MEMS in Consumer Electronics – Taxonomy of Motion Sensors

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MEMS Motion Sensors

- Market
- Accelerometers
- Gyroscopes
- Inertial Measurement Units (IMU)

2007: The first use of a MEMS accelerometer in a phone
Jobs introduces the gyro

- 3-axis gyro (angular velocity)
- Pitch, roll & yaw
- Rotation about gravity
- Gyro + accelerometer provide 6-axis motion sensing
- New CoreMotion APIs
- Perfect for gaming
- Standard in every iPhone 4
Accelerometers

Principles
• Linear acceleration causes proof mass to move
• Displacement of mass is measured

Sensing of:
Tilt angle, orientation
Motion
Vibration/shock
Crash

Fig. 1. Schematic structure of an accelerometer
Accelerometer Applications

- Automotive airbag deployment
- Shipping container monitoring
- Carpentry tools, industrial equipment
- Vibration monitoring
- iPhone, smartphones
- Nintendo Wii, Guitar Hero, gaming devices
- Segway, robotics
- Pedometers
- Etc.
# Accelerometer Sensing Principles

<table>
<thead>
<tr>
<th></th>
<th>How it works</th>
<th>Pro</th>
<th>Con</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capacitive</strong></td>
<td>Mass motion changes capacitive gap distance</td>
<td>High sensitivity and bandwidth</td>
<td>Needs ASIC</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low power consumption</td>
<td>Susceptible to shock</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Challenging process</td>
</tr>
<tr>
<td><strong>Piezoresistive</strong></td>
<td>Mass motion causes mechanical strain which is transduced as change in resistance</td>
<td>Simple process</td>
<td>Needs temperature compensation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simple control electronics</td>
<td></td>
</tr>
<tr>
<td><strong>Thermal</strong></td>
<td>Warm gas bubble motion is sensed by thermopile array</td>
<td>Shock resistant</td>
<td>Slow response time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low cost</td>
<td>Poor Z-axis accuracy</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Power consumption</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Large die size</td>
</tr>
</tbody>
</table>
3-Axis Accels for Consumer Apps

- Specs for these accelerometers are similar

<table>
<thead>
<tr>
<th></th>
<th>Kionix</th>
<th>Bosch</th>
<th>Analog Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Device</strong></td>
<td>KXP84</td>
<td>BMA150</td>
<td>ADXL 330</td>
</tr>
<tr>
<td><strong>Range, g</strong></td>
<td>+/- 2</td>
<td>+/- 2, 4, 6</td>
<td>+/- 3.6</td>
</tr>
<tr>
<td><strong>Cross-Axis Sensitivity, %</strong></td>
<td>2</td>
<td>2</td>
<td>+/-1</td>
</tr>
<tr>
<td><strong>Sensitivity, mV/g</strong></td>
<td>819 counts/g (660)</td>
<td>256/128/64 LSB/g</td>
<td>300</td>
</tr>
</tbody>
</table>
MEMS Accel Designs – all different

Kionix
Bulk Micromachining

Bosch
Surface Micromachining

Analog Devices
Surface Micromachining
Gyroscopes

Principles
• Senses angular acceleration
• Rotation of component exerts perpendicular Coriolis force on resonating proof mass
• Displacement is measured
Gyroscope Applications

• Automotive stability control
• Camera image stabilization
• Gesture detection: phones, gaming, user interfaces
• Navigation: cars, robots, toys
  – Indoor navigation
MEMS Gyroscope Design

Over 720 different combinations possible!

Design Style
- Z-axis Sensor
- X/Y-axis
- Vibrating Mass
- Vibrating Ring
- Linear Vibration
- Rotary Vibration
- Single Mass
- Dual Mass Tuning Fork

MEMS Technology
- Bulk Silicon
- Poly Silicon
- Mixed Process

Actuation Mechanism
- Electro-Static
- Electro-
- Piezoelectric
- Parallel Plats
- Torsional Plates
- Comb Drive

Coriolis Sensor
- Electro-Static
- Electro-Magnetic
- Piezoelectric
- Parallel Plats
- Comb Fingers

Red selections:
InvenSense gyro

## Gyro Grades

<table>
<thead>
<tr>
<th></th>
<th>Consumer</th>
<th>Tactical / Navigation</th>
<th>Strategic / Spacecraft</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias drift (stability) deg/hr</td>
<td>10-1000</td>
<td>.1-10</td>
<td>&lt; .01</td>
</tr>
<tr>
<td>Scale Factor Accuracy, %</td>
<td>.1-1</td>
<td>.01-.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Angle Random Walk, deg/hr^1/2</td>
<td>&gt;0.5</td>
<td>.05-.5</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

MEMS Technology
InvenSense Gyro
ADI Gyro
Accel vs. Gyro

• Accel
  – Measures linear acceleration, orientation to gravity
  – Better for robotic or automotive motions

• Gyro
  – Measures angular acceleration
  – Better for tracking human gestures
Inertial Measurement Units (IMU)

- Single package with:
  - 3-axis accelerometer
  - 3-axis gyroscope
  - Enables precise motion tracking and navigation

- Original IMUs for aircraft, spacecraft and missile guidance systems: 40 lbs. and $50K

- MEMS IMUs: automotive, robotic navigation systems, sophisticated user interfaces, smartphones
  - Current price will inhibit near-term use in consumer devices (>$100)
Selecting Motion Sensors

- Application (Range)
- Precision
- Temperature Stability
- Noise
- Power Consumption
- Cost
## Manufacturers (partial list)

<table>
<thead>
<tr>
<th>Accels</th>
<th>Gyros</th>
<th>IMUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADI</td>
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</tr>
<tr>
<td>Bosch</td>
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<td>Honeywell</td>
</tr>
<tr>
<td>Freescale</td>
<td>Epson Toyocom</td>
<td>InvenSense</td>
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<tr>
<td>Honeywell</td>
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<td>Kionix</td>
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<tr>
<td>InvenSense</td>
<td>Honeywell</td>
<td>MEMSIC</td>
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<tr>
<td>Kionix</td>
<td>Infineon</td>
<td>Murata</td>
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<tr>
<td>MEMSIC</td>
<td>InvenSense</td>
<td>STMicro</td>
</tr>
<tr>
<td>Murata</td>
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<td>VTI</td>
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<tr>
<td>STMicro</td>
<td>Murata</td>
<td>Silicon Sensing</td>
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<tr>
<td>VTI</td>
<td>Sensoror</td>
<td>STMicro</td>
</tr>
<tr>
<td>etc.</td>
<td>VTI</td>
<td>etc.</td>
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Summary

• Brief introduction to MEMS motion sensors
• Next: Overview of other MEMS sensors for consumer electronics

STMicro Microphones
Microvision Pico-P