The Next Wave of Sensors – Smart and Connected

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President and CEO - STMicroelectronics
Who We are

- A global semiconductor leader
- 2016 revenues of $6.97B
- $1336 M R&D expenses in 2016
- Listed: NYSE, Euronext Paris and Borsa Italiana, Milan

- Approximately 43,500 employees worldwide
- Approximately 7,500 people working in R&D
- ~16,000 patents; ~500 new filings (in 2016)
- 11 manufacturing sites, Over 80 sales & marketing offices

As of December 31, 2016
Application Strategic Focus

- Smart Things
- Smart Home & City
- Smart Industry
- Smart Driving
Connected Sensing
A key part of the Internet of Things & Smart Driving

Sense → Smart Driving Applications → Actuate
Sense → IoT Applications → Actuate

Smartphone
Gateway
In-vehicle Gateway

Cloud
Analytics
Storage

Servers
Network infrastructure
(Switch / Router)

Big data & cloud
Internet of Things
Enabled by Connected Sensors

Smart Things
- Sensing to understand the environment around an IoT device
- Bio-information capture for wearable device
- Micromirrors for multimedia projection and scanning

Smart City
- Remote monitoring, activation and dimming control for street lighting
- Connected monitoring stations for air quality, security and traffic
- Empty space detection for Smart parking

Smart Home
- Smart control of heating, air-con, appliances, locks & alarms
- Voice-controlled home environment
- Smart Meters for electricity, gas and water

Smart Industry
- More efficient factories
- More flexibility and customization
- Safer working environments
- Better man-machine cooperation
Sensors for Smart Industry
What Will Smart Industry Bring?
And What Role Will Sensors Play?

More Intelligent & Aware
More Connected
More Efficient
Safer

Enabled by Sensors & Actuators
Enabled remote use of Sensor & Actuator data
Enabled by Sensors & Actuators
Enabled by Sensors & Actuators
Temperature sensors
- Analog and digital contact temperature sensors
- Combo humidity and temperature sensor

Humidity sensors
- Combo humidity and temperature sensor

Pressure sensors
- With water proof solutions

MEMS Microphones
- Analog, digital, top and bottom port solutions

Time-of-Flight Sensors
- Ranging, Multi-zone detection

Local Temperature Monitoring
Environment Humidity Monitoring
Environment Pressure Monitoring
Acoustic Monitoring
Proximity, Position, Presence Detection
Condition monitoring enables a predictive maintenance strategy.

Different defects and wear level have different signatures.

<table>
<thead>
<tr>
<th>Machine condition</th>
<th>Vibration</th>
<th>Power</th>
<th>Noise</th>
<th>Heat</th>
<th>Smoke</th>
<th>Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditions start to change</td>
<td>months</td>
<td>weeks</td>
<td>days</td>
<td>minutes</td>
<td>Vibration Measurements</td>
<td>Model</td>
</tr>
</tbody>
</table>

Condition monitoring enables a predictive maintenance strategy.
Connectivity Options for Sensors

New Manufacturing Installation

• Smart Sensors pre-installed in new equipment
• Connection via wired (IO-Link) or wireless connections

Existing Manufacturing Installation

• Smart Sensor add-on to existing equipment
• Wireless connections for local and cloud connectivity
Motion Sensors for Smart Industry

- Ultra-low power and high performance context sensing solutions
- Dedicated products family for Industrial with 10 year committed availability
- Accelerometer, Gyroscope and 6-axis IMU offer with high accuracy, flexibility, and ultra-low power in tiny packages
- Wide range of sensors drivers and free software libraries from ST’s Open.MEMS SW environment and STM32 Open Development Environment

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
<th>Idd (mA)</th>
<th>Parameters</th>
<th>Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>IIS2DH</td>
<td>3-axis accelerometer with digital output</td>
<td>0.011</td>
<td>6μA consumption in Low-power mode @ 50Hz ODR</td>
<td>LGA-12L 2.0 x 2.0 x 1mm</td>
</tr>
<tr>
<td>IIS328DQ</td>
<td>3-axis digital output accelerometer</td>
<td>0.250</td>
<td>Automotive grade derivative</td>
<td>QFN-24L 4 x 4 x 1.8mm</td>
</tr>
<tr>
<td>I3G4250D</td>
<td>3-axis digital output gyroscope</td>
<td>6.1</td>
<td>Automotive grade derivative</td>
<td>LGA-16L 4 x 4 x 1.1mm</td>
</tr>
<tr>
<td>ISM330DLC</td>
<td>iNEMO Inertial Module: 3D accelerometer and 3D gyroscope</td>
<td>0.75</td>
<td>Noise density in HPM Gyroscope: 3.5mdps/√Hz. Accelerometer: 90μg/√Hz</td>
<td>LGA-14L 2.5x 3.0 x 0.83mm</td>
</tr>
</tbody>
</table>
Sensors for Smart Driving
Market for Sensors for Smart Driving

- Autonomous Driving (ADAS) is a key growth driver requiring multiple high-value sensing elements.
- Sensors for Chassis and Safety applications also continue to grow strongly.

Source: IHS-Markit
The 5 Levels of Vehicle Automation

**Adding Senses**
- Accelerometers and Gyro
- Steering Wheel Angle
- Ultrasonic sensors
- Front Radar Sensor
- Blind Spot sensor
- Rear View Cameras
- Front View Cameras
- Surround View Cameras

**Learning to Drive**
- Systems Networking
- Sensor Fusion
- Distance Measurement
- Traffic Sign Recognition
- Lane Reconstruction
- Free-path Definition
- Precise Positioning
- Real-time Mapping
- Driving Rules Implementation
- Critical Arbitration

**Levels 0-2**
Human driver monitors the driving environment

**Levels 3-5**
Automated driving "system" monitors the driving environment

Source: SAE standard J3016

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**No Automation (Level 0)**
Driver in control

**Driver Assistance (Level 1)**
Driver in control

**Partial Automation (Level 2)**
Driver monitors system at all times

**Conditional Automation (Level 3)**
Driver needed to be able to resume control

**High Automation (Level 4)**
Driver is not required for specific use cases

**Full Automation (Level 5)**
No Driver Required
MEMS Sensor Technologies for Smart Driving

**SENSORS**

- **Acoustic/Vide**o
  - Voice process.
  - Microphone array
  - Digital microphone
  - Camera/Stabilization

- **Motion**
  - Accelerometer
  - Gyroscope
  - Magnetometer
  - 6, 9-axis Inertial

- **Environmental**
  - Humidity
  - Temperature
  - Pressure

**Active Safety**
- Engine control
- Pressure sensor

**Passive Safety**
- Airbag
- Airbag Central Unit

**Non Safety**
- Navigation assistance
- Infotainment
- Key Fobs
- Telematics
- Vertical Dynamics
- Roll Stability Control
- Anti-theft systems
- Electronic Stability Control
- Tire Pressure
- Airbag
- Airbag Central Unit
- Electronic Stability Control (Brakes)
- Key Fobs
- Telematics
Smart Automotive Camera Solutions
Transforming Driver Assistance

Sensing & Viewing Camera
Front-Facing View
Rear & Surround View
eMirror

LiDAR
Autonomous Driving through Sensor Fusion
How to Make a Great Sensor

Physical Sensing + Sensor Features + Sensor Accuracy

- Vibration
- Light
- Movement
- Sound

Size
Power Consumption
Smart Features
MEMS Sensor Accuracy
A key Challenge for IoT & Smart Driving Sensing

- MEMS Sensors for IoT & Automotive applications are required to become ever more accurate:
  - Precise rotation for VR and AR
  - Precise machine motion or vibration sensing
  - Highly accurate motion sensing for dead reckoning
  - Highly accurate barometric reading for altitude measurement
  - High fidelity voice and ambient noise pick-up for voice recognition & noise cancelling

- Higher accuracy generally means more power consumption so sensor makers must innovate to keep within power budgets
MEMS Sensor Accuracy
The Key Parameters

Sensor Accuracy

Noise
- Vibration rejection
- Flicker noise
- High frequency noise

Stability
- Stability over Time
- Stability vs temperature
- Repeatability
MEMS Sensor Accuracy
In Manufacturing Technology & Equipment

Manufacturing equipment
Precise geometries, etching, assembly
Enabling sensor accuracy at yields suitable for high volume manufacturing

Test & Calibration equipment
Accurate Stimuli, Multi-calibration points, Multi Degrees of Freedom (DoF) -tests, high parallelism
Enabling accurate sensors at high volume
Optical Sense Challenges
From Image Capture To Smart Sensing

Robust pixel detection

Embedded safety & security

Tailoring technology to applications
MEMS Sensors, Micro-Actuators & Imaging

**MEMS Sensors and Micro-Actuators**

- **MEMS Motion Sensors**
  - Accelerometer
  - Gyroscope
  - Magnetometer
  - 3,6,9-Axis IMU

- **Environmental Sensors**
  - Pressure
  - Temperature
  - Humidity

- **MEMS Microphones**
  - Digital
  - Analog

- **MEMS Micro-Actuators**
  - Micro-mirrors
  - Fluidic micro-actuators
  - Piezo-actuators

- **Sensor Hub & Sensor Fusion**

- **Open.MEMS libraries**
  - Activity Tracking
  - Carry position
  - Acoustic algorithms

**Imaging**

- **Time-of-Flight Solutions**
  - Camera assist
  - Ranging & Proximity
  - Presence Detection
  - LiDAR, AR/VR, …

- **Specialized Image Sensors**
  - Consumer
  - Automotive

- **Key Assets**
  - Imaging system expertise
  - Innovative pixel design
  - Low power architecture
  - SPAD-based Time-of-Flight
  - Imager silicon process
  - Optical package/module

- **>350 Million Time-of-Flight units shipped**
- **Billions of image sensor units**

Leveraging ST proprietary manufacturing processes & world-class manufacturing capabilities