HUMANIZING THE DIGITAL EXPERIENCE

TDK Developers Conference 2018

TDK InvenSense EPCOS tronics microsystems Chirp MICRONAS

HUMANIZING THE DIGITAL EXPERIENCE

High Performance Pressure Sensors

Improve and Enable New Use Cases in IoT and Beyond

Vamshi Gangumalla, System Engineering

TDK Developers Conference
September 17-18, 2018
Santa Clara Marriott

Agenda

- Why Pressure Sensing?
- Types of Pressure Sensors
- Performance Parameters of Pressure Sensors
- Technology Comparison
- Use Case Enablement of High Performance Pressure Sensors
  - ¬ Outdoor vs. Indoor Pressure Sensing
  - ¬ Wearable Activity Monitoring
  - ¬ AR, VR, and Gaming
  - ¬ 3D Navigation
  - ¬ Air Flow
  - ¬ Security Systems
  - ¬ Drones
- Wrap Up

Does The World Need Another Sensor?

Activity Monitoring

Caloric Counting
Fall Detection
Improved Training

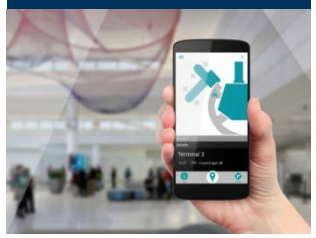
Drones

Improved Flight Control
Lower Cost

AR, VR, Gaming

Improved User Experience

Indoor Navigation



Improved Interior Routes and Travel Time

3D Navigation Apps

AR Indoor Applications

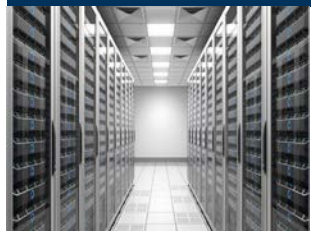
E911

Rapid Emergency Response

Driving

Multi-Level & Underground Navigation

Data & Comms



Improved Total Cost of Ownership & Power Usage Efficiency

Security Systems

More Robust Monitoring & Extended Battery Life

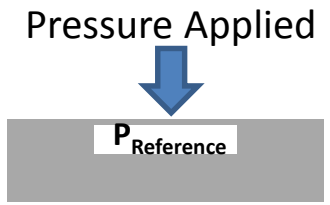
Recreation Products

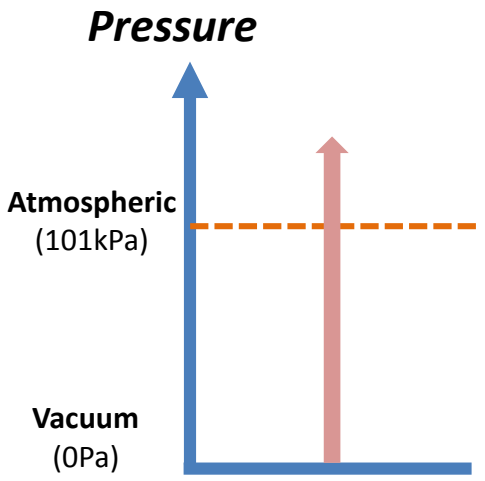
Healthier Alternatives & Improved Training

Types of Pressure Sensors

Absolute

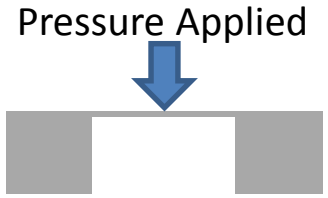
Sensor measure pressure relative to reference pressure or vacuum

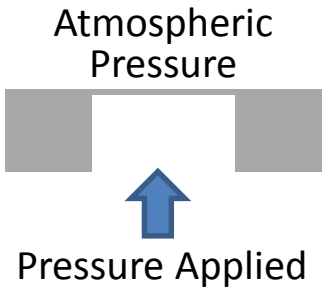


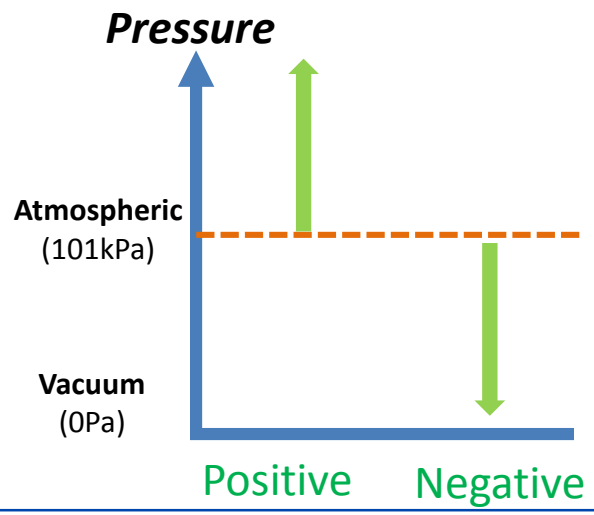


Gauge

Sensor measure pressure relative to atmospheric pressure

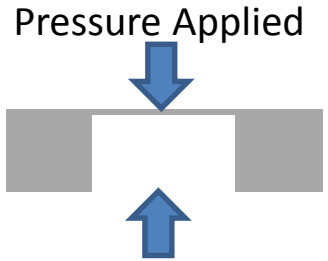


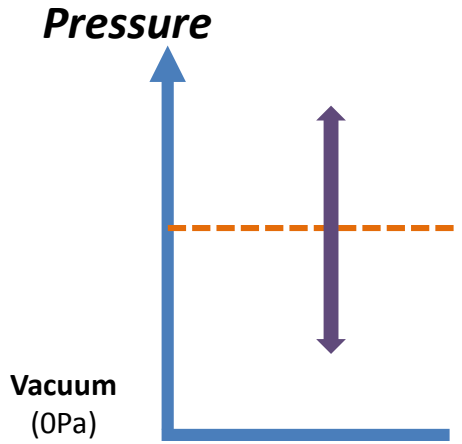




Differential

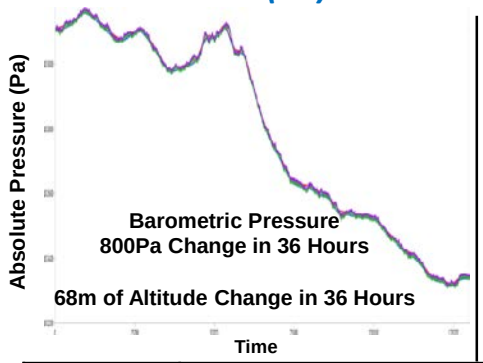
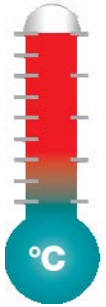
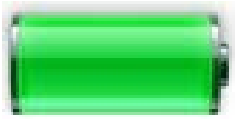
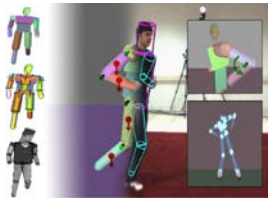
Sensor measures the difference between two pressures





Performance Parameters of Pressure Sensors

- **Sea Level is considered: 1atm = 101kPa = 101,325Pa = 1.01325bar**
  - **Rule of thumb = 1Pa = 8.5cm**

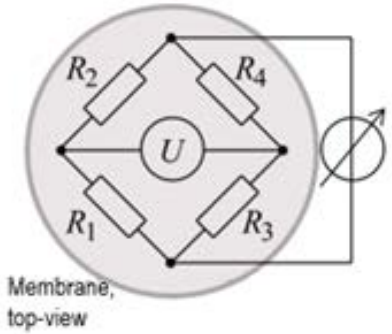
	Absolute Accuracy (Pa)	*Relative Accuracy (Pa/1kPa)*	*Temp Coefficient (Pa/C)*	*Output Data Rate (Hz)*	*Power (uA)*	*Noise (Pa RMS)*	*Environmental Compatibility*
							
Definition	Worst case absolute offset	Sensitivity change between two pressures (i.e. 1kPa change)	Pressure output sensitivity to temperature	Sensor output data rate	Sensor current consumption at 1Hz ODR	Variation in sensor output at constant condition	Compatibility of sensor contact to media (i.e. water etc.)
Use Case	Weather Station E911 (with sensing fusion)	Floor counting (<1kPa)	Wide-temp range applications	Real-time user control & feedback	Extends battery life	Measure small pressure/motion changes	Usage in wide-range of application environments

Commonly Talked About → **Application Dependent** → **Enable New Use Cases**

Piezoresistive vs Capacitive Pressure Sensors

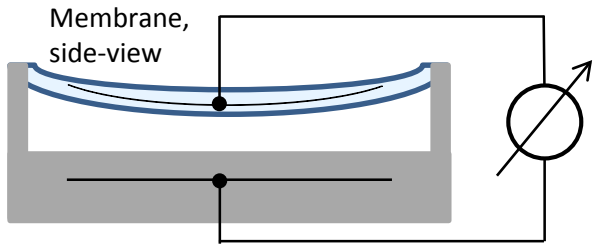
HUMANIZING THE DIGITAL EXPERIENCE

Piezoresistors
Strain Measurement



Detect diaphragm deflection by stress
Convert stress to electrical signal

Capacitive
Measure of Capacitance

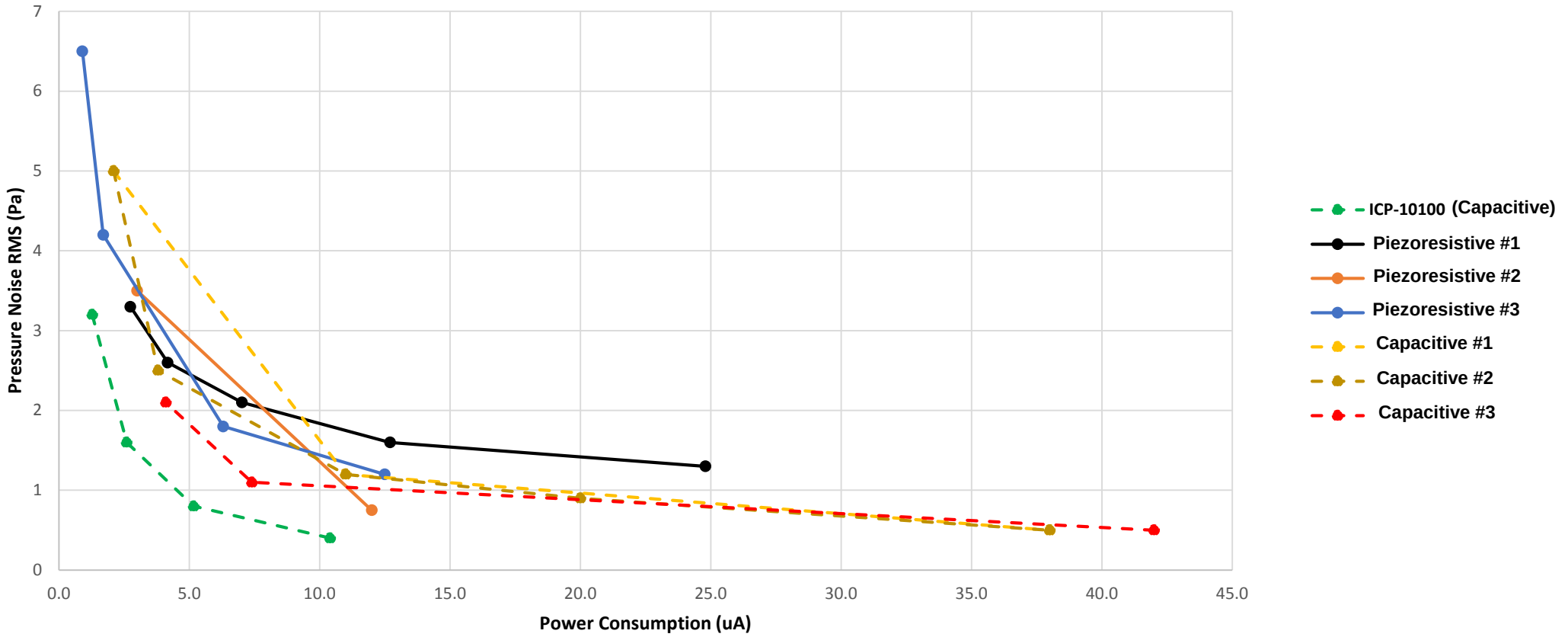


Directly convert diaphragm deflection to electrical signal

Advantages of Capacitive pressure sensors:

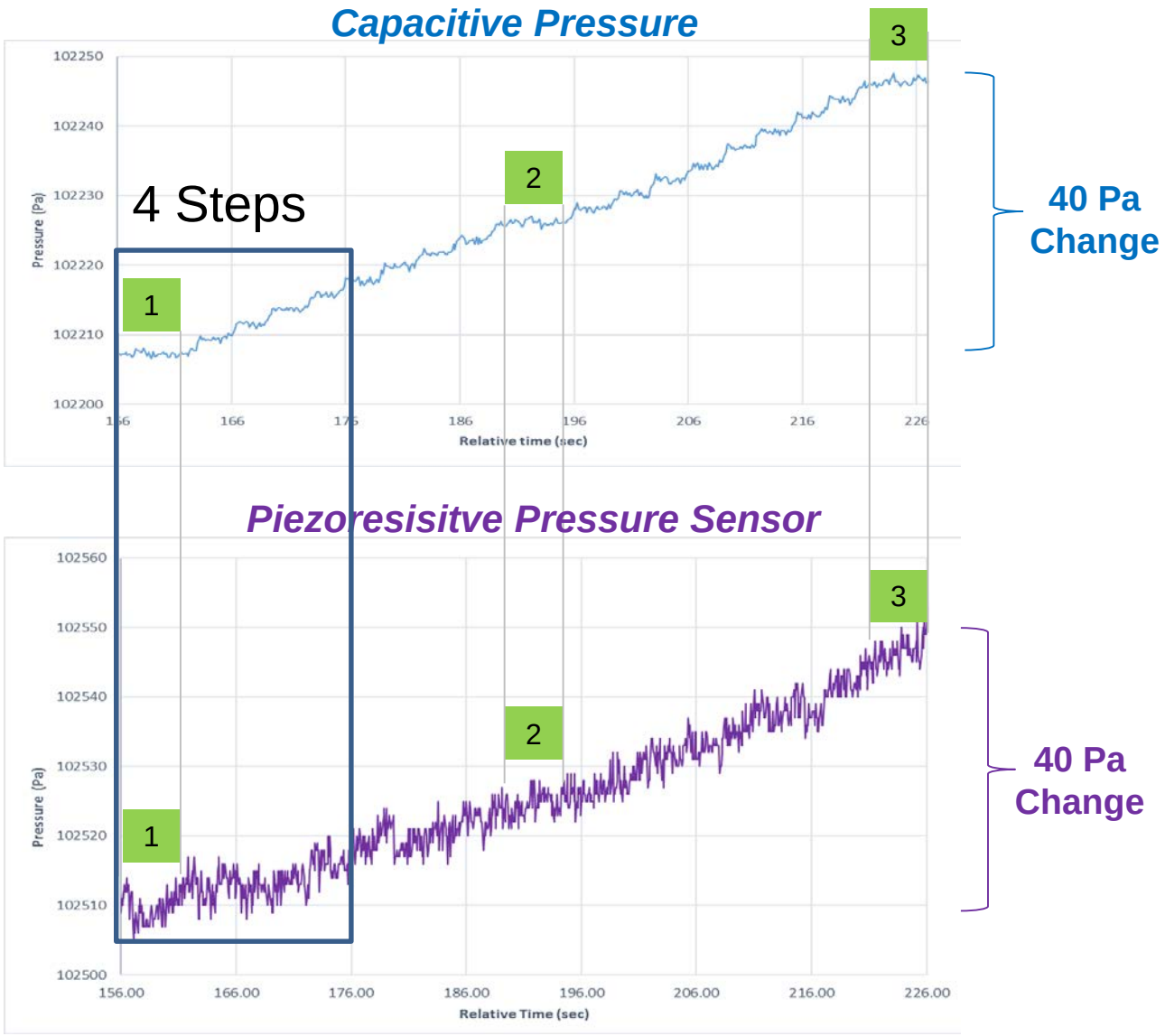
- **Lower power**: No current consumption during capacitance measurement
  - Lower power at same performance
  - Better performance at same power consumption
- **Lower noise**: Thermal noise of piezoresistors fundamentally limits sensitivity/resolution
- **Better temperature stability**: Piezoresistors are highly sensitive to temperature
- **High Accuracy**: Capacitive principle enables greater sensitivity and resolution to pressure changes

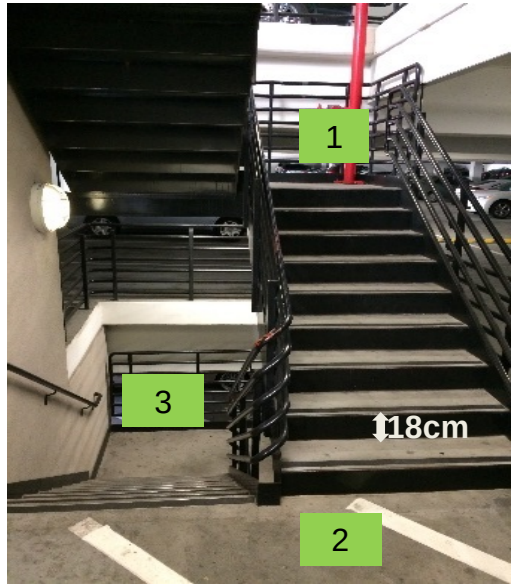
Piezoresistive vs Capacitive Pressure Sensors

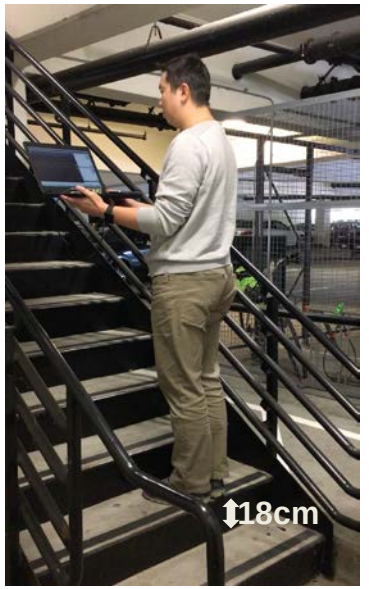


Capacitive Pressure Sensors: Optimized for the lowest pressure noise RMS at the lowest power

Piezoresistive vs Capacitive Pressure Sensors



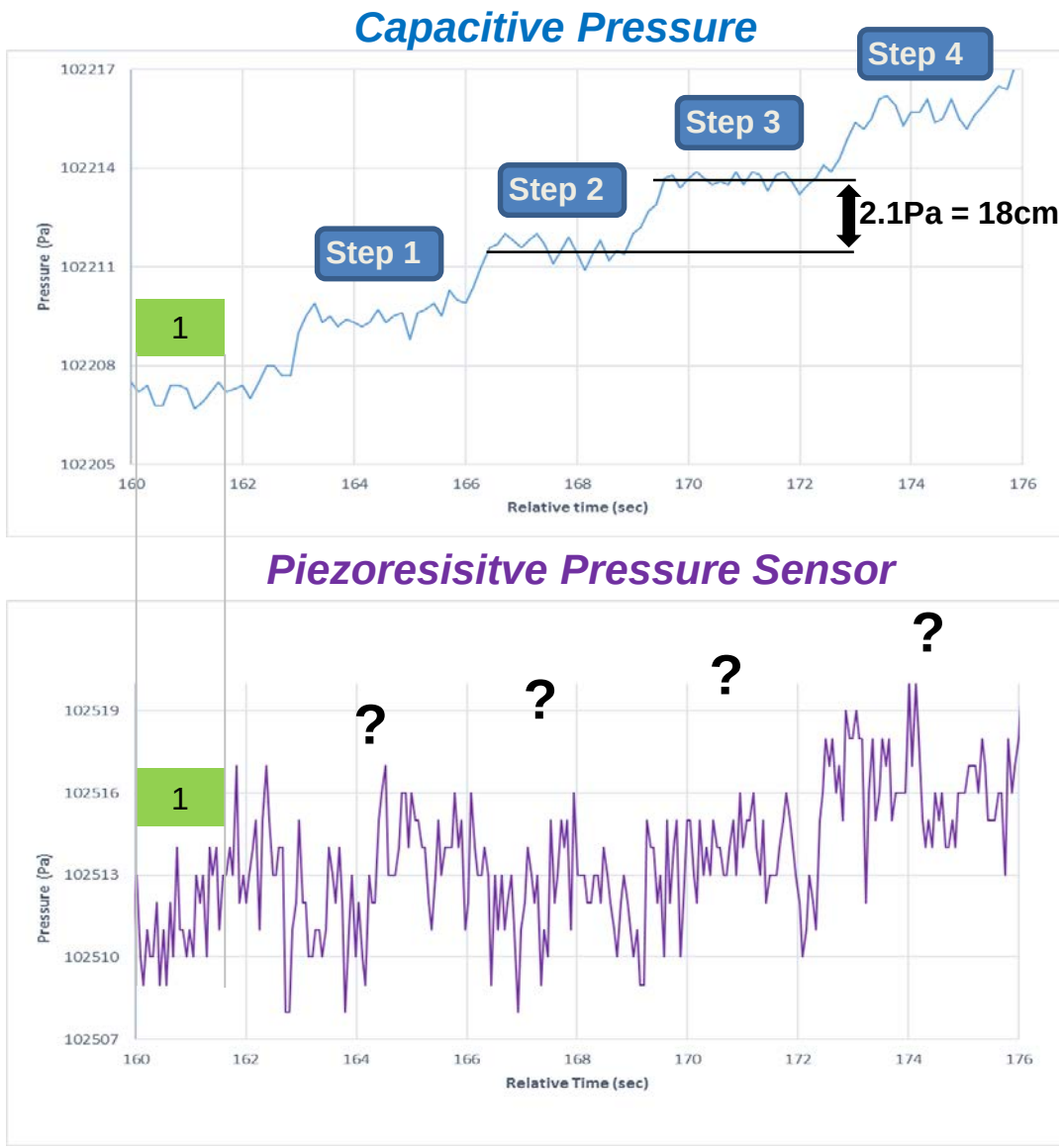


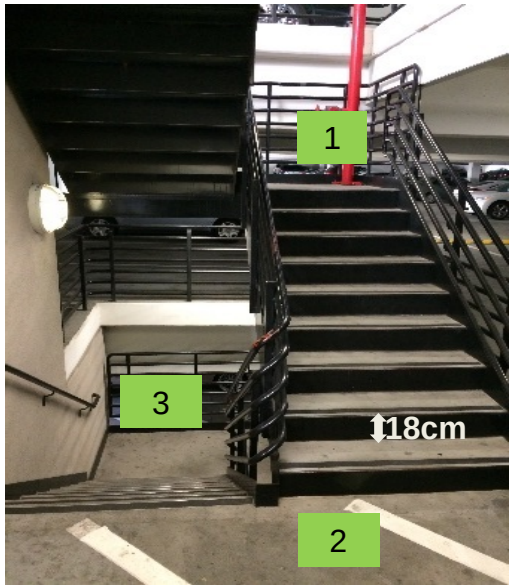


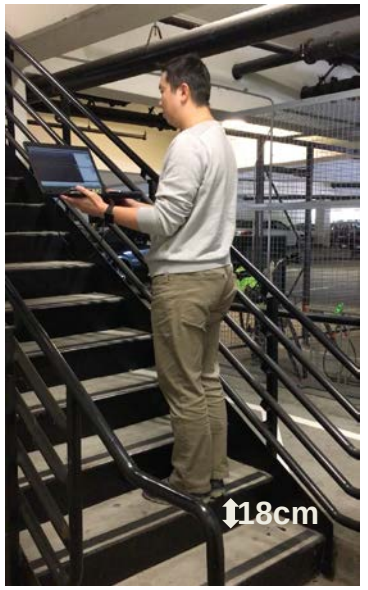
Capacitive Pressure Sensor

Detects Individual Stair Steps

Piezoresistive vs Capacitive Pressure Sensors



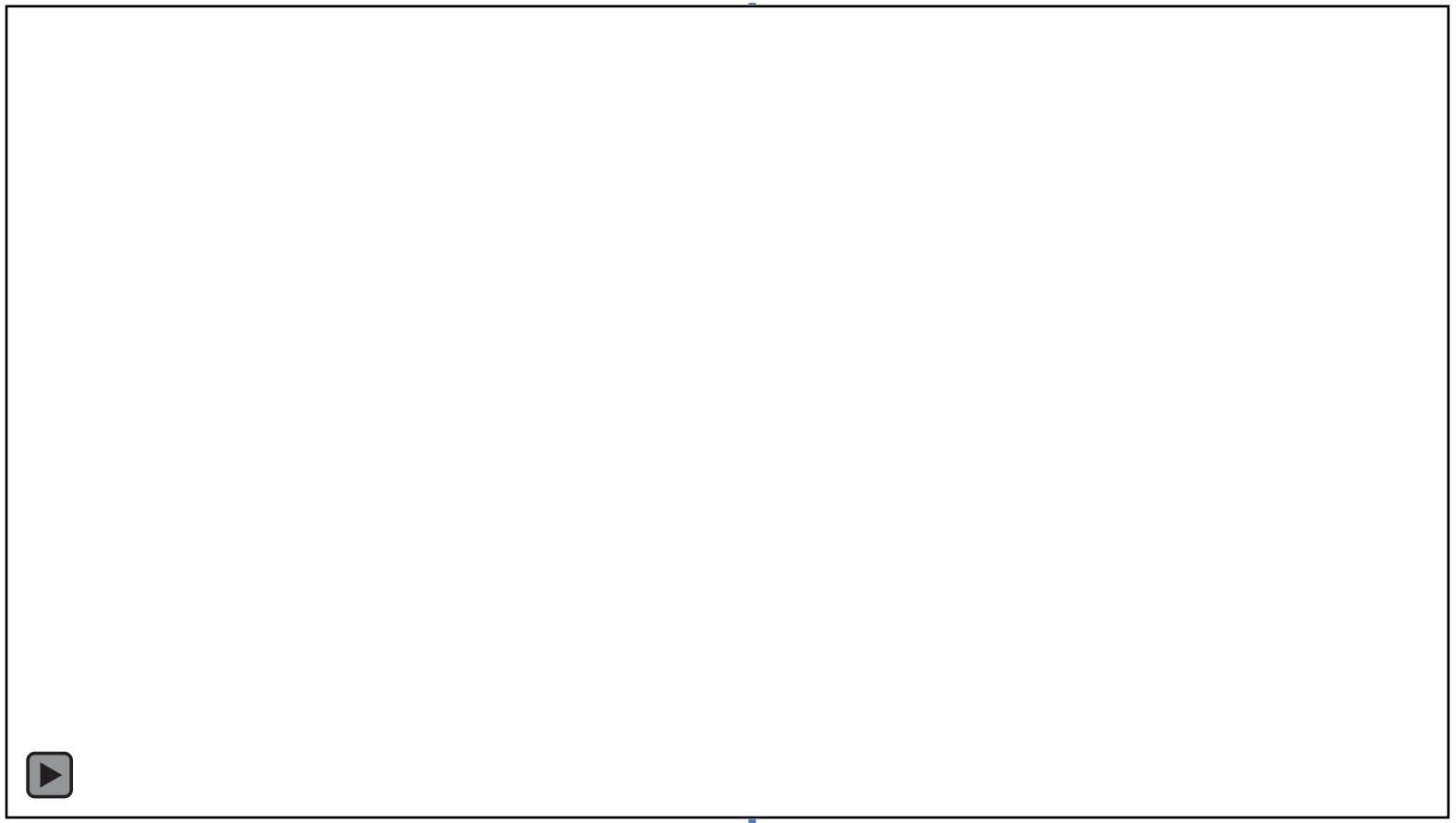




Capacitive Pressure Sensor

Detects Individual Stair Steps

Piezoresistive vs Capacitive Pressure Sensors

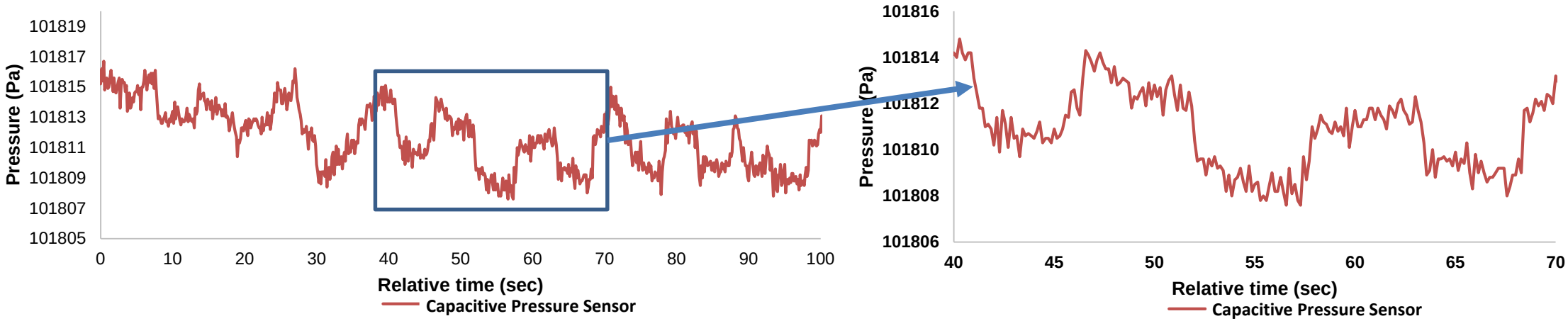


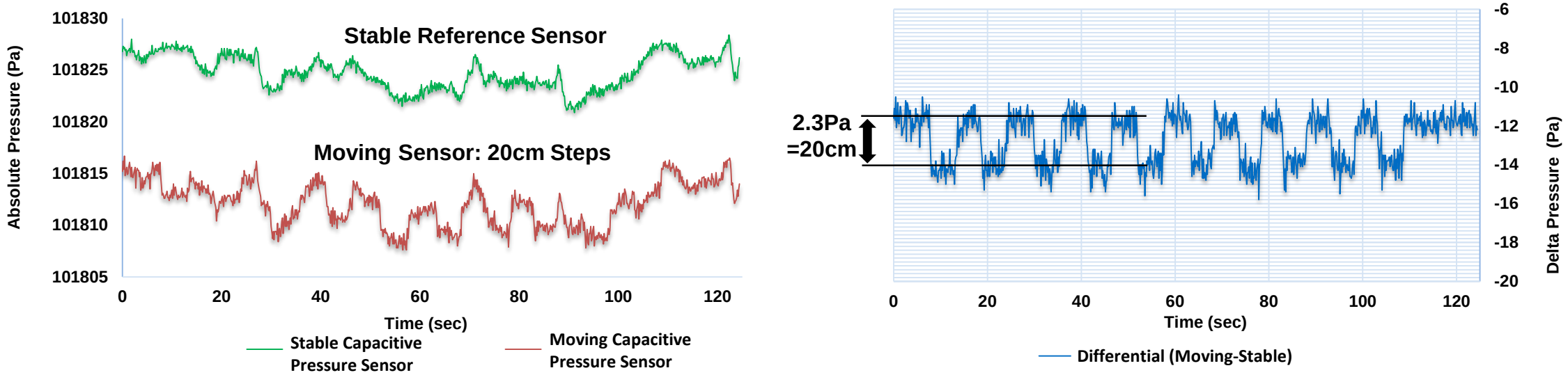
Piezoresistive Pressure Sensor: Altitude Hold ~75cm

Capacitive Pressure Sensor: Altitude Hold ~15cm

Indoor Pressure Measurements

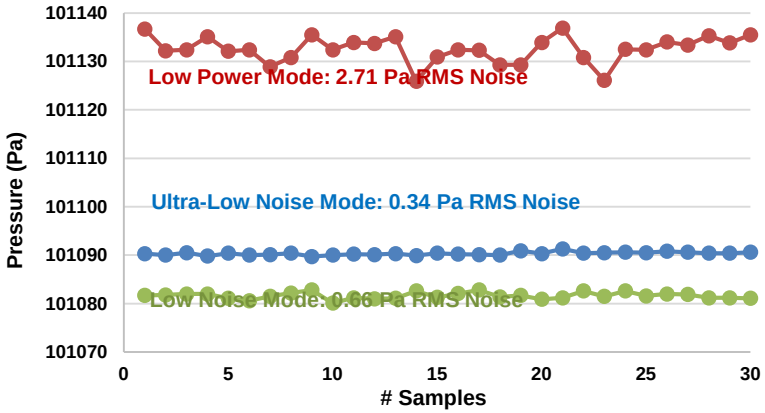
20cm Step Height

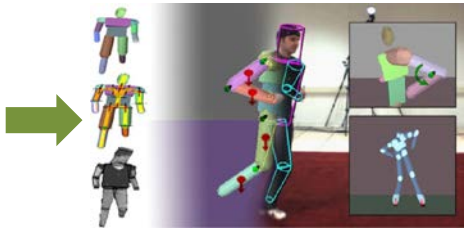


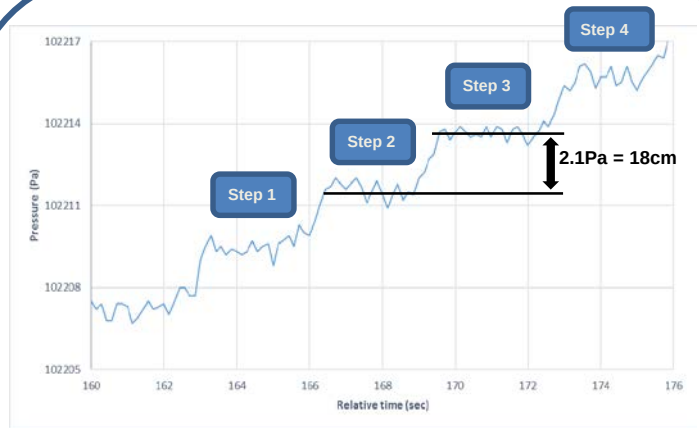


Activity Monitoring

- Wearables are no longer a fleeting gimmick
  - MLB and NFL approved use of wearables in competition
  - U.S. Olympic Committee – confirmed heavy use of wearables at it's training camps
- Trends
  - Identify type of activity for better caloric monitoring
  - New use cases without impact to battery life
    - Path of travel for more accurate map navigation
    - Fall detection
- Performance Needs
  - Path of travel (stairs, escalator, elevator): resolution < 1 stair, ~10cm
  - Type of Fitness Activity: resolution of 10cm << arm movement
  - Fall Detection: resolution < chair seat height (~25cm)
  - < 5uA to increase functionality without penalty to battery life
  - >20Hz sample rate to effectively monitor high speed motion

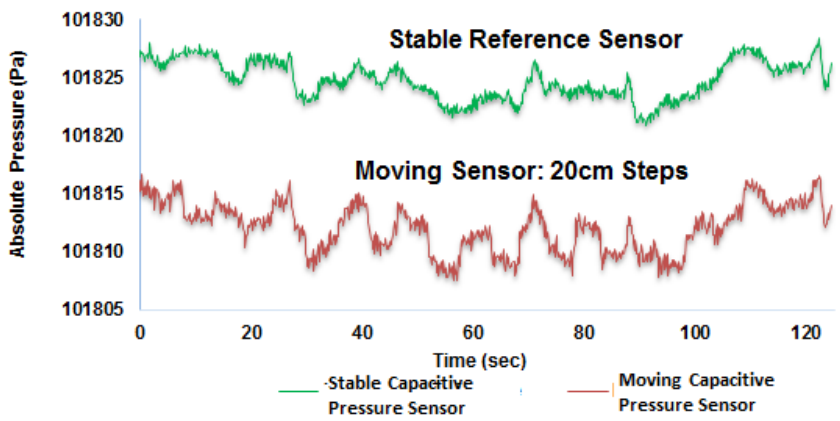


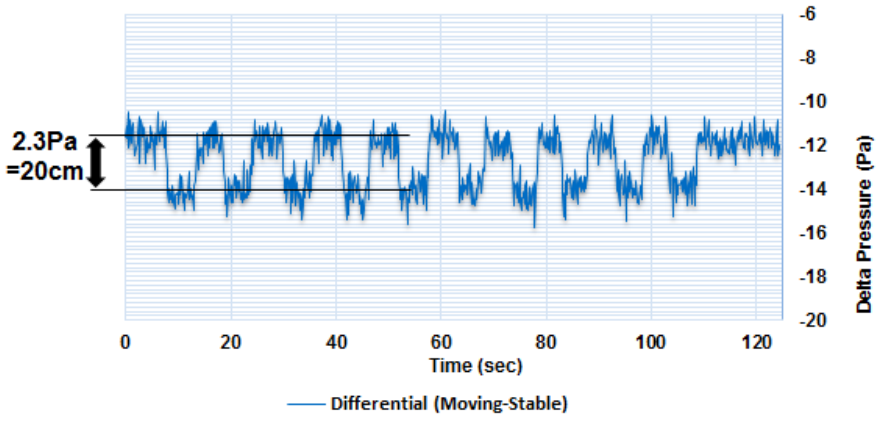




AR, VR, and Gaming

- AR and VR: The future OR Just a passing Trend?
  - Today: Largely an installed base of high end gaming computers
  - Explosive growth expected as more VR/AR SW content is created with more mainstream hardware available
- Trends
  - Improved user experience with sensor redundancy
    - Fusing high resolution Z-height from pressure sensor with other motion sensors
  - Improve safety by detecting standing and sitting of user
- Performance Needs
  - Monitor Z-height to identify:
    - User standing or sitting: <20cm
    - Arm movement holding gaming controller: resolution < 8cm
    - User's head movement up or down: <8cm
  - 2 sensors: Measure pressure differentially to eliminate common mode ambient pressure variation
  - >20Hz sample rate to effectively monitor high speed motion



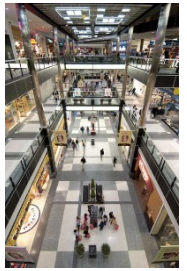


3D Navigation

HUMANIZING THE DIGITAL EXPERIENCE

- 3D Navigation is Coming to a Building Near You
  - FCC E911 Legislation: Starting in 2015, 6 year phase-in for location accuracy for Z-height of 3m for 80% of calls
  - Apps: Mapping Apps and AR Apps enabled to utilize your floor location (malls, airports, train stations, stadiums etc.)
- Trends
  - Increasing pressure sensor attach rates:
    - Meet E911 regulation
    - Path of travel: Improve time estimate accuracy from end point to end point
    - AR indoor Apps
- Performance Needs
  - Floor detection: Relative Accuracy < 1m
  - Path of Travel: < 10cm (stairs, escalator, elevator etc.)

E911



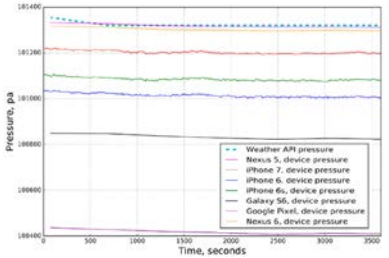
Indoor Navigation

Elevation API (WGS84)

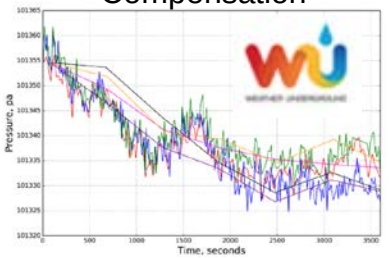
+

Correlating Barometer & Weather

Smart Phone Barometer

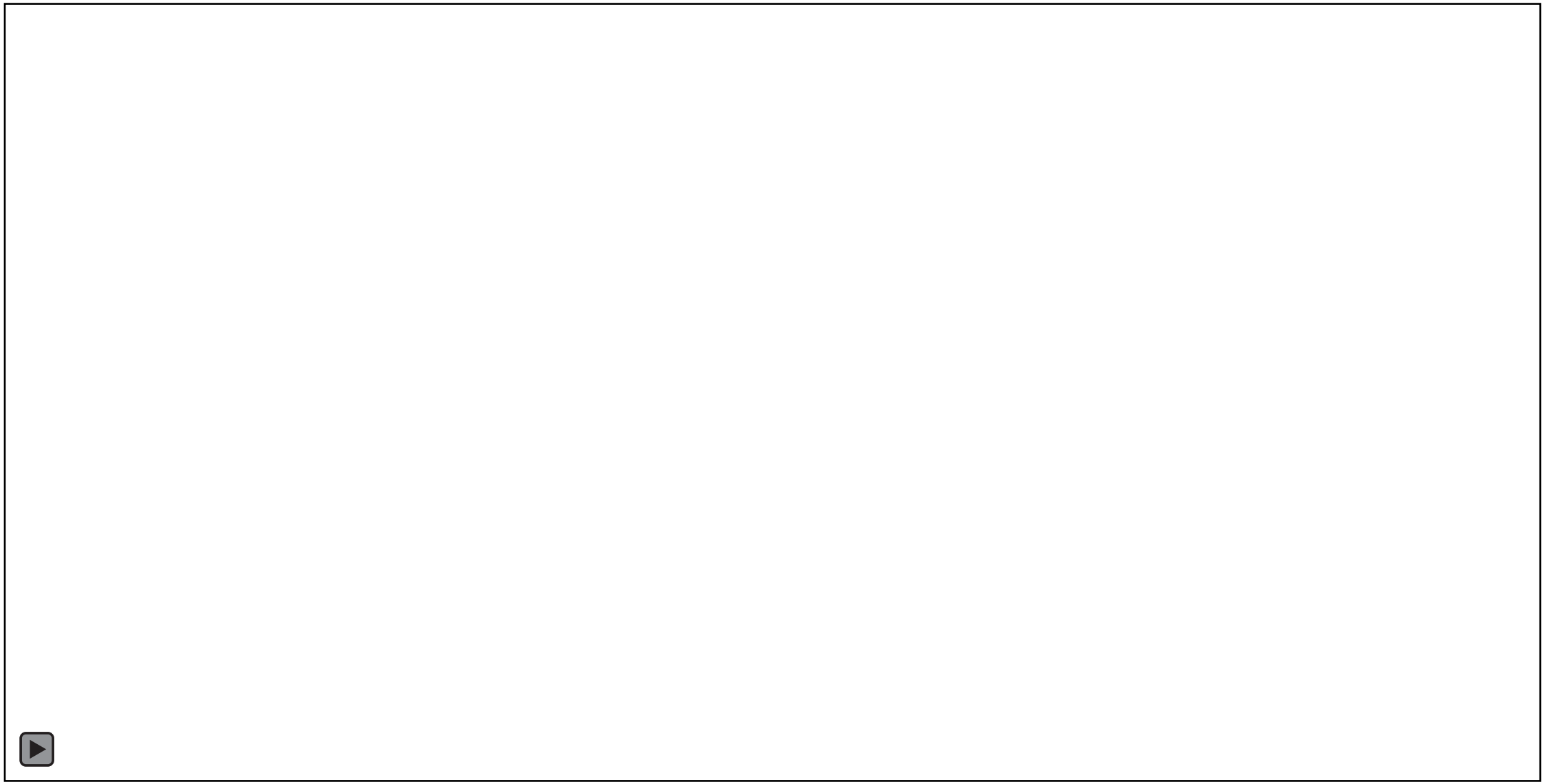


Real-time Weather Compensation

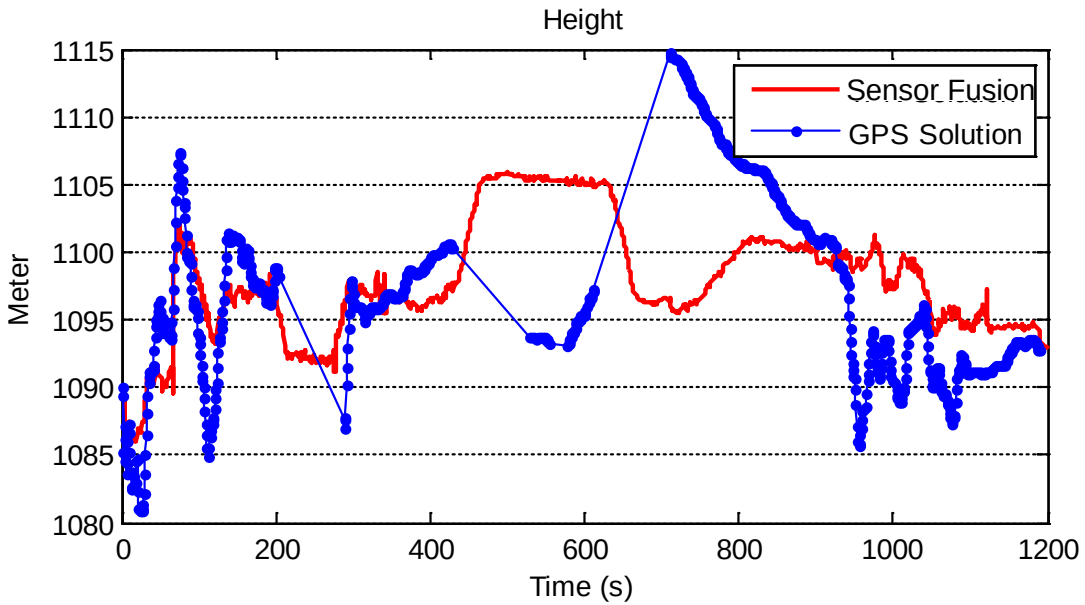


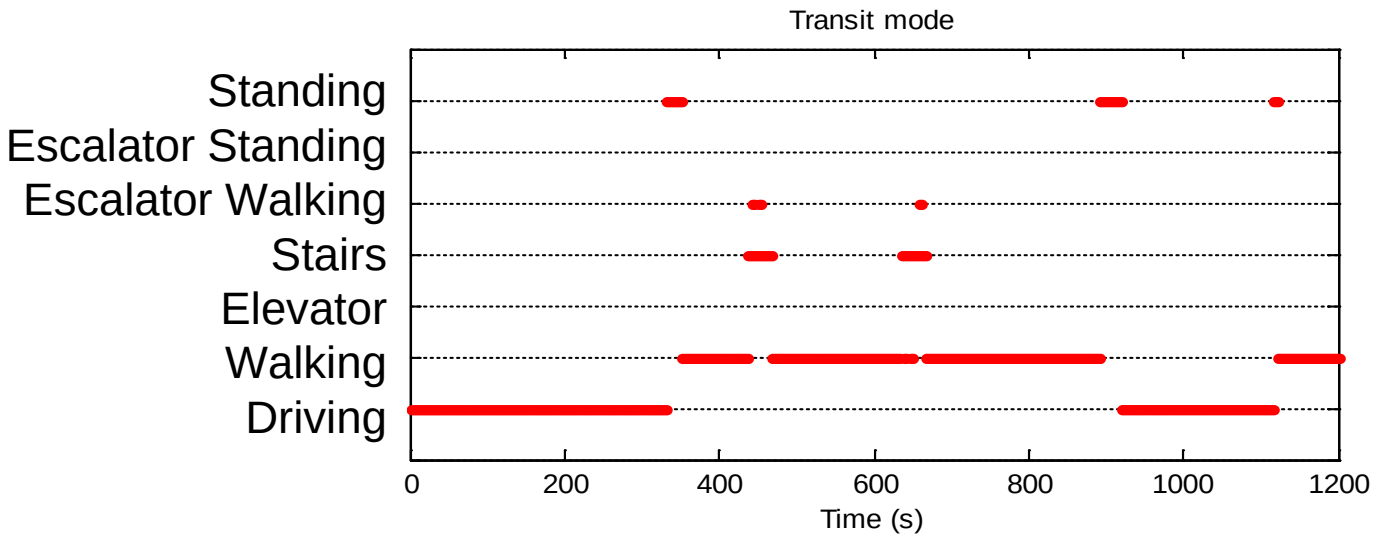
Apps Utilizing 3D Location

Altitude Measurements with Sensor Fusion



Altitude Measurements with Sensor Fusion

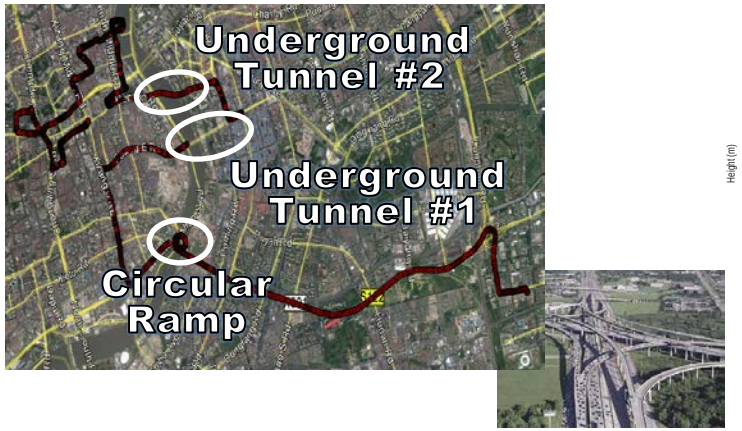




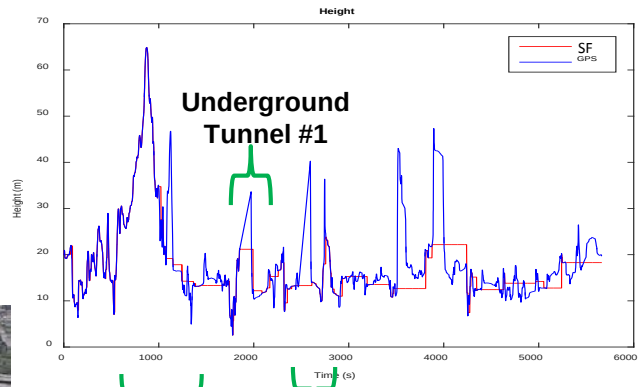
3D Navigation: With and Without Pressure Sensor

HUMANIZING THE DIGITAL EXPERIENCE

Tunnels and Ramps



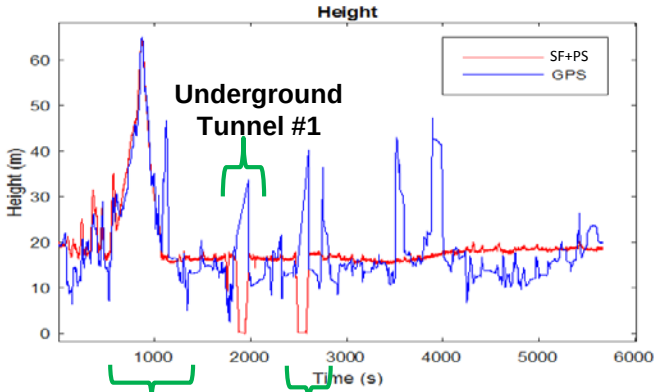
Sensor Fusion without Pressure Sensor



Circular Ramp

Underground Tunnel #2

Sensor Fusion with Pressure Sensor

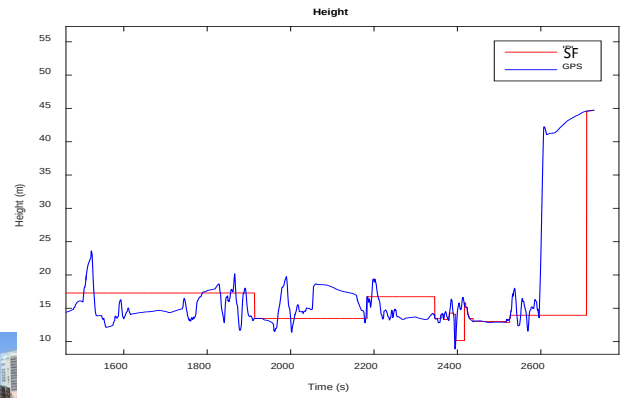


Circular Ramp

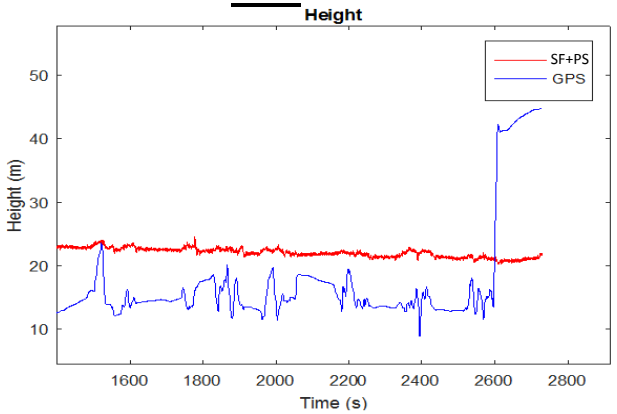
Underground Tunnel #2

Multi-Level Highway

Sensor Fusion without Pressure Sensor



Sensor Fusion with Pressure Sensor



Air Flow

- A Large Energy Footprint – Data and Communications
  - World-Wide data centers consume >400 terrawatt-hours of electricity, more than the UK!
  - ~50% of data center power consumed by “environmental management”
  - Total energy consumption is driving the Total Cost of Ownership
- Trends
  - Data and Communications
    - Focus on lowering total cost of ownership -> “Power Usage Effectiveness” (PUE)
    - Optimize cooling power:
      - Maximize air flow where needed, reduce air flow where no cooling benefit
      - Predictive air control: correlate temp+air+load to prevent over exercising fans
      - Dynamically adjust air flow to environment: data center architecture, expansion cards, fan aging
  - General Air Flow
    - Auto-turn for low air flow rates and sensitivity to detect small changes in flow for control

Data and Communications

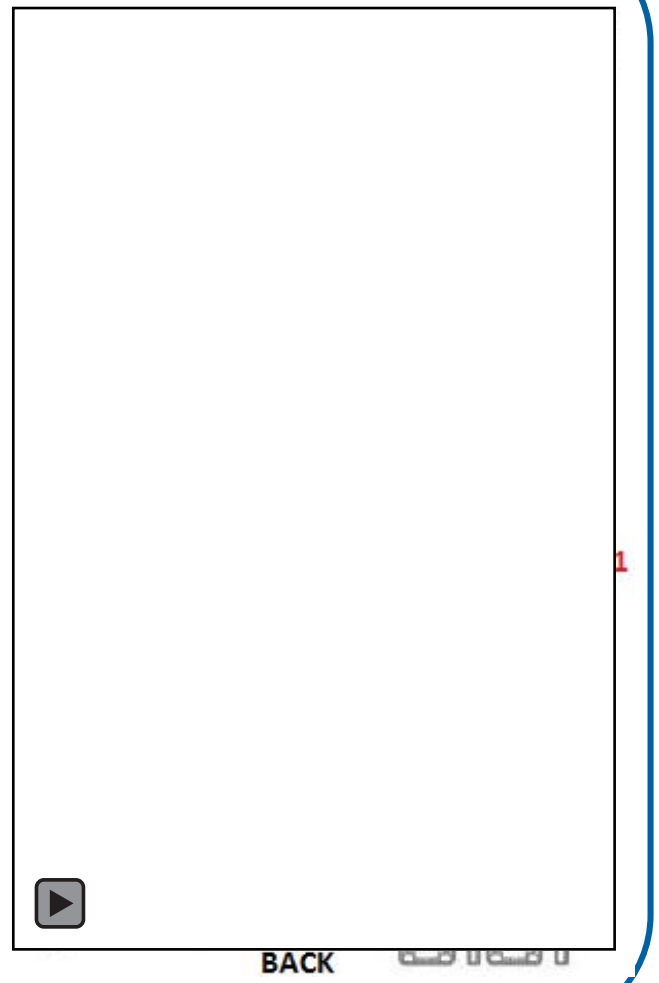
Data Center Management

Server

Wireless Base Stations

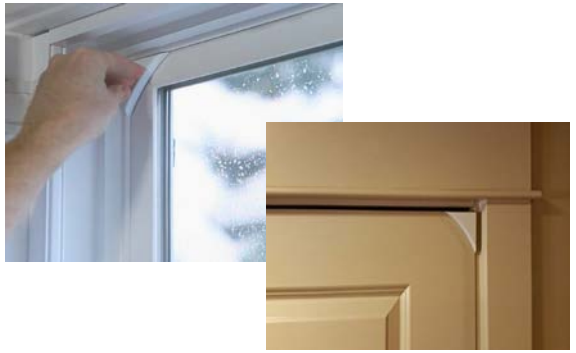
Service Provider Routers

Server Air Flow

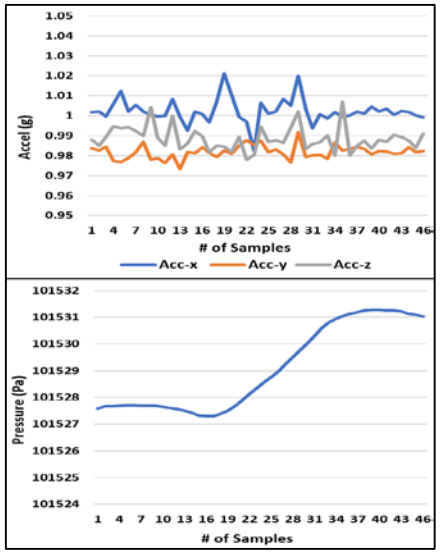


Security Systems

- Easy to Use and Low Cost
  - Significant growth driven by:
    - DIY's
    - Low power wireless technology
  - Legislative mandates to reduce false positives -> reduce erroneous dispatch of emergency services
- Trends
  - Eliminate easily defeated sensors: magnetic reed switches, solo accelerometers
  - Remote battery powered sensor nodes: need to reduce power



Pressure Sensor Detects Motion Accelerometer Misses

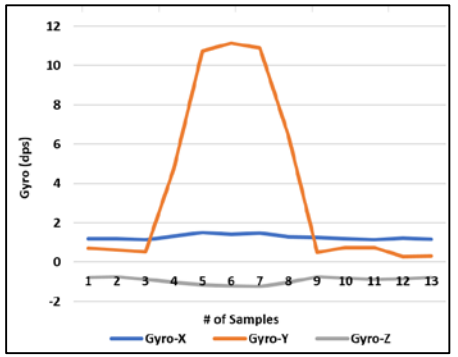


25cm Window Movement:
3Pa pressure change, only 20mg acceleration

Save Power: Continuous Pressure Monitoring

25cm Window Movement:
>1.5Pa pressure change, secondary verification using Accel/Gyro

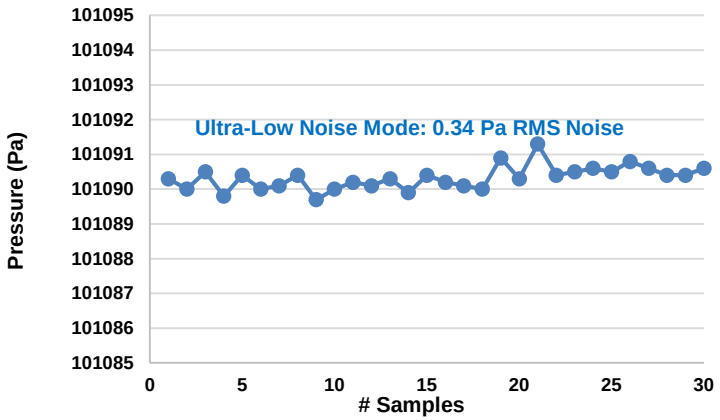
Detect Door Movement

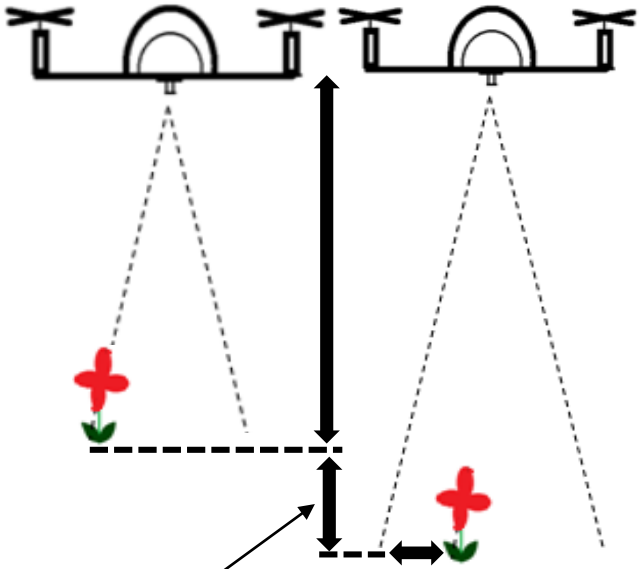


15cm Door Swing:
Gyro detects >10dps movement "event"

Drones

- The Drones Are Coming!
  - >50M Drones and Flying Toys
  - More uses coming: Infrastructure maintenance, Entertainment/Media, Agriculture, Goods Delivery, Planning/Exploration
- Trends
  - Improve hover capability to increase the user experience
  - Improved video/camera systems and stabilization
  - Dramatic reduction of BOM
- Performance Needs
  - Stable temperature performance near hot HD video components
  - Low pressure noise
    - Improve altitude-hold
    - Eliminate expensive ultrasonic TOF used in Optical Flow





Measured Noise Pressure of 0.34Pa RMS:

- <5cm of altitude resolution enables excellent altitude-hold
- Improved altitude-hold enables stable Field of View for Optical Flow
- Pressure sensing stabilized Field of View:
  - Eliminates need for ultrasonic TOF
  - Reduces undesired drone movement in X-Y

Wrap Up

Summary

- Capacitive Sensing Advantages
  - Lower: Noise, Power, Temperature Coefficient
- Significant benefits in: Mobile, Gaming, Wearables, Navigation, Security, Air Flow, Drones
- Enabling New Use Cases:
  - Caloric Counting, Floor Identification, Indoor Navigation, Air Flow, E911, Low Power Motion Sensing

ICM-20789: 7-Axis

ICM-20789

7-Axis: 6-Axis Motion Sensor and Barometric Pressure Sensor

Solution Features

- Digital Motion Processor (DMP) for autonomous operation
- Programmable interrupts, filters, and 4k-byte FIFO
- Gyroscope Full-Scale Range: ±250/500/1000/2000 deg/sec
- Accelerometer Full-Scale Range: ±2/4/8/16 g
- Pressure Operating Range: 300hPa – 1100hPa
- Relative Pressure Accuracy: **±1Pa** (10hPa change,700-1000hPa)
- Absolute Pressure Accuracy: ±1hPa(300hPa-1100hPa,0°C-65°C)
- Temperature Sensor Accuracy: ±0.4°C
- Operating Temperature Range: -40°C-85°C
- Operating Voltage Range:
  - VDD 1.7V – 3.45V
  - VDDIO: 1.8V ±5%
- Host Interface: SPI 8MHz, I²C up to 400kHz
- Packages: 4 x 4 x 1.365mm 24-pin LGA

ICP-101xx: Stand Alone Pressure Sensor

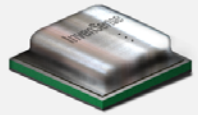
ICP-101xx

Barometric Pressure and Temperature Sensor

Solution Features

- Pressure Operating Range: 300hPa – 1100hPa
- Relative Pressure Accuracy: **±1Pa** (10hPa change,700-1000hPa)
- Pressure Noise RMS and Current Consumption:
  - Low-Power Mode: **3.2Pa at 1.3µA**
  - Low-Noise Mode: **0.8Pa at 5.2µA**
  - Ultra Low-Noise Mode: **0.4Pa at 10.4µA**
- Absolute Pressure Accuracy: ±1hPa (300hPa-1100hPa,0°C-65°C)
- Pressure Sensor Tempco: ±0.5Pa/°C (25°C-45°C, 100kPa)
- Temperature Sensor Accuracy: ±0.4°C
- Operating Temp & Voltage: -40°C-85°C, 1.8V ±5%
- Host Interface: I²C up to 400kHz

PACKAGE	3-HOLE IPX8: 1.5m WATERPROOF	1-HOLE
2x2x0.72mm 10L LGA	ICP-10100	ICP-10101
2x2.5x0.92mm 8L LGA	ICP-10110	ICP-10111



Thank You!