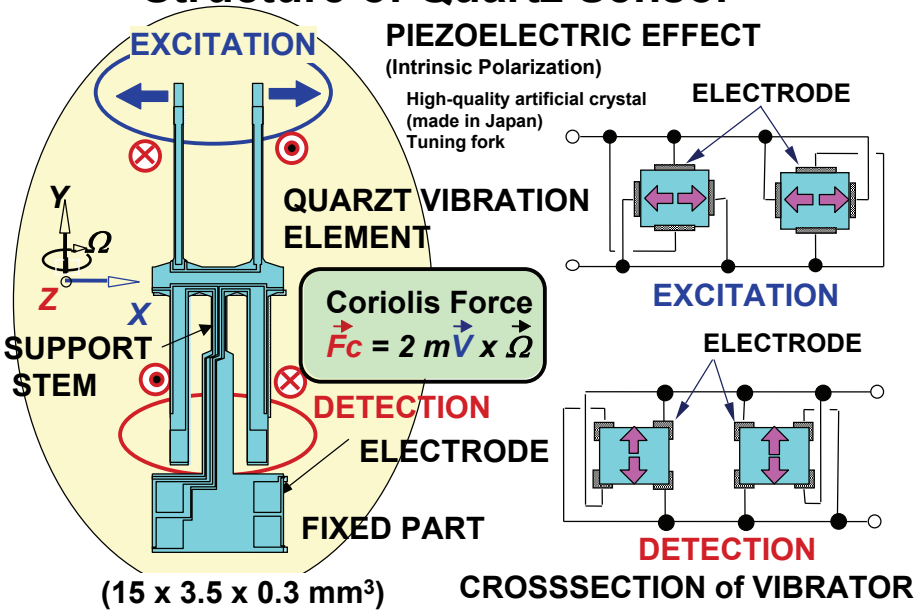
What is VSC

Generate anti-spin force and the vehicle runs safety



from Y. Nonomura et. al., Sensors & Actuators (2004)

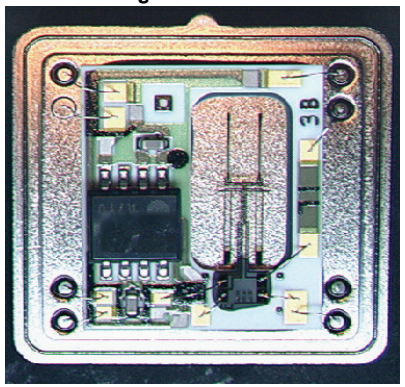
Structure of Quartz Sensor



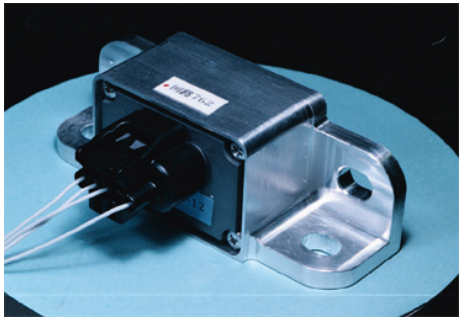
from Y. Nonomura et. al., Sensors & Actuators (2004)

Quartz Yaw Rate Sensor

clear & glitter sensor element



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
Strong & tough case

from Y. Nonomura et. al., Sensors & Actuators (2004)

2. Sensors for Automobiles

2.3 3-Axis Accelerometer

An SOI 3-Axis Accelerometer with a Zigzag-shaped Z-electrode for Differential Detection

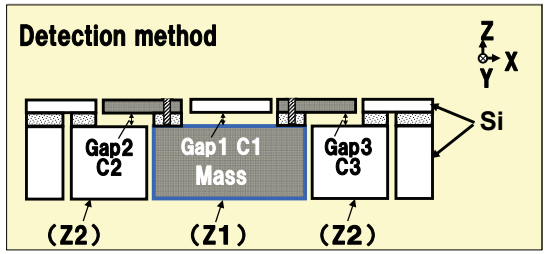
Transducers2011

Motivation

- A highly-accurate and reliable 3-axis accelerometer is required for automobiles and robots control.
- Differential detection for Z-axis is essential to improve the accuracy of the accelerometer.

● **Zigzag-Shaped Z-electrode (ZSZ)**

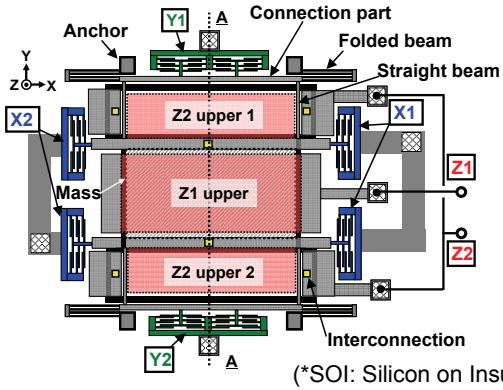
- Differential detection for Z-axis is achieved with only two Si layers.
- Gap distances 1-3 are equal by the uniformity of the oxide layer.



from M. Fujiyoshi, Y. Nonomura, et al. Transducers 2011

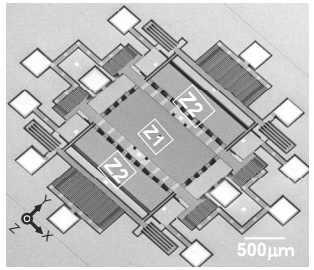
Zigzag-Shaped Z-electrode (ZSZ)

SOI 3-Axis Accelerometer with ZSZ

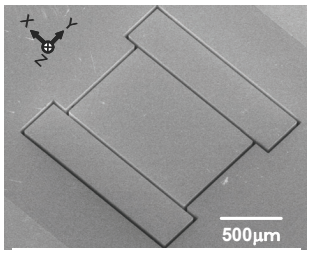


(*SOI: Silicon on Insulator)

1. SOI* for sensor material
2. All translational motion detection
3. Zigzag-Shaped Z-electrode (ZSZ)



front side



back side

from M. Fujiyoshi, Y. Nonomura, et al. Transducers 2011

TOYOTA CRDL., INC.

IEEE SENSORS 2014

November 2-5, 2014 ● Valencia. Spain

Best Poster Competition

Best Wednesday Poster Award

is presented to

"SOI 3-Axis Accelerometer with a Stress-Reduction Structure"

Motohiro Fujiyoshi[1], Yoshiteru Omura[1], Hirofumi Funabashi[1], Teruhisa Akashi[1], Yoshiyuki Hata[1], Yutaka Nonomura[1], Takahiro Nakayama[2], Hitoshi Yamada[2]

[1]Toyota Central R&D labs., Inc., Japan; [2]Toyota Motor Corporation, Japan

IEEE

Ignacio R. Matias

IEEE SENSORS 2014 Technical Program Chair

Sensors Council

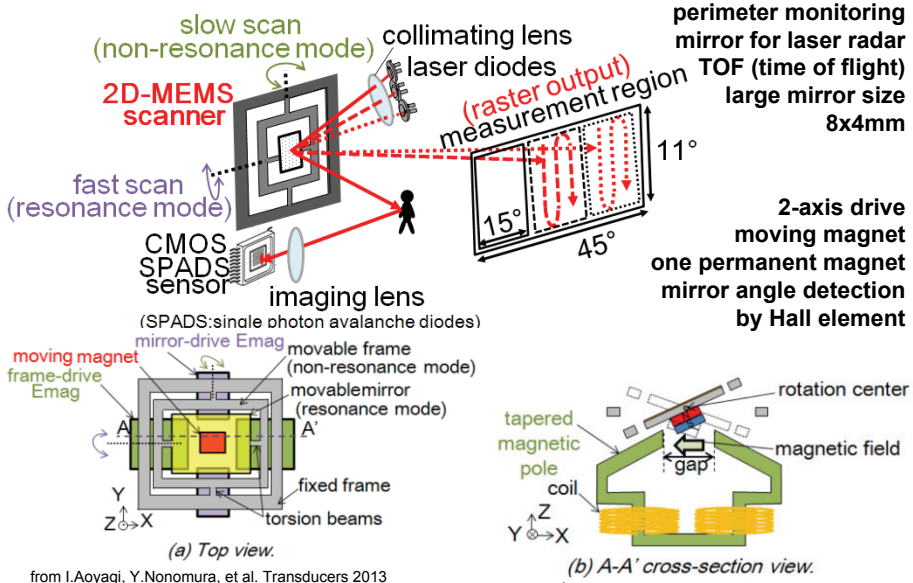
TOYOTA CRDL., INC.

2. Sensors for Automobiles

2.4 Optical MEMS

TOYOTA CRDL., INC.

MEMS Scanner

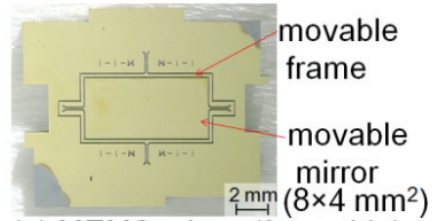


perimeter monitoring
mirror for laser radar
TOF (time of flight)
large mirror size
8x4mm

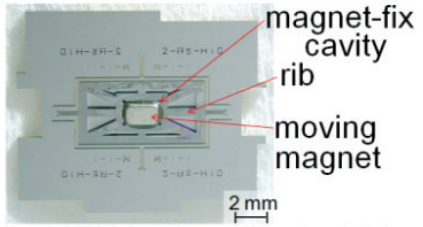
2-axis drive
moving magnet
one permanent magnet
mirror angle detection
by Hall element

from I.Aoyagi, Y.Nonomura, et al. Transducers 2013

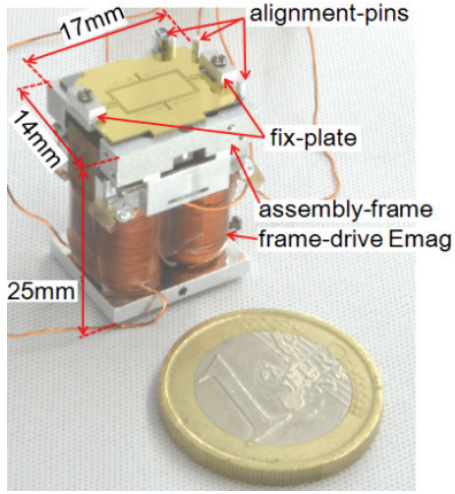
Structure of MEMS Scanner



(a) MEMS mirror (front side).

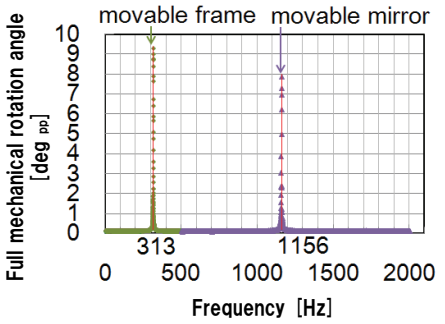


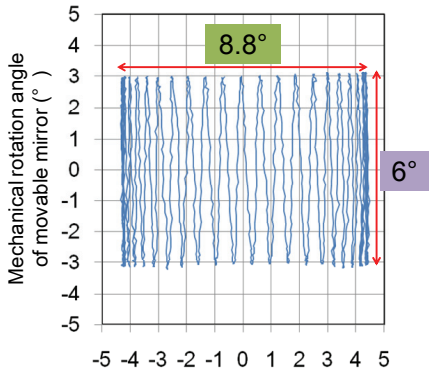
(b) MEMS mirror (back side).



from I.Aoyagi, Y.Nonomura, et al.Transducers 2013

Characteristics of MEMS Scanner





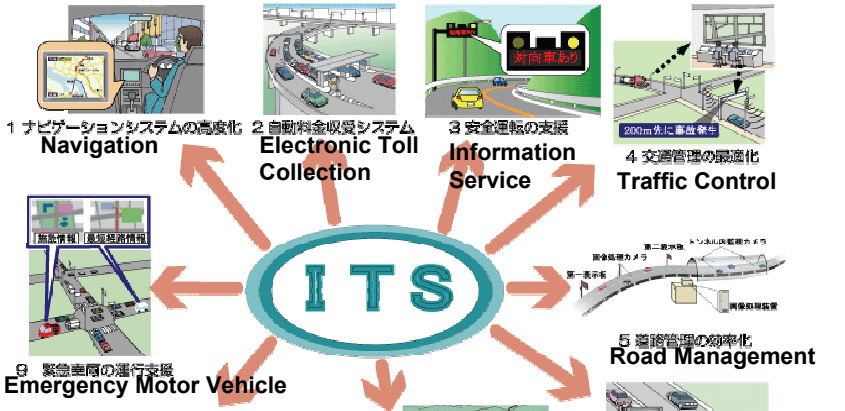
Driving condition
-frame (non-resonance): 30 Hz, 700mA$_{pp}$
-mirror (resonance) : 1.3 kHz, 19mA$_{pp}$

from I.Aoyagi, Y.Nonomura, et al.Transducers 2013

3. ITS & Probe Car

ITS in Japan

intelligent transportation system

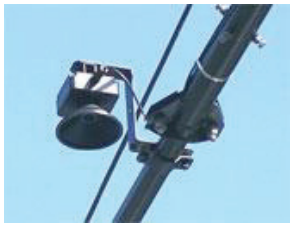


http://www.dc.ogb.go.jp/road/michiarekore/its/img/its_image.gif

ITS Sensors

▲光ビーコンヘッド Optical Beacon

光ビーコン、路車協調システム、住友電エグループ
http://www.sei.co.jp/newsletter/2012/10/product.html



Ultrasonic Sensor

Video Camera

大阪府警察
https://www.police.pref.osaka.jp/03kotsu/kisei/kansei/kansei03_1.html

Ultrasonic Sensor System

一般社団法人UTMS協会 UTMS:Universal Traffic Management Systems
http://www.utms.or.jp/japanese/cont/syusyuu/index2.html

Probe Car

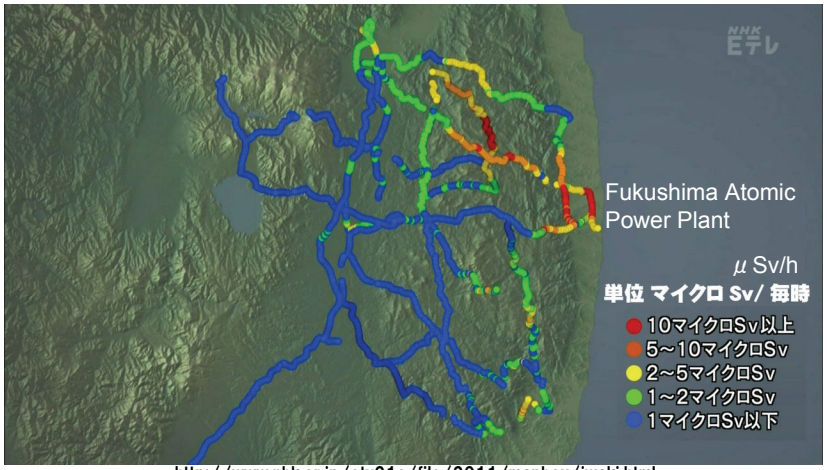
A road map made by the probe cars
by ITS Japan with TOYOTA, HONDA, NISSAN and Pioneer
The Great Eastern Japan Earthquake on March 11, 2011
Very useful for a rescue and transport
Blue lines are travelable. Red crosses are closures.

Probe Car: GPS (Global Positioning System), map, gyro and speed sensors, and wireless network

Data Center: data gathering and big data analysis

Car Navigation System or Internet: showing the map immediately

Probe Car
Car & Radiation Sensor
The road to the Fukushima Atomic Power Plant



http://www.nhk.or.jp/etv21c/file/2011/mapbox/iwaki.html

Probe Car

Google Street View

Sensors: GPS, Camera, Laser Rader, Gyro, Speed, Acceleration

http://www.google.com/maps/about/behind-the-scenes/streetview/privacy/

http://internet.watch.impress.co.jp/docs/news/20130926_617016.html

http://vancouver.keizai.biz/headline/photo/760/

Abundance of Automotive Sensors

Automotive Sensors

More than a hundred sensors / car

Temperature | Gas | Pressure | Position | Angle | Speed

Angular Rate | Acceleration | Force | Vibration | GPS

Windshield Wiper | Brake | Lights

Camera

Laser Rader

Inside Sensors

Millimeter-wave Rader

Sonar

Outside Sensors

Annual automobile production is about 100 million .
Total number of sensors in automobiles will be 10 billion a year.

Automobiles keep running around each and every roads on the earth.

4. Sensors for Robots

4.1 Robot Use of Automotive Sensors

Toyota Group has a dream
to create a new world and style of life with robots as partners.

Role of the Artificial Three Semicircular Canal

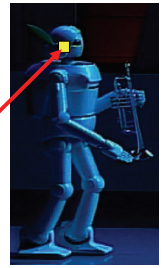
Person

IMU: inertial measurement unit

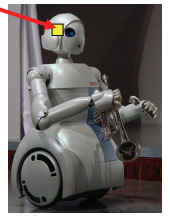
Walk on stilts
with keeping balance

Artificial
Three Semicircular Canal
(Gyro)

Ride on wheel
with keeping balance



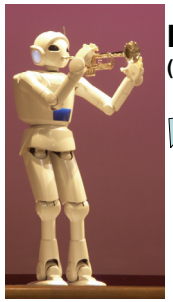
Biped-type Robot



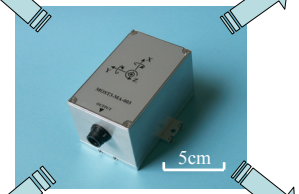
Rolling-type Robot
(Inverted Pendulum)

from Y. Nonomura et. al.,Sensor Symposium, (2006)

Robots with the Inertial Force Sensing System



Biped-type Robot
(Plays the Trumpet)



Artificial Three Semicircular Canal
with three gyro sensors, three acceleration sensors, and a digital signal Processor

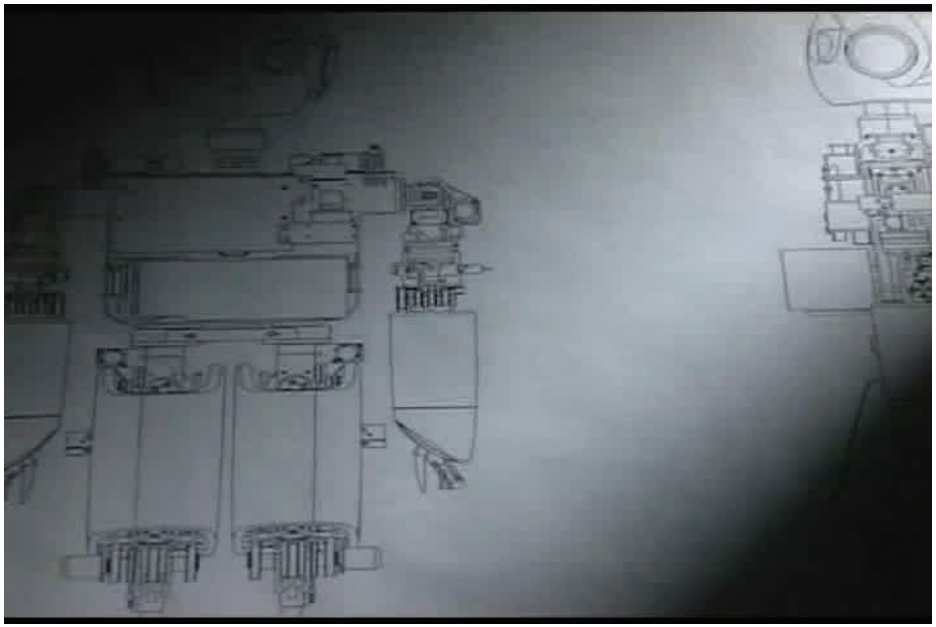
Biped-type Robot with Wire Drive

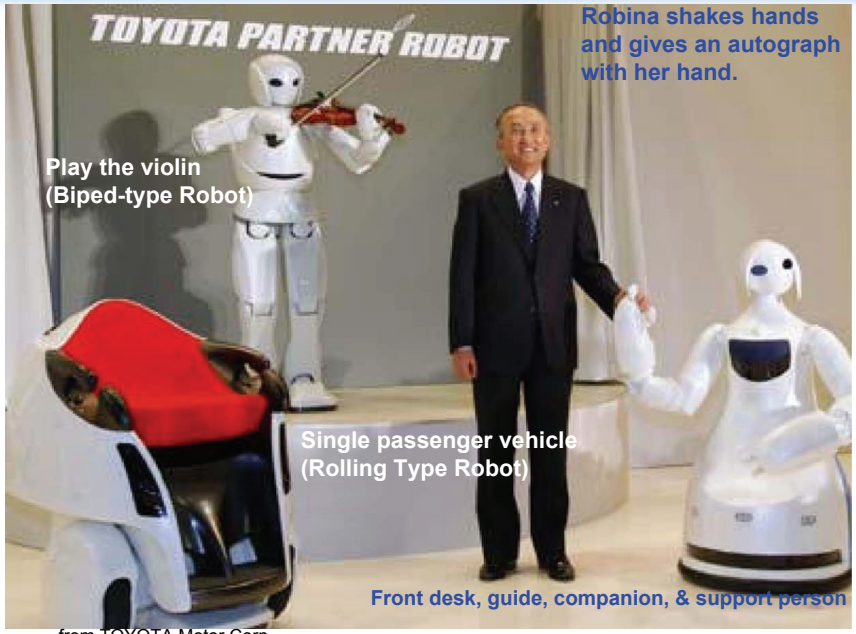
Parson Carrier Biped-type Robot
2005
AICHI EXPO

Rolling Type
(2 + 1 wheels)
<i-Swing>
2006
Motor Show

Rolling Type (2 wheels) Robot
(Inverted Pendulum)

from Y. Nonomura et. al.,Sensor Symposium, (2006)



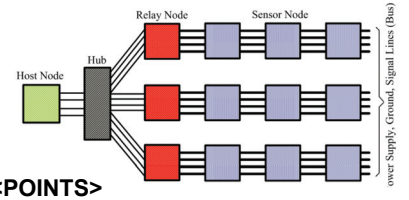


from TOYOTA Motor Corp.

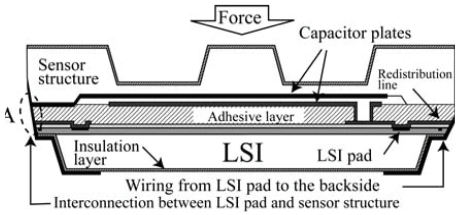
4. Sensors for Robots

4.2 Tactile Sensor with Nerve Network

Nerve Net Type Tactile Sensor

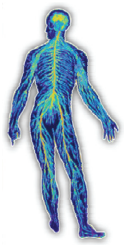


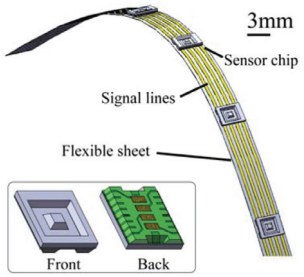
<POINTS>
Serial bus, Event driven against congestion
Sensor chip on signal processor
Signal outputs when force changes
Nerve like relay node (several tens of thousands)



Tactile sensor chip

Robina, TOYOTA



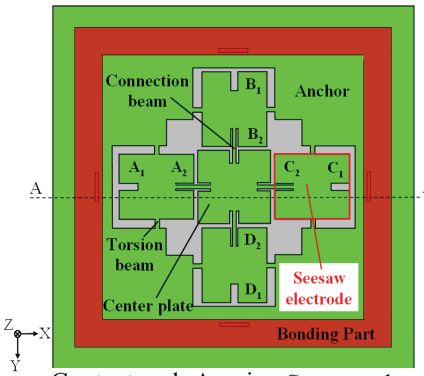


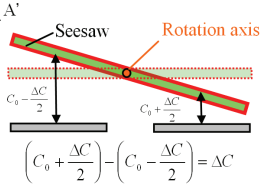
Tactile sensor chip and signal line

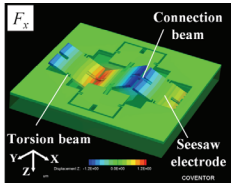
from M. Makihata, Y. Nonomura, et al. Transducers 2011

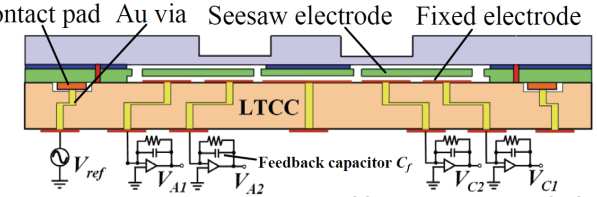
Structure of Tactile Sensor Element

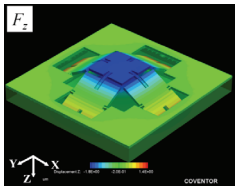
- triaxial force detection with seesaw electrode
- complete differential detection
- electrostatic capacitance detection
- SOI (Silicon on Insulator) substrate stable material
- integrated architecture sensor element and LSI







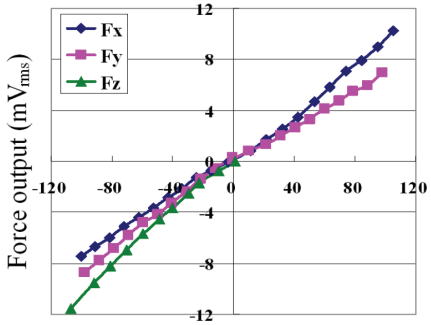




from Y. Hata, Y. Nonomura,et al.,MEMS 2014

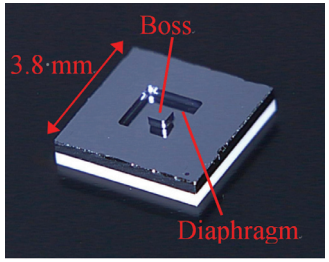
- LTCC (Low Temperature Co-fired Ceramic)

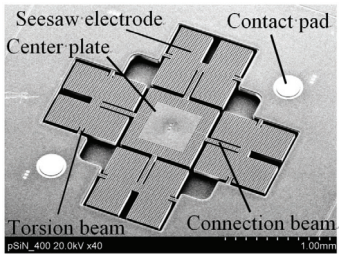
Characteristic of Sensor Element



$$\begin{pmatrix} F_x \\ F_y \\ F_z \\ 0 \end{pmatrix} = \frac{1}{4} \cdot \begin{pmatrix} 2 & 0 & -2 & 0 \\ 0 & 2 & 0 & -2 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} \Delta V_A \\ \Delta V_B \\ \Delta V_C \\ \Delta V_D \end{pmatrix}$$

from Y. Hata, Y. Nonomura,et al.,MEMS 2014





5. Summary

➢ **Sensors for automobiles have been advanced with the MEMS technology.**

➢ **New sensors are created with new MEMS technology. The technology will continue to grow.**

➢ **The sensors for the automobiles are connected to the intranet (CAN) for high performance and to the internet with wireless communication systems (ITS & probe car).**

➢ **The automotive sensors are useful for robots. The partner robots need new technologies and new sensors.**