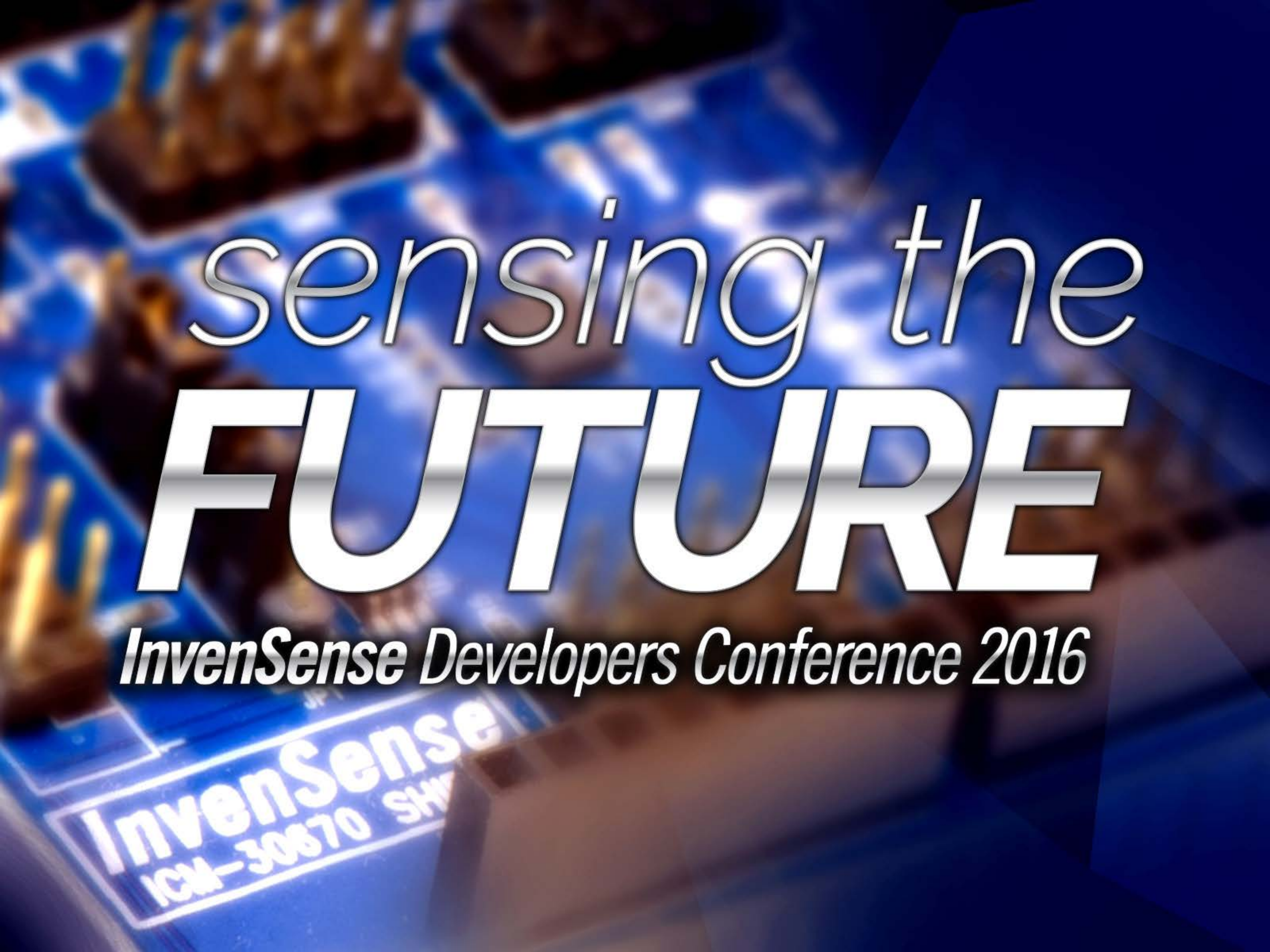
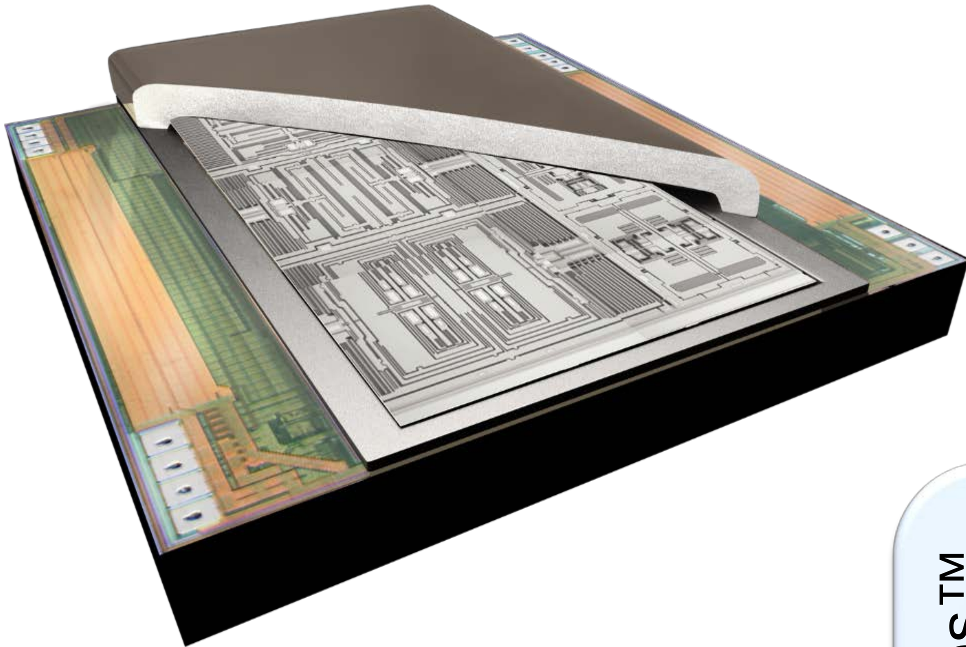

sensing the
FUTURE
InvenSense Developers Conference 2016
InvenSense
ICM-30670

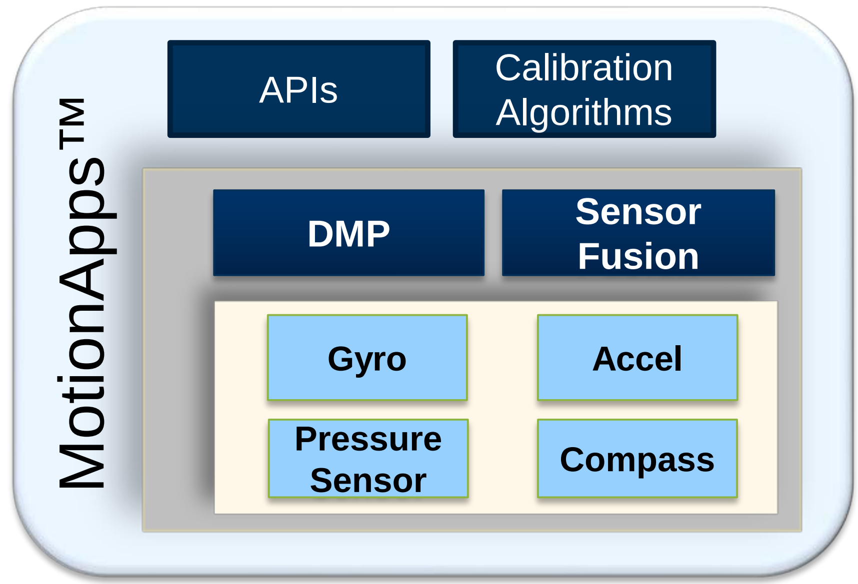
# Motion Sensor Technology and Applications Overview

*Vishal Markandey, Sr. Marketing Manager*

# Motion Sensors



Six-Axis Motion Device

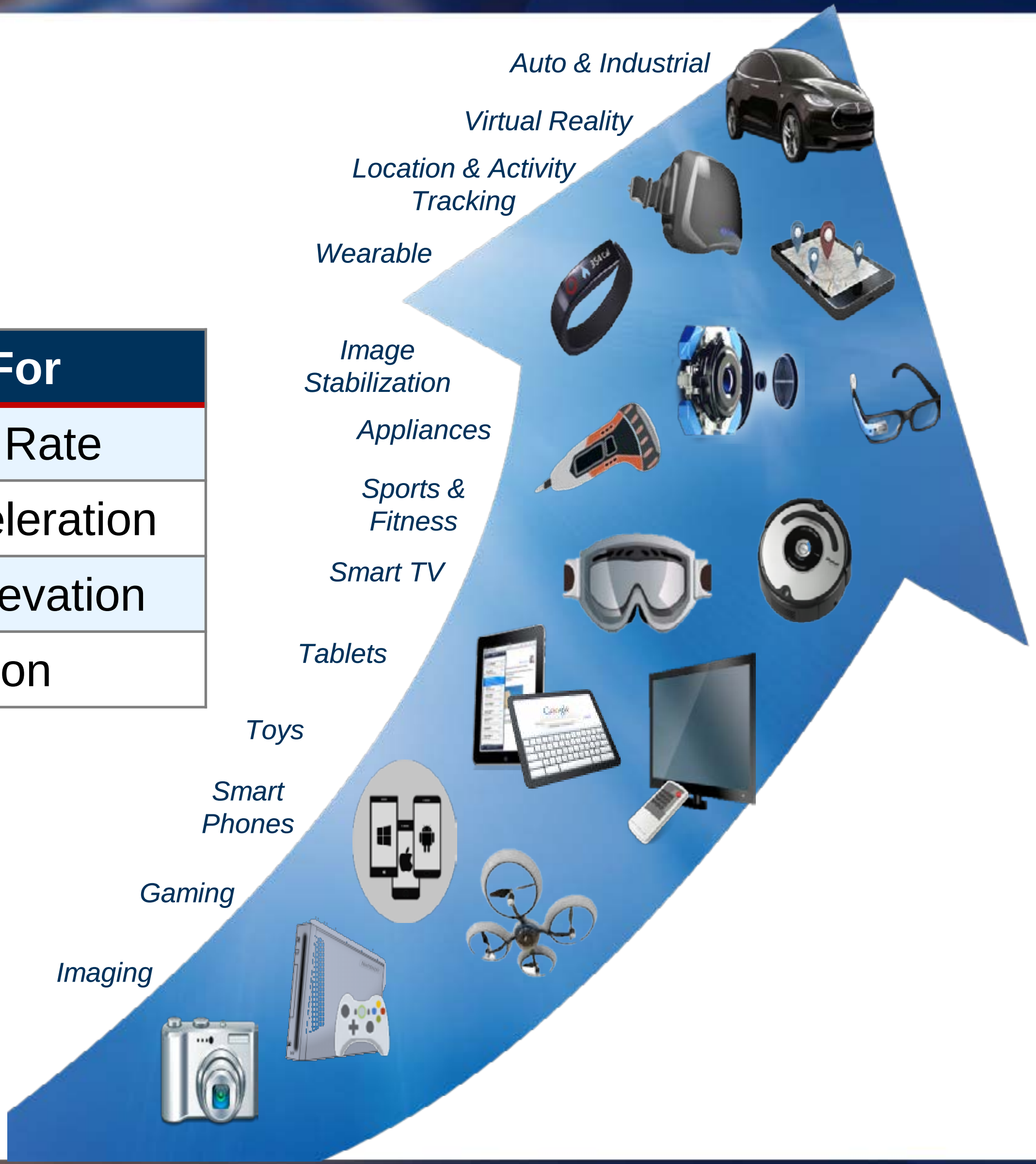



Sensor + Processor Core

# Motion Sensor Applications

sensing the FUTURE

| Sensor | Used For |
| --- | --- |
| Gyroscope | Rotation Rate |
| Accelerometer | Linear Acceleration |
| Pressure Sensor | Relative Elevation |
| Compass | Direction |

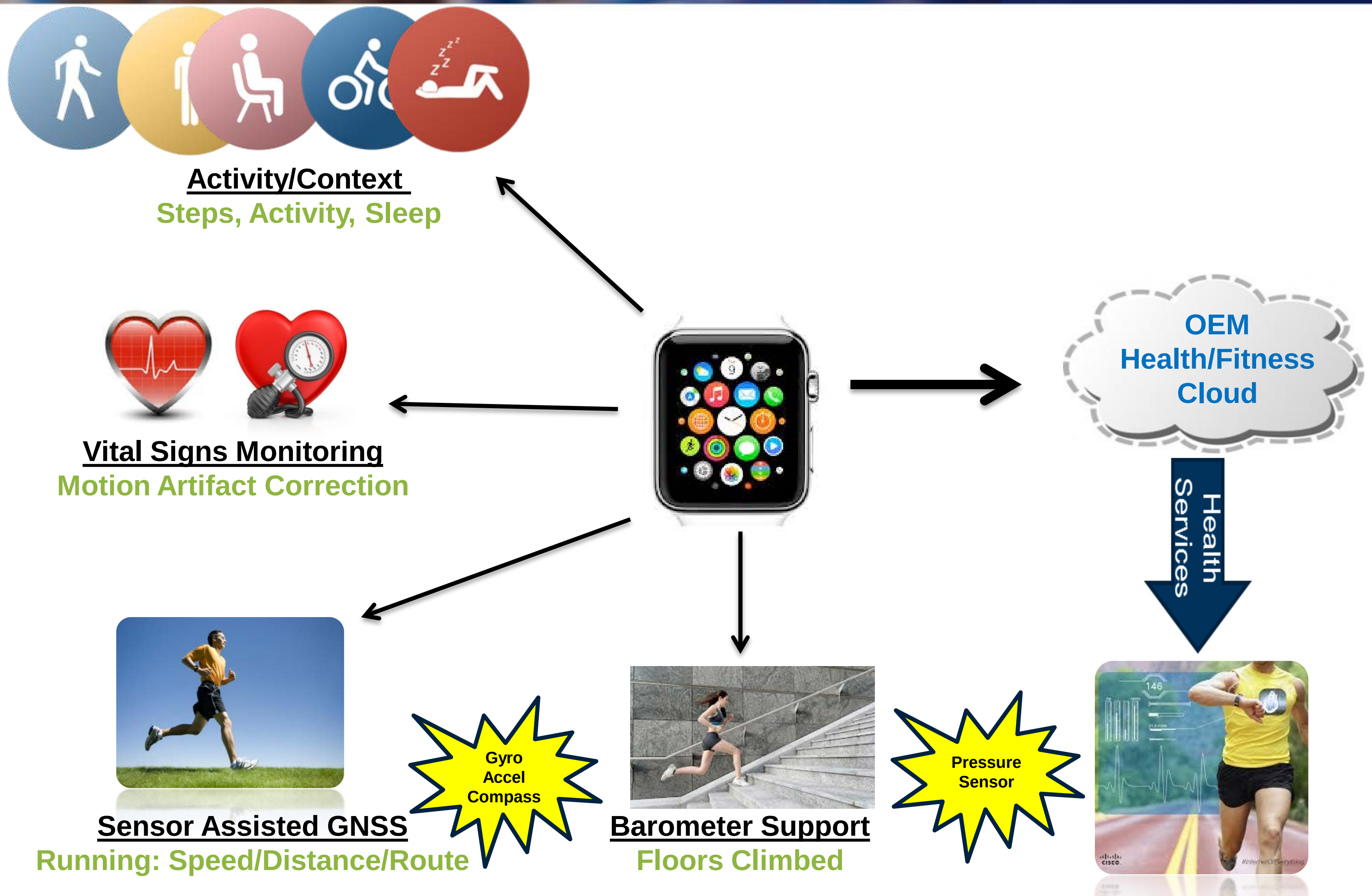




InvenSense

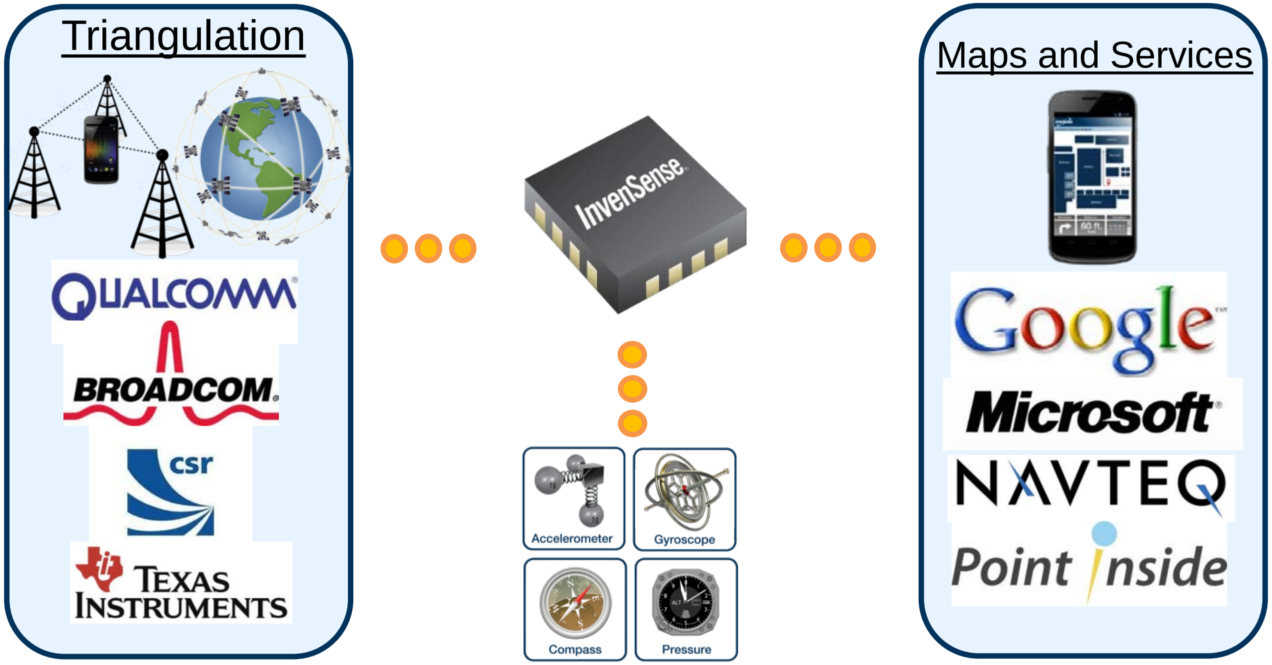
# Application: Health/Fitness Tracker





# Application: Navigation

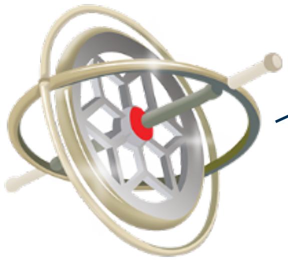
- Outdoor Navigation:
  - GPS + Compass is common (<10m accuracy)
  - 9-axis helps in urban canyon environments
- Indoor Navigation:
  - No GPS, WiFi triangulation for 10-30m accuracy
  - 9-axis provides 1-10 meter accuracy
  - Pressure Sensor: Which floor?



# Application: AR/VR Gaming



**All-in-One HMD**

**Mobile AR/VR Gaming**

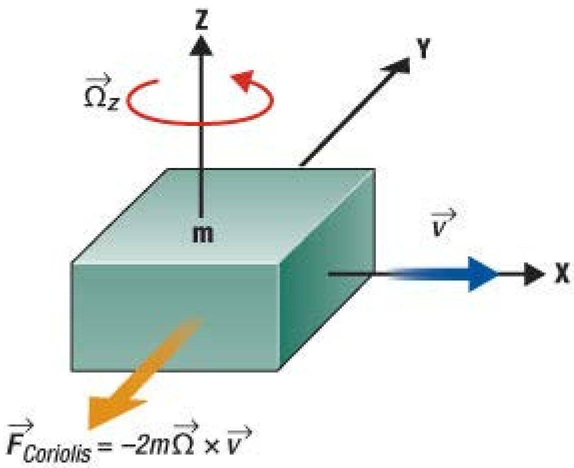
- <u>High performance</u> Gyroscope is important for AR/VR
  - Key specs: Gyro Noise, Gyro Offset, and Gyro Sensitivity
  - **<u>User Experience:</u>** Orientation stays fixed to the real world so that Pokeman stays in same location even after user hand jitter
  - Mobile gets hot because GPS, AP/Graphics, Display and Gyro on 100%
  - Stable gyroscope performance over temperature is critical
  - **<u>User Experience:</u>** Pokeman won't drift over camera scene as mobile temp increases

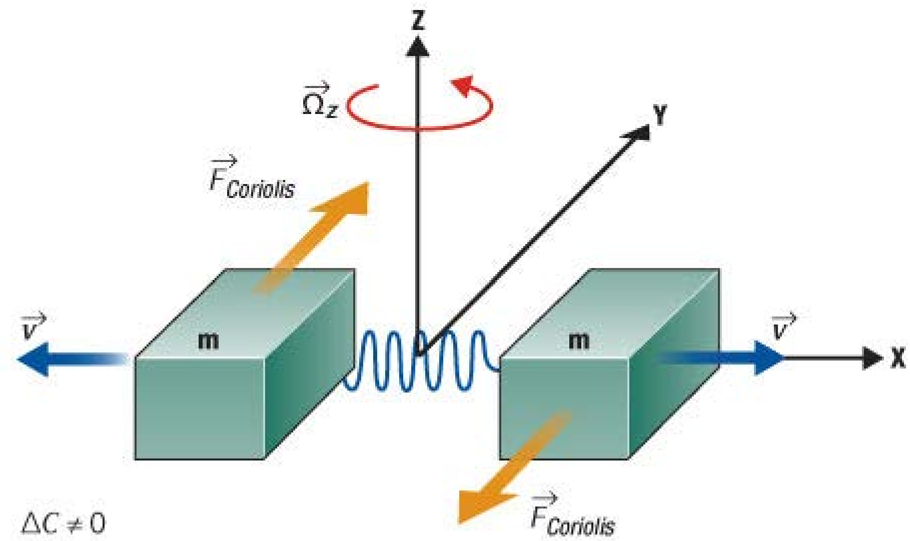
# Gyroscope

# MEMS Gyroscope



## MEMS Gyroscopes use Coriolis Effect to measure Angular Rate




- Mass m is moving with velocity **v** and Angular velocity **Ω** is applied to m
- Resulting force **F** = **-**2m**Ω** x **v** (called Coriolis force) causes object displacement
- **Ω** can be calculated from the measured displacement
- Displacement is measured via capacitive change between the moving mass v. fixed structure
- In practice 2 masses moving in opposite directions are used
  - Resulting Coriolis forces are in opposite directions
  - Differential capacitance between the two masses used to measure **Ω**
  - If linear force is applied the two masses move in the same direction and differential capacitance is zero – makes gyroscope robust to linear acceleration

# MEMS Gyroscope 3-Axis



## InvenSense MEMS Gyroscopes

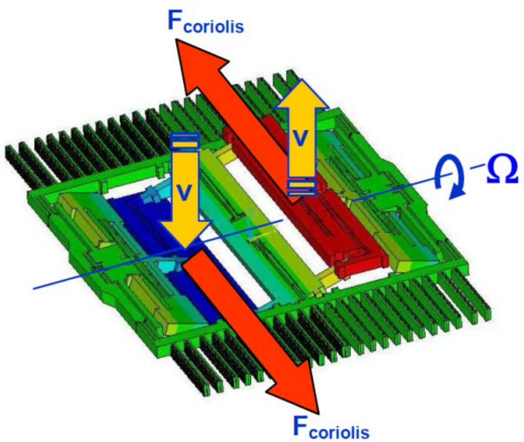



**Figure A**

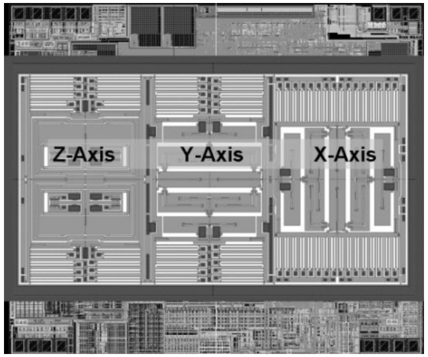



**Figure B**

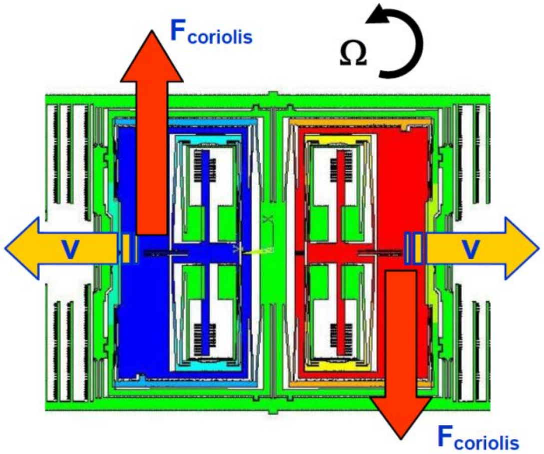



**Figure C**

- X-axis and Y-axis Gyroscopes: Masses move up and down (perpendicular to package plane) resulting in in-plane Coriolis forces for X and Y rotation
- X-axis and Y-axis Gyroscope are basically the same structure mounted 90° from each other as shown in Figure B
- Z-axis Gyroscope: Masses move in-plane as shown in Figure C

# Key Gyroscope Parameters

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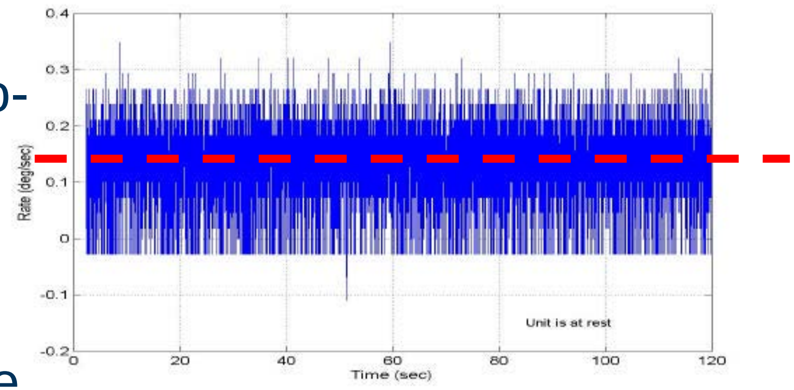
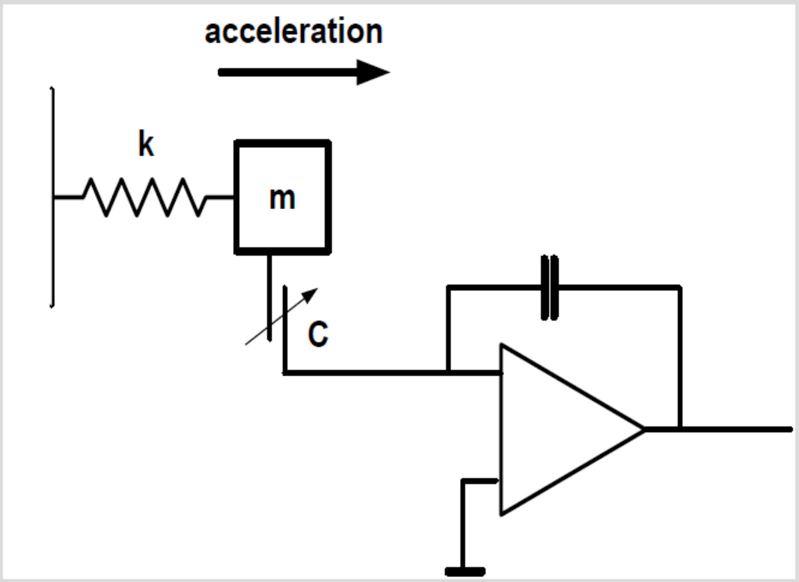
- Sensitivity
  - — Gyroscope output change when subject to 1 dps or deg/sec
  - — ADC word of 16-bits, number of possible output levels $2^{16}$
  - — With a Full Scale Range (FSR) ±250 °/sec, sensitivity scale factor is $2^{16}/(\pm 250)$ = 131 levels (or LSBs)/dps
- Bias & Variation over Temperature
  - — Ideally at zero at rest, but in reality is non-zero, affected by temperature
  - — Called Zero-Rate Output (ZRO) and expressed in deg/sec (dps)
- Noise
  - Random low rate change at rest due to-
    - Mechanical non-linearity
    - White noise from CMOS
  - Measured rate (density) & RMS
  - Seen as drift when integrated over time




ZRO or Bias (dashed red line)= 0.15dps

# Accelerometer

## MEMS Accelerometer




- Suspended proof mass **m** reacts to acceleration in its axis of orientation by moving
- Movement changes capacitance **C** between the mass and its sense electronics
- Capacitance converted to voltage & digitized to provide a measure of acceleration

# Key Accelerometer Parameters

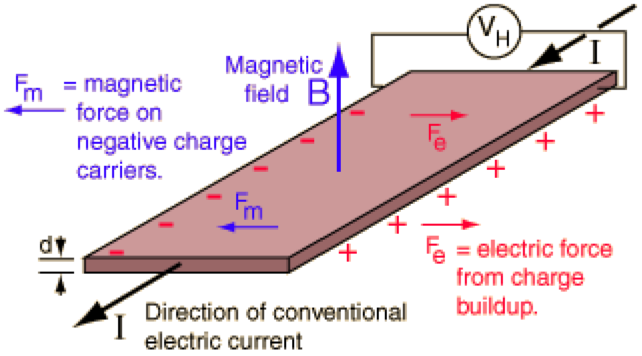
sensing the FUTURE

- Sensitivity
  - Accelerometer output change when subject to 1g
  - ADC word of 16-bits, number of possible output levels $2^{16}$
  - With a Full Scale Range (FSR) ±2g, sensitivity scale factor is $2^{16}/(\pm 2)$ = 16,384 levels (or LSBs)/g
- Bias & Variation over Temperature
  - Ideally at zero at rest, but in reality is non-zero, affected by temperature
  - Called Zero-G Output (ZGO) and expressed in mg
  - Ideal output for X, Y, Z accel at zero is 0, 0, 1g
- Noise
  - Random low rate change at rest due to-
    - Mechanical non-linearity
    - White noise from CMOS
  - Measured rate (density) & RMS
  - Seen as drift when integrated over time

# Compass

# Compass Basics

- Hall Effect
  - Occurs when a magnetic field is applied transverse to flowing current
  - Magnetic field deflects the charges that make up the current, inducing a voltage (called Hall Voltage)
  - Hall voltage can be measured to determine the strength of magnetic field transverse to the current
  - Use multiple sensors oriented in different directions to measure total magnetic field



# Features of AKM's e-compass

- Features of device
  - **Using Hall elements as magnetic sensor**
    - **Wide range of magnetic sensing: ±4900μT**
    - **Excellent linearity**
    - **Reset operation is not necessary** against exposure of strong magnetic field.
  - **Si monolithic structure**
    - 3-axis magnetic sensor and ASIC are integrated into **one chip Si-monolithic IC**
    - Small, thin and simple structure
    - Higher-order orthogonal 3-axis sensing of magnetic field

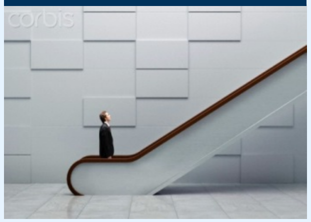
***Having above features, AKM's e-compass is most suitable for various mobile devices.***

# Pressure Sensor

# Pressure Sensor Use Cases

sensing the FUTURE

## Navigation

### Floor Change


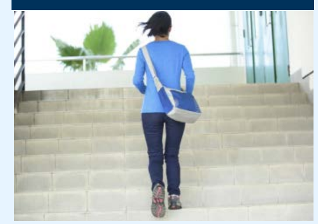
### Absolute Height


### Indoor Navigation

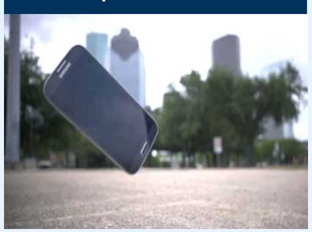

## Fitness

### Calorie Counter


### Cumulative Height


### Stair Step Count


## Context

### Drop Detection


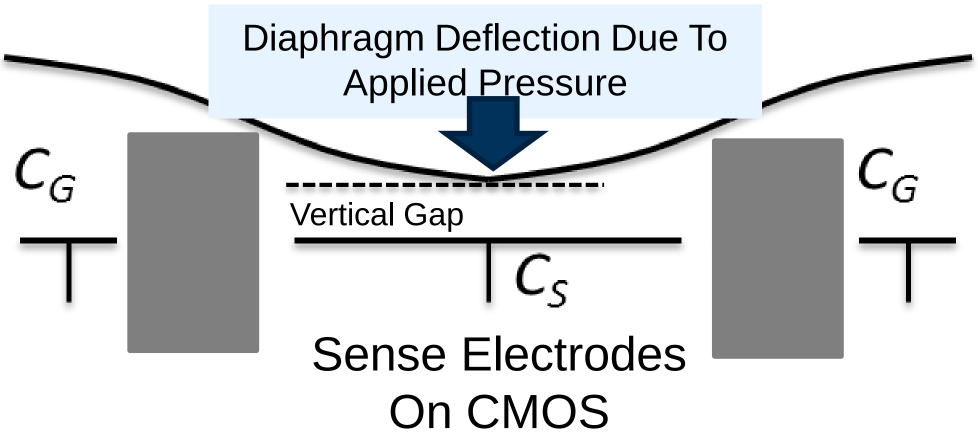
### Guestures


### In-Water Detect


# Pressure Sensor MEMS Structure



- The barometer measures change in pressure, not altitude
- Composed of a diaphragm, exposed to the external environment.
- Underneath the diaphragm are electrodes on the CMOS
- Diaphragm deflection is a function of the external pressure
- CMOS electrodes measure the change in vertical gap (capacitance) due to deflection of the diaphragm

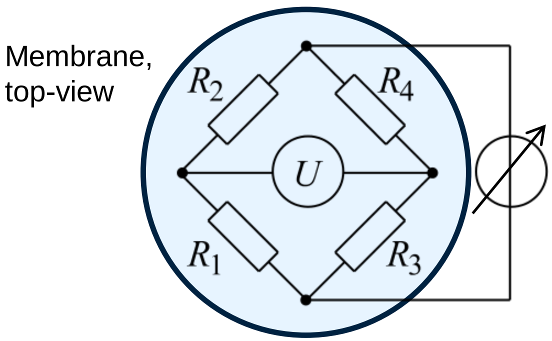



- **Absolute Accuracy:**
  - The difference in measured pressure from the actual pressure
- **Relative Accuracy:**
  - Relative difference between absolute pressure measurements at two different locations, a measurement of pressure change
  - *Used to track altitude change for tracking vertical motion*

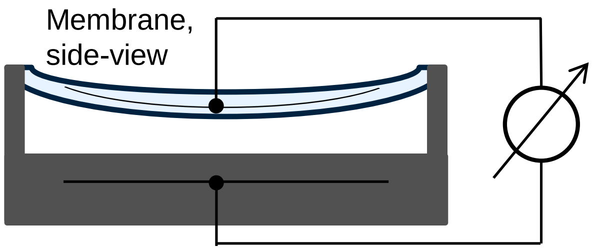
# Pressure Measurement Principle



Strain measurement with **piezoresistors**




Measurement of **Capacitance**




Advantages of capacitive sensors over current state of the art resistive ones:

- Low power consumption: No current flow when measuring capacitance
- Best temperature stability: Piezoresistors are highly sensitive to temperature
- Low noise: Thermal noise of piezoresistors fundamentally limits repeatability at output
- High accuracy: Capacitive principle more sensitive to pressure changes

# Pressure Change: Stair Step Detection

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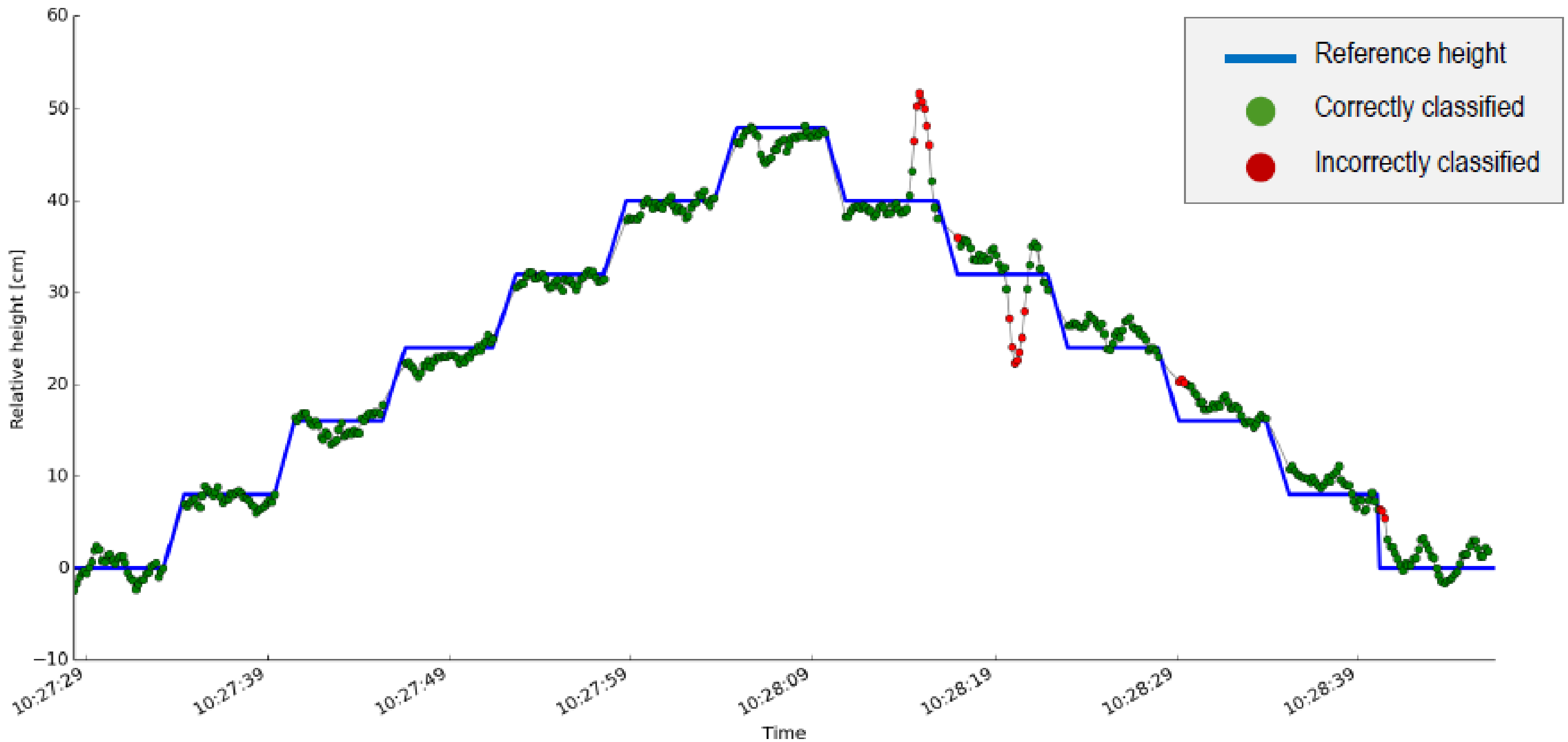



Correctly classified: 94%

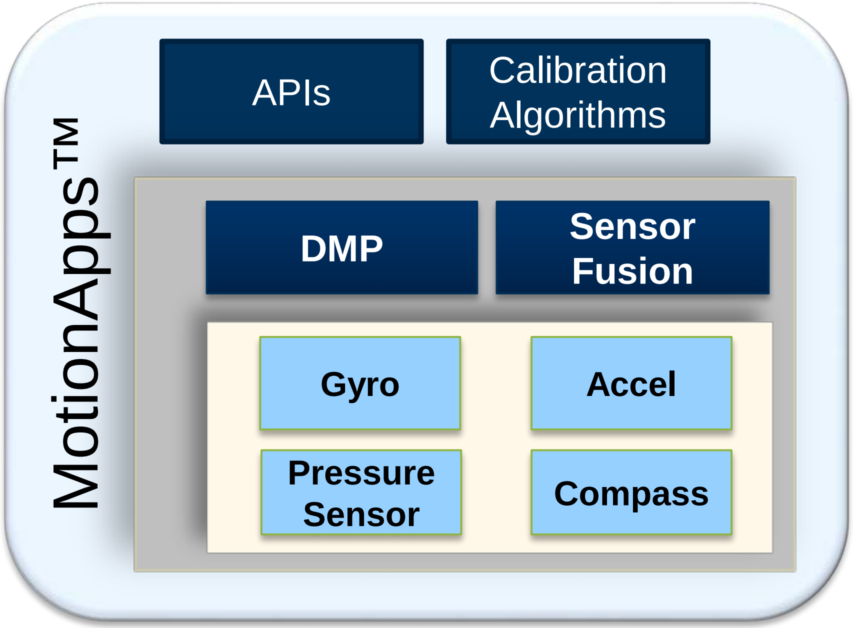
InvenSense Pressure Sensor tracking steps up and down

# Motion Sensor Devices

# MotionTracking Solution



- Sensors calibrated as a complete system for best performance
- Optimized *MotionFusion* software for guaranteed performance
- Smallest board space, low power
- Less components and fewer vendors to qualify
- Higher system reliability



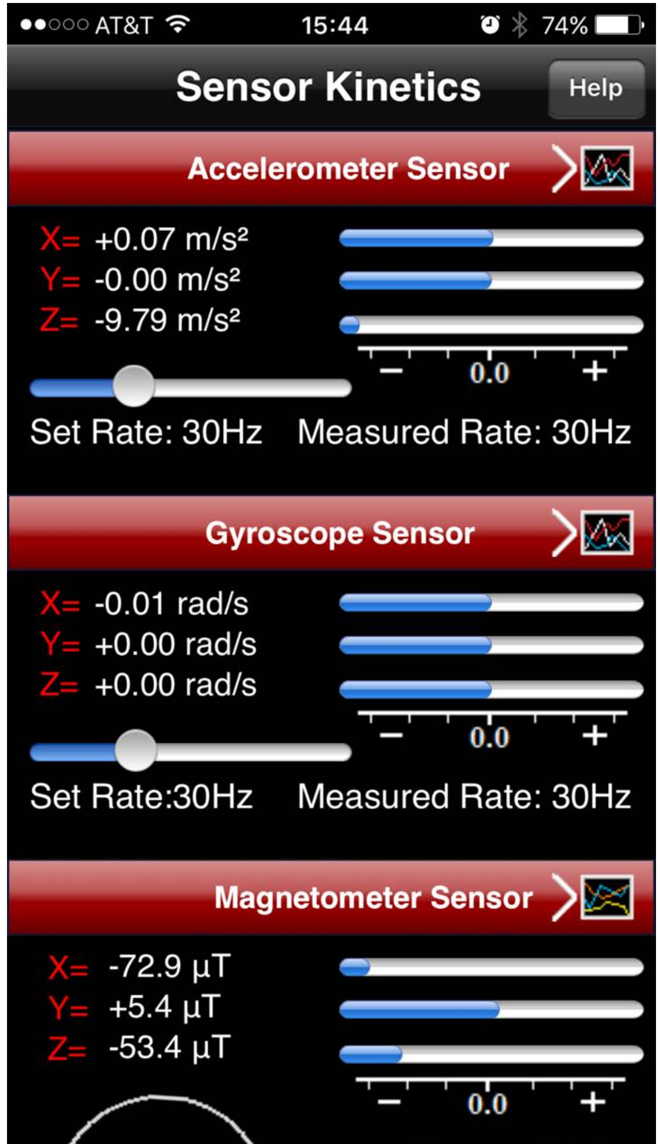
# 6-Axis and 9-Axis Products

sensing the FUTURE

| Device | Highlights | Mobile | Sports | AR/VR | Wear | Image | IoT |
|---|---|---|---|---|---|---|---|
| ICM-20648 | 4K FIFO + DMP | ✓ | | | ✓ | | ✓ |
| ICM-20649 | ±4000dps, ±32g | | ✓ | | | | |
| ICM-20948 | 9-axis, ±2Kdps, ±16g | | | | ✓ | | ✓ |
| ICM-20600/2 | 2.5x3mm; 3x3mm | ✓ | | ✓ | ✓ | | ✓ |
| ICM-20603 | 3x3mm w/ HMD/VR SW | | | ✓ | | | |
| ICM-20690 | Dual Interface; Wide FSR | ✓ | | | | ✓ | |

# Motion Sensors Output





# Thank You