Abstract

The trend in Wearables is increasing at an incredible pace as people look to both leverage and augment the advances brought by the Smartphone Revolution. There are many similarities in the sensors and applications used in smartphones and Wearables. But there are also substantial differences which will need to be addressed by both wearable and sensor manufacturers. This session covers a number of sensors applicable to the wearable market as well as discussing some of the challenges and solutions for designers and manufacturers.

IEEE Wearable Electronics Seminar

Selecting Sensors for Wearables

Kionix®

A GLOBAL LEADER IN INERTIAL SENSORS

A SUBSIDIARY OF ROHM CO, LTD.

John M Chong

VP Product and Business Development

jchong@kionix.com

August 20, 2014

COMBINED WITH ROHM, KIONIX OFFERS A COMPREHENSIVE PORTFOLIO OF SENSORS TO ADDRESS CUSTOMER NEEDS.

	Sensor Type	Measures	Status
Motion Detection	Accelerometer	Acceleration	●
Motion Detection	Gyroscope	Angular Velocity	▲
Motion Detection	Touch Sensor	Touch	●
Motion Detection	Magnetometer	Geomagnetism	▲
Motion Detection	Hall Sensor	Proximity	●
Motion Detection	GPS Receiver	Location	
Motion Detection	Human Pulse Sensor	Human Pulse	▲
Environment Detection	Image Sensor	Optical Image (FIR, NIR)	▲
Environment Detection	Pressure Sensor	Pressure	▲
Environment Detection	Silicon Microphone	Voice/Tone	
Environment Detection	Ambient Light Sensor	Visible Light	●
Environment Detection	Proximity Sensor	Visible Light + Infrared	●
Environment Detection	Pyroelectric Sensor	Infrared	●
Environment Detection	Temperature Sensor	Temperature	●
Environment Detection	Humidity Sensor	Humidity	
Environment Detection	UV Sensor	UV Rays	●
Environment Detection	IrDA Transceiver	Infrared	●
Environment Detection	Gas Sensor	Gas	▲
Environment Detection	X-ray Sensor	X-ray	

● Current MP ▲ In Development

SETTING THE STAGE

The smartphone, stuffed with its MEMS and sensors, has worked its way into the core of our lives and has fundamentally changed the way we live, learn and communicate.

SMARTPHONE REVOLUTION….
& THE ADVENT OF WEARABLES

WHAT HAS THIS DONE?

- It's ***educated*** people about MEMS and sensors - what they are and what they can do.
- It's dramatically raised ***expectations*** for what the rest of the objects in our lives can, and in some people's opinions, should do.
- And it has also provided the ***infrastructure*** –
  - from a supply chain with high volumes of affordable sensors and components
  - to a pervasive communications infrastructure
  - to computational capabilities and a user interface that's familiar and nearly always with us

Thus the smartphone revolution has both led the way and is now a catalyst for the explosion of new devices that are Wearables.

The Proposition –
Awareness & Feedback = Improved Life

Basic Structure of a Wearable

Wearables

ARCHITECTURE/BLUEPRINT`

Wearables

ARCHITECTURE/BLUEPRINT`

SENSING

- Physical condition
- Command

→

ANALYSIS

- Signal processing
- Logic & Decision Making

→

ACTION

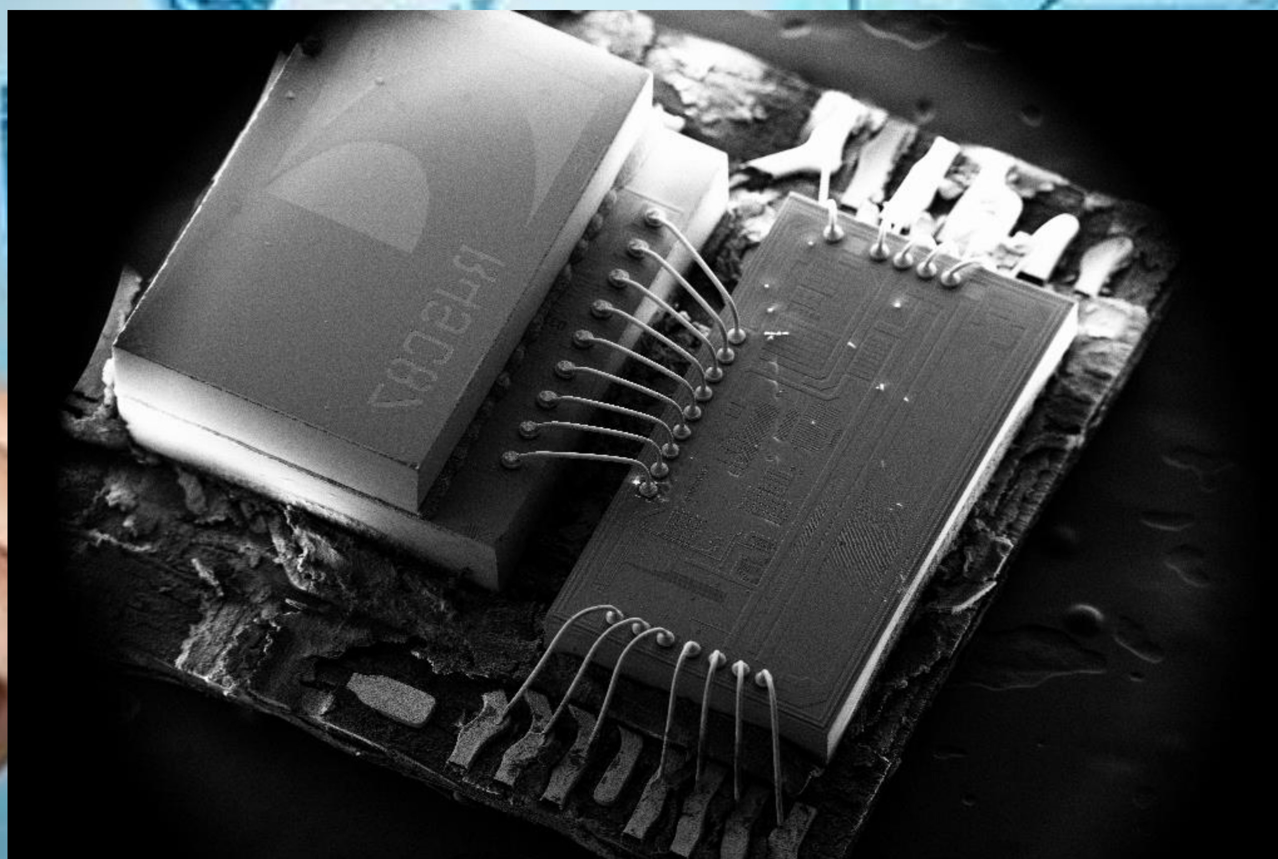
- Control
- Transmission

SENSOR *COMPONENTS*

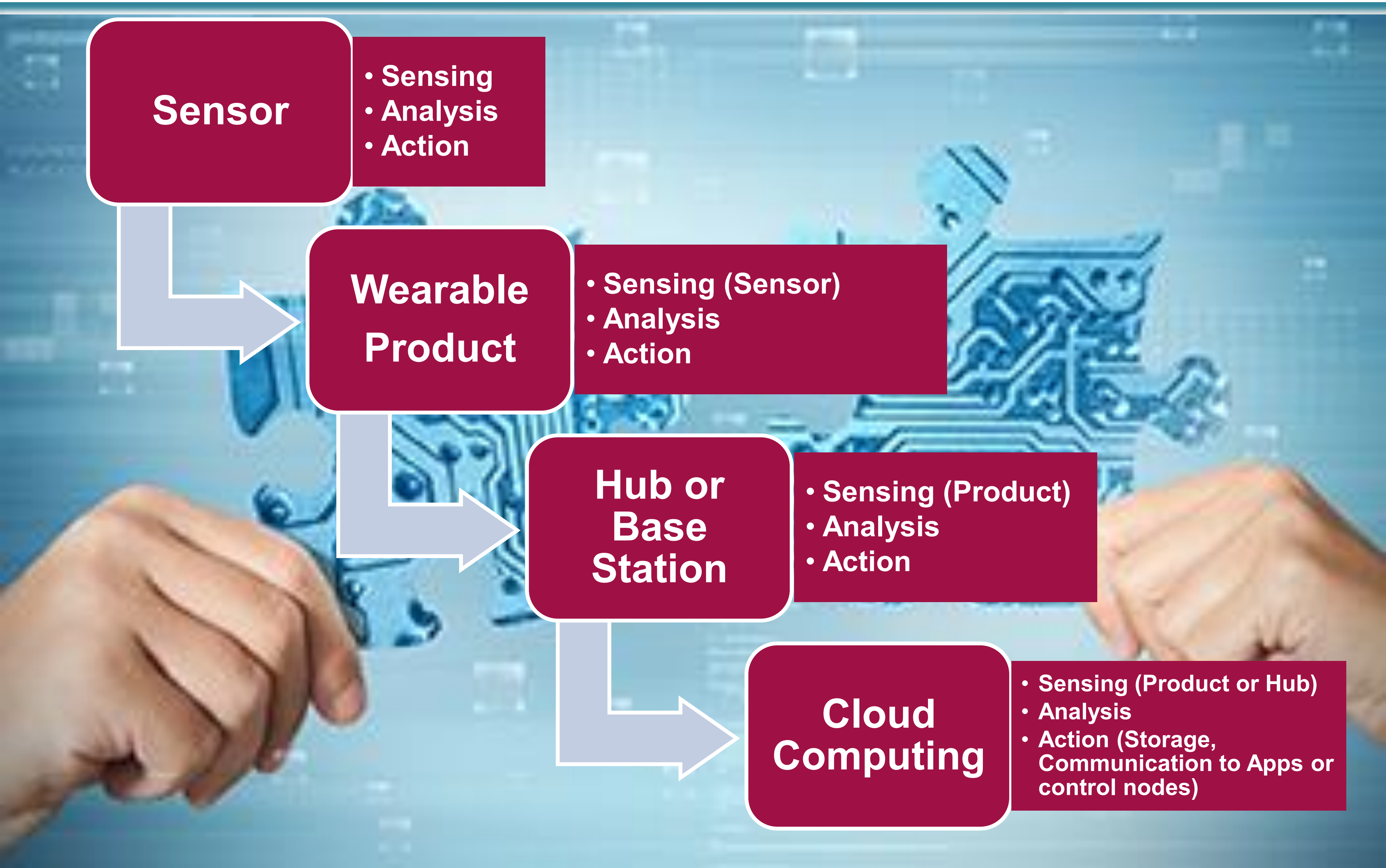
SENSING
- Physical condition
- Command

ANALYSIS
- Signal processing
- Logic & Decision Making

ACTION
- Control
- Transmission



WEARABLES COMPONENTS



Types of Wearable Devices

Narrow Focus — High Functionality

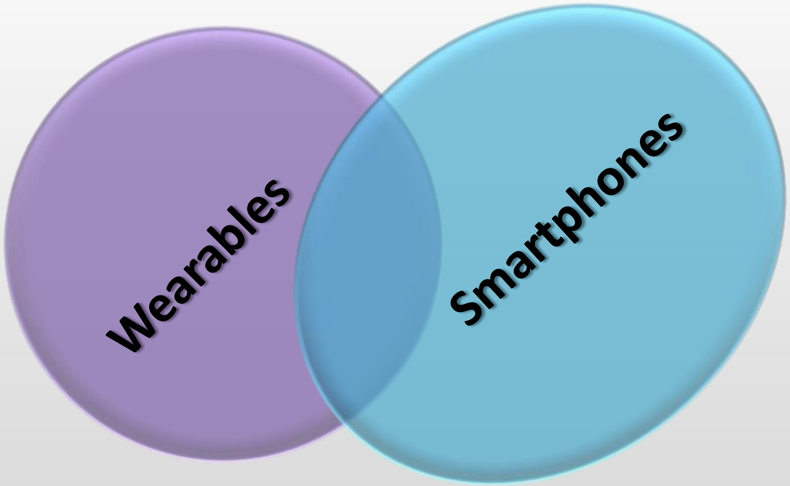
Wearables vs Smartphones

Differences

- Limited real estate (Impacts Size, Power, UI)
- Functionally less flexible but more targeted
- Need to be more robust
- Cost: More or Less

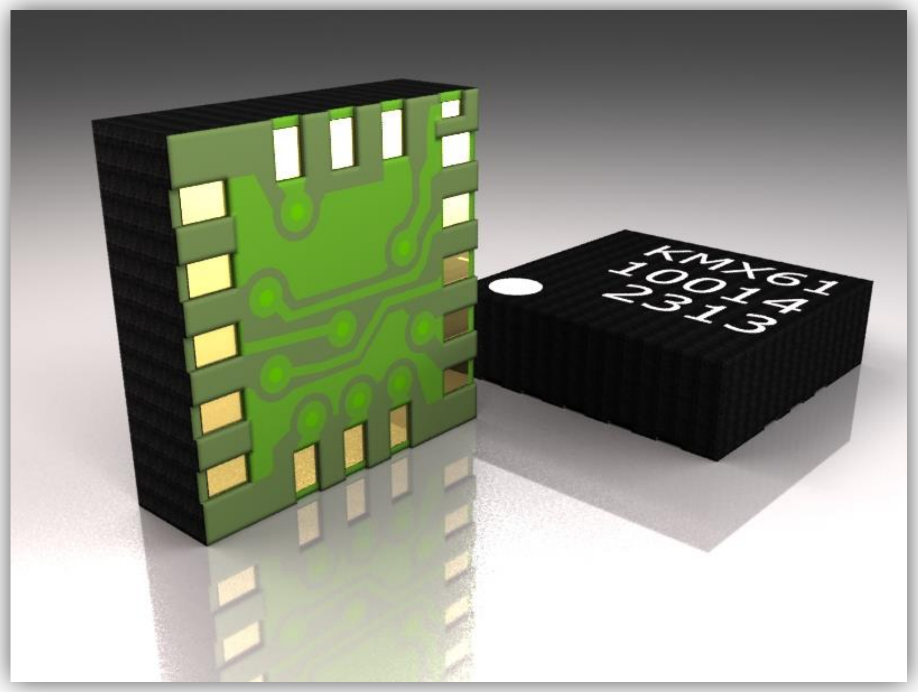
Wearables in conjunction with Smartphones

- Smartphones can be used for
  - Interface
  - Data processing
  - Connectivity
- Wearables can be used as
  - Remote / Local sensors
  - Identification/Authentication
  - Interface



SENSORS in WEARABLES – Primary and Peripheral

- Data and information is at the heart of Wearables
- The collection, analysis and reaction to data is what it's all about
- The data starts at the Sensor. It's the sensor that generates the data
- But sensors can also function on the peripheral role, assisting with analysis and communication of data, maintaining privacy, as well as power management



SENSOR ROLES

Quantify
- Motion
- Environmental
- Biometric

User Interface
- Shake, Rotation, Tap, Orientation

React / Notify
- Condition
- Event or Criteria

Power Management
- Activity, Proximity

PRODUCT CONSIDERATIONS

USER FACING FEATURES

Functionality

User Interface

PRODUCT CONSIDERATIONS

INTERNAL FEATURES

SECURITY

- Protecting Data and Privacy
- Identification/Authentication
- Generally at odds with convenience, simplicity, interoperability, and reliability

CONNECTIONS

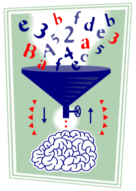
- Interoperability
- Wireless
- Less important for early adoption
- Eventuallly critical for commercial success

DURABILITY

- Shock
- Water and humidity
- Corrosion

POWER

- Power source (AC, Rechargeable, Single use battery)
- Energy Management



DATA ANALYTICS

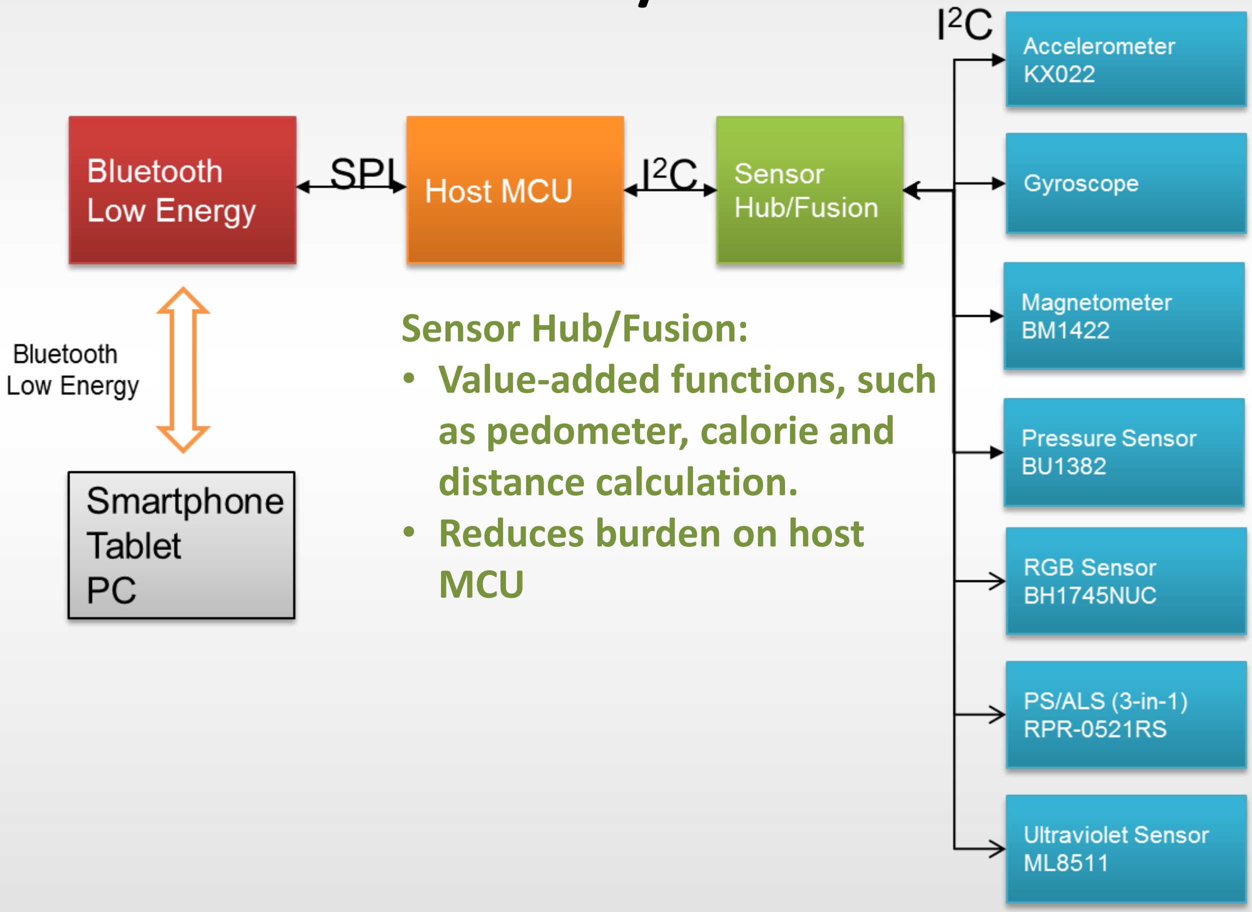
- Leveraging data over time
- Multiple sensor streams
- Sensor fusion

COST

Functionality Requires Power

- Many sensors collecting huge amounts of data
- “Always On” and Context Awareness can strain power budgets, especially if the Host Controller remains awake
- Radios take a lot of power

Intelligent Sensors and Sensor Hub/Fusion



Sensor Hub/Fusion:

- Value-added functions, such as pedometer, calorie and distance calculation.
- Reduces burden on host MCU

Sensors:

- Data buffering
- Pre-processing
- Event-triggered functioning
- Low power consumption

Sensor Selection

- Type
- Performance and Features
- Cost
  - It’s not just $$ cost, but power and space cost
  - It’s not just *sensor* cost, but **system** cost
- Sensor Provider
  - Eco-system
  - Support
  - Manufacturing and logistics

Sensors: Motion and Orientation

Accelerometer

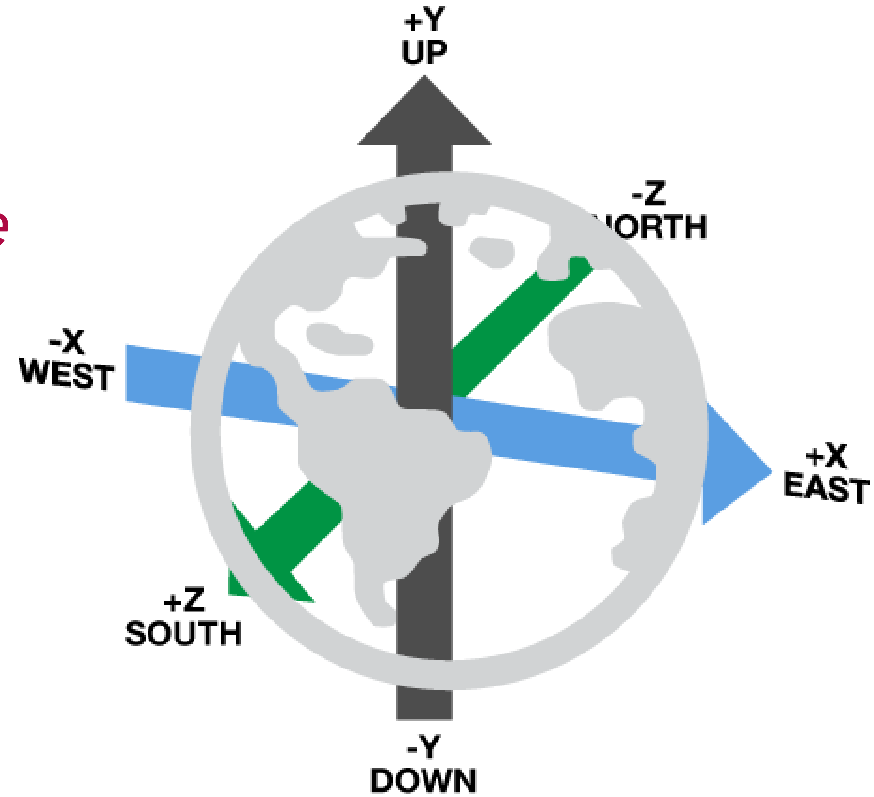
- *Measures linear acceleration*
- *Orientation relative to gravity*

Magnetometer

- *Used as e-compass to orient relative to earth*

Gyroscope

- *Used to measure rotational speed*



Sensors: Environmental and Biometric

- UV Light Sensors
- Ambient Light Sensors
- Proximity Sensors
- Pressure
- Heart/Pulse Rate Sensors
- Blood Oximetry

System Architecture and Integration

Digital vs. Analog

What is the difference?

- Analog
  - Analog range outputs are specified in volts
  - Often used in feedback control systems
  - Often more accurate output than digital
  - Requires analog-to-digital converter
- Digital
  - Internally converts voltage outputs to digital outputs
  - Digital range outputs are specified in counts
  - Easier to implement in digital systems with microprocessors

Why it is important:

- System integration generally dictates which type of device is needed. Some applications may require that a specific type of accelerometer be used.
- Multiple digital sensors can be connected via a single communication bus (reducing system overhead), whereas analog sensors cannot

Voltage Supply

What is it?

- Sensor Supply Voltage - voltage required to operate sense element
- Communications Voltage – voltage range allowed for digital communications
- Internal Regulators – keep internal supply voltages constant
- Ratiometricity – output depends on supply voltages

Why it is important:

- Sensor and Communication voltages impact system integration and compatibility
- Internal regulators can keep sensor performance constant while sensor supply voltages changes (either due to noise or depleting battery power)
- Ratiometricity is not typical in digital systems

Power Consumption

What is it?

- The amount of current required or power consumed for the sensor to function

Why it is important:

- Most wearables have severe power constraints
- Manufacturers often offer multiple modes to manage power and trade-off power and performance (such as low power or high resolution modes, varying ODRs, etc.)

Packaging

What is it?

- Packaging is the physical material surrounding the sensor

Why it is important:

- Size is a significant constraint in wearables
- Since sensors interact with the physical world, packaging can impact part placement and durability (over temperature, shock, etc.)

Communications Protocol

What is it?

- The type of protocol used to communicate with the sensor. Most typical is I2C and SPI

Why it is important:

- Affects compatibility, pin count, system integration, power (I2C requires pull up resistors).
- Communication speed can have profound effects on power consumption

Performance

Range

What is it?

- Range is the +/- maximum amplitude that a sensor can measure before distorting or clipping the output signal.

Why it is important:

- A device's range determines the maximum signal that the device can measure accurately.

Accuracy (Zero Offset)

What is it?

- Zero-g offset is the output for an axis when there is no acceleration on that axis.
- Zero-g offset is closely related to sensor bias error, or a small difference between the ideal output (0g offset on the x and y axes and +1g output on the z axis) and the actual output reported by the sensor.

Why it is important:

- Zero-g offset is an indicator of the device's output accuracy.
- All sensors have a bias error to some degree, so it's important for customers to know what this value is to try to reduce the error.

Sensitivity and Resolution

What is it?

- The sensitivity and resolution of a sensor are both measures of the smallest change the device can detect in the quantity that it is measuring.
- Sensitivity and resolution are different measurements, but our competitors often use them interchangeably

Why it is important:

- High resolution and sensitivity allow for greater precision in pointing applications, for example, where the accelerometer is measuring low-level signals and the smallest movement by the user needs to be detected and processed.

Cross-Axis

What is it?

- Ratio of the measured value for an axis to the input acceleration along each axis orthogonal to the measured axis

Why it is important:

- Cross-Axis contributes to error in the measurement of acceleration

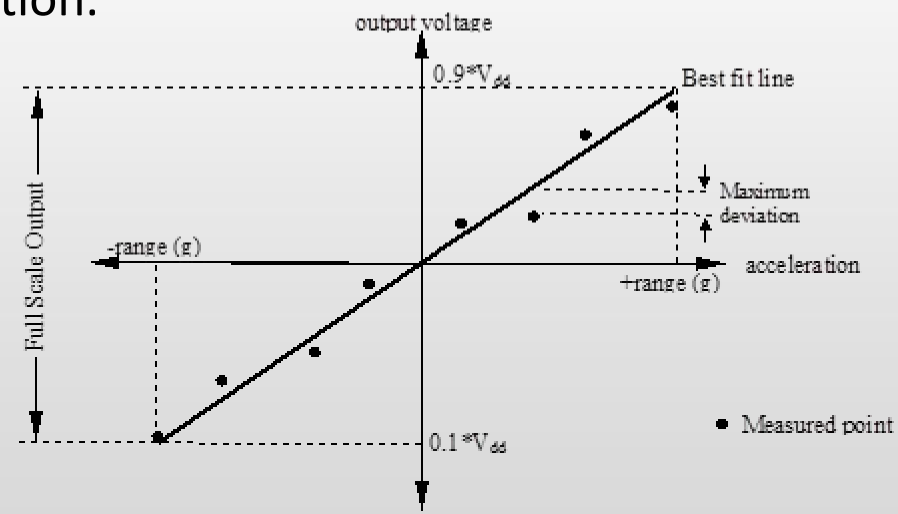
Non-Linearity

What is it?

- Non-Linearity is a measure of how much a device's output differs from ideal behavior over the full range of the sensor (how close to linear the output is).
- Nonlinearity is measured as a percentage of Full Scale Output (FSO).

Why it is important:

- Non-linearity contributes to error in the measurement of acceleration.
- Lower non-linearity is more desirable because it results in a more accurate measurement of acceleration.



Noise/Noise Density

What is it?

- Noise is a random deviation of the signal that varies in time. Noise is caused by physical or electronic variations within the device. Noise Density is specified in µg/√Hz.
- There are two types of noise in an accelerometer – electronic noise from the circuitry that is converting the motion into a voltage signal and the mechanical nose from the sensor itself.

Why it is important:

- Noise affects the precision of the accelerometer, that is, how closely individual measurements agree with each other.
- High noise levels can block, distort, change or interfere with the accelerometer output.
- Noise typically decreases as frequency increases, so noise at low frequencies is more of a problem than at high frequencies.
- Many industrial and medical applications require low noise because the accelerometer must be able to accurately measure low-frequency events.

Stability and Robustness

What is it?

- Ability of sensor to maintain accuracy with varying external conditions

Why it is important:

- External conditions and events such as temperature changes, reflow processes, and shock can all affect sensors calibration and accuracy.
- Accuracy affects performance

Bandwidth and Filtering

What is it?

- Bandwidth describes the range of frequencies (frequency content) a sensor can measure
- Low Pass and High Pass Filters are commonly included

Why it is important:

- If your signal of interest is at a higher frequency than the natural frequency of the sensor, it will not be able to accurately measure it
- Low Pass Filters are used to reduce noise from high frequency noise
- High Pass Filters are used to reduce low frequency noise or ignore DC offsets

Timings

What is it?

- Oscillator Tolerance
- Measurement Latency
- Power Up Time
- Start Up Time
- Output Data Rates (ODRs)

Why it is important:

- Power up and start up times come in to play when duty cycling a device to save power
- Oscillator Tolerance and measurement latency affects how accurately you know a parameter vs Time (impacts algorithm)
- ODRs affect power, noise, time resolution

Intelligence

Programmability

What is it?

- Various levels of programmability is included inside sensors ranging from
  - Embedded Engines
  - State Machines
  - MCUs

Why it is important:

- Impacts system architecture (where is data stored?)
- Power consumption (usually sensors are optimized for lowest power. Allows other portions to be powered down until needed)
- Speed and responsiveness

Embedded Algorithms, Digital Engines and Interrupts

What is it?

- On-board ability to process sensor data and signal conditions. Examples:
  - Motion Wakeup
  - Freefall
  - Tilt/Orientation and changes
  - Tap/Double-Tap

Why it is important:

- Impacts system architecture and integration
- Power consumption (usually sensors are optimized for lowest power. Allows other portions to be powered down until needed)
- Interrupt saves power over polling

Features

What is it?

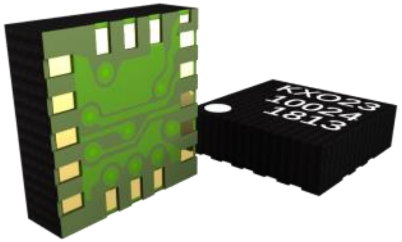
- Special features beyond primary measurement functionality
  - Buffers and Buffer Functionality (FIFO, FILO, Streaming, Trigger)
  - SelfTest

Why it is important:

- Impacts system architecture
- Adds capability that might not be possible or may be more costly or difficult to implement at a higher level
- Can impact power
- Buffering
  - Ensure no double or missed reads
  - May offer more compact data storage
  - Enables other parts of system to be duty cycled, thereby saving power

Accelerometers

KX012 / KX022 / KX122



Power

- Scalable power consumption as low as 2μA

Package and Interface

- **2x2x0.6mm**
- **2x2x0.9mm**
- LGA package
- 12-pin
- 3-Axis
- Digital I2C/SPI

Performance Characteristics

- User Selectable ± 2g, 4g, 8g Range
- Superior Offset Stability
- 16-bit resolution
- Excellent combination of thermal, shock, and reflow performance

Embedded Functionality

- **Up to 2 kB FIFO/FILO buffer**
- Digital high-pass filter outputs
- User-configurable wake-up function
- Internal voltage regulator
- **Wide range of ODRs from 0.781 Hz up to 25.6 kHz**

Embedded Algorithms

- Orientation
- Directional Tap/Double-Tap™
- **Freefall**

FlexSet Optimizer

- Dynamically adjustable power and noise values for optimized system performance

FOR:
Smartphones and Mobile Devices
Laptops
Gaming and Virtual Reality
Health and Fitness

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What is a MicroAmp Magnetic Gyro?

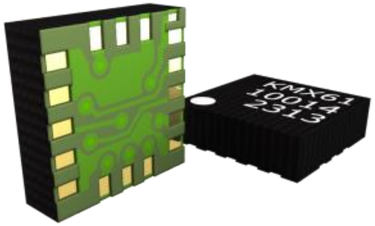
A perfect example of sensor fusion

=

Magnetometer
+
Accelerometer
+
Software

Gyroscope
Functionality
With < 1mA

KMX62G



9-Axis Solution

Accel + Mag + Emulated Gyro

Power

- Scalable power consumption <=1µA standby
- **Accel only power <=150µA, mag/accel power <= 395µA**
- **9-axis output with total power consumption of 940µA[1]**
- **1.7-3.6V Vdd**

Package and Interface

- 3x3x0.95mm
- LGA package
- 16-pin
- 9-Axis output[2]
- Digital I2C up to 3.4MHz
- **Communications down to 1.2V**

Performance Characteristics

- User selectable ± 2g, 4g, 8g, **16g** accel range
- ±1200µT mag range
- Superior offset stability
- Up to **16-bit** resolution
- Excellent combination of thermal, shock, and reflow performance

Embedded Functionality

- 384 bytes FIFO/FILO buffer with watermarking
- Digital high-pass filter outputs
- Internal voltage regulator
- Accel self-test
- **Mag self-test**

Algorithms

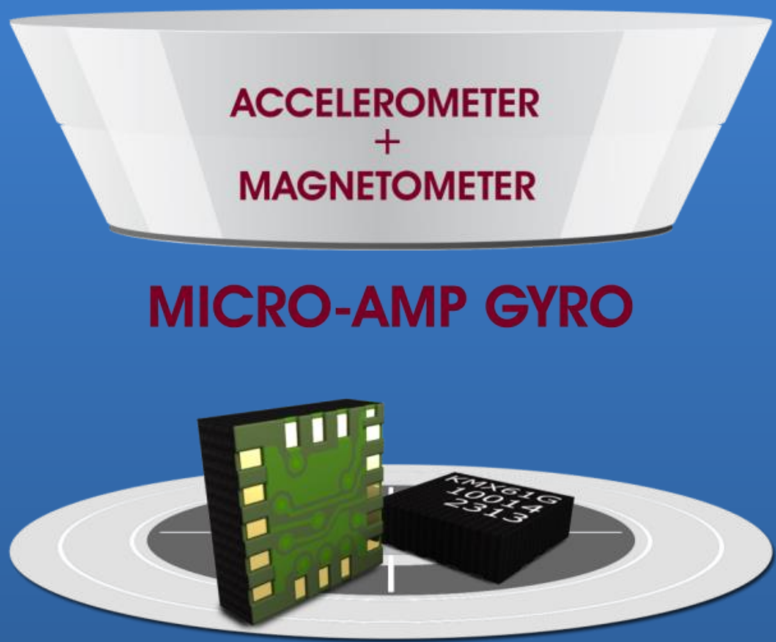
- User-configurable motion wake-up function
- **Magnet field change detection and notification**
- **Freefall detection**

Other

- Synthesized gyro output[2]
- Magnetometer algorithms for auto-calibration and MI rejection
- **Dynamically adjustable power and noise values for optimized system performance**

[1]Includes power consumed by Atmel ATUC128L4U operating at 48 MHz executing at 3MIPS to produce gyro output
[2]Via sensor fusion software

9-Axis Solution
with Micro-Amp Magnetic Gyro



- Ultra-low power, 6-axis accelerometer-magnetometer device delivering the industry's first highly accurate *synthetic* gyro equivalent to a traditional 9-axis solution.
- <1mA power consumption including processor MIPS
- Sensor Fusion SW runs on a sensor hub or app processor. Supported platforms include Qualcomm Snapdragon, Atmel AVR UC3 and ARM-based SAM D20 .
- Certified for Windows 8 and 8.1


Product Overview of the
KX23H
Smart-Sensor
Hub from Kionix
The KX23H smart sensor hub from Kionix integrates a 16-bit accelerometer and ARM Cortex-M0 in a tiny LGA package to simplify sensor integration and enable more efficient designs. Because the Cortex-M0 is a full multipoint control unit (MCU), certain applications will be able to run wholly within the KX23H, making it not just a sensor hub but the main application processor. Kionix also includes a library of advanced motion processing software.

KX23H MCU+Accelerometer

Small, low power motion detection and activity monitoring total solution

Power	Package and Interface	MCU Performance Characteristics	Embedded Accelerometer Functionality	Algorithms
• High-speed operation (32MHz operation): 6.0mA • HALT Mode: 2.0µA • Accel only power <=145µA • Digital I/O section: 1.7V to 1.9V • Accelerometer section: 1.7V to 3.6V	• 3x3x0.9mm • LGA package • 16-pin • Digital I2C slave to host interface • Digital I2C master to sensors interface	• 32-bit RISC CPU (ARM Cortex™-M0) • Maximum Operating Frequency 32MHz • Serial Wire Debug (SWD) port support • 128-kByte Built-in Flash ROM for application program • 16-kByte SRAM • High-speed clock: 32 MHz (generated by internal FLL from input clock) • Low-speed clock: 32.768 kHz	• User-selectable g Range and Output Data Rate • Digital High-Pass Filter Outputs • Embedded 256 byte FIFO/FILO buffer • Low Power Consumption with FlexSet™ Performance Optimization • Enhanced integrated Directional Tap/Double-Tap™, and Device-orientation Algorithms • User-configurable motion wake-up function	• Pedometer and calorie counting • Contextual awareness • Sensor fusion • Custom user programming

Note: product capabilities and specifications are preliminary as product is under development

Solutions for Activity Monitors

Bluetooth | Pressure Sensor | Activity Monitor・Pedometer

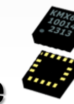
G SENSOR+SensorHUB

Bluetooth

BT Low Energy

LAPIS SEMICONDUCTOR

Act Monitor・Pedometer



- High Processing16bit
- Low Power, Low Noise
- User Flexibility and Programmability

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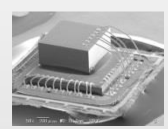
Pressure Sensor



- Detects altitude for more accurate activity tracking
- Temperature compensation
- High accuracy (+/- 0.2m)

ROHM SEMICONDUCTOR

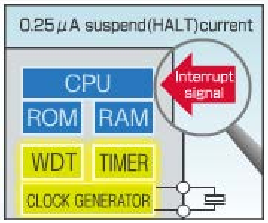
Solutions for Semi-smart Watches

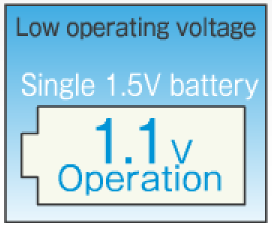
Long Battery Life

Low Power MCU

Integrated LCD Driver

Low Power Consumption





LAPIS SEMICONDUCTOR

Total shipments
Over 2 million

Bluetooth

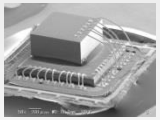
BT Low Energy

Bluetooth

Act Monitor · Pedometer

ROHM SEMICONDUCTOR

Pressure Sensor



- Detects altitude for more accurate activity tracking
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Act Monitor · Pedometer

G SENSOR+SensorHUB

- High Processing16bit
- Low Power, Low Noise
- User Flexibility and Programmability

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Solutions for Smart Watches

Bluetooth | Activity Monitor · Pedometer | Auto Adjust Brightness

Brightness Control

LIGHT SENSOR

- High Sensitivity
- Include IR cut filter
- Various Line up

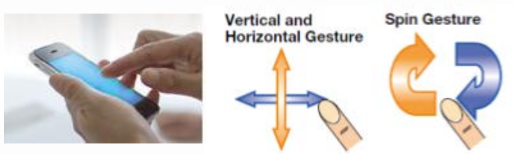
Bluetooth

BT Low Energy

Touchscreen

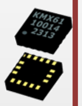
CTP Controller

- 5mm x 5mm Package
- HIGH SNR over 40dB



Act Monitor · Pedometer

G SENSOR+SensorHUB



- High Processing16bit
- Low Power, Low Noise
- User Flexibility and Programmability

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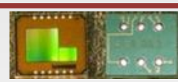
New Product Offerings

UV SENSOR



Low Power Consumption 300uA
Small PKG (2.1 x 1.8mm)

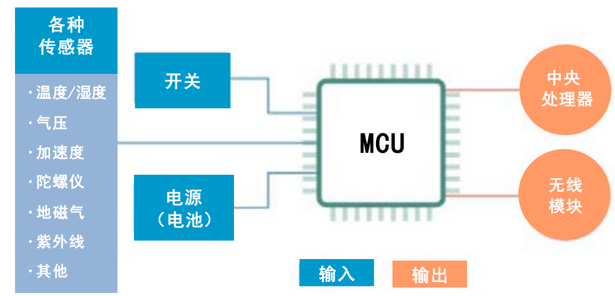
LAPIS SEMICONDUCTOR

SHARP
934SH

KYOCERA
URBANO

SENSOR HUB

Integrated low power
control of various sensor



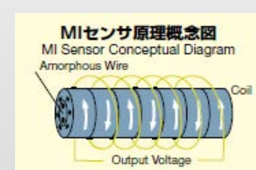
LAPIS SEMICONDUCTOR

Wireless Charger

Ultra Low Power 0.5 ~ 1W
High Efficiency

3-axis Electronic Compass

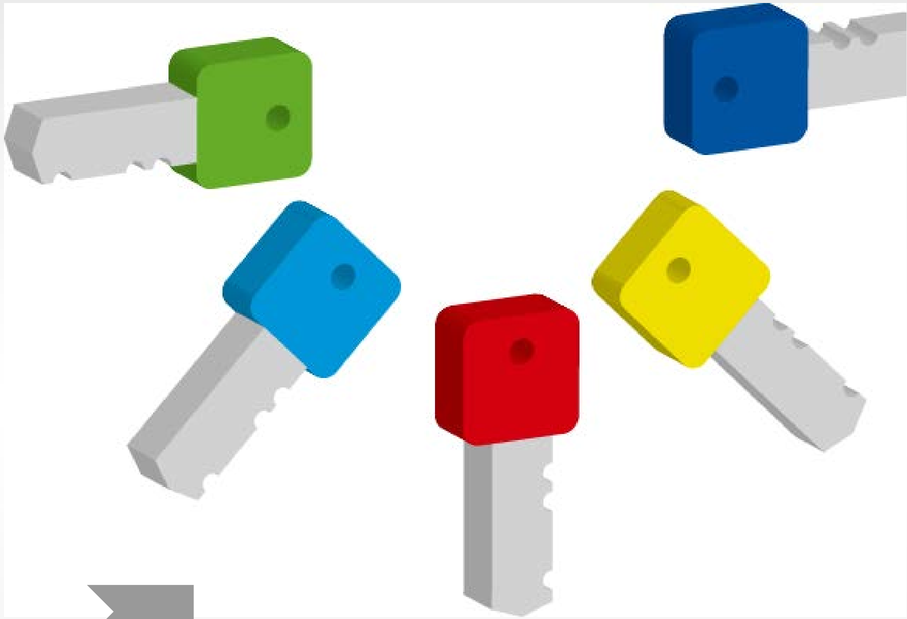
Small PKG 2.0×2.0×1.0mm
Ultra Low Power Consumption
Fast Measurement Time
High Accuracy

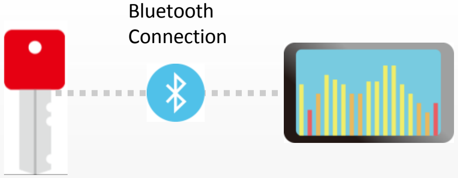


Device Concept

Wearable Key Device

This versatile device features multiple embedded sensors that can detect a variety of environmental conditions and activities, while the key-shaped design is small and light enough to use everyday.

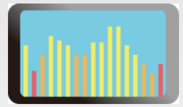




Embedded Devices

Application Example

Activity Monitor



The lightweight form factor makes carrying effortless and unobtrusive. Not only can it measure calories burned and steps taken to promote better health & fitness, it can even detect when wearers are riding in a vehicle (i.e. bus, train, car) and track time traveled.

In addition, by simply wearing it around the neck or attaching it to a key ring on a belt loop or in a pocket, the device can notify users if they need to ramp up their activity to meet target goals or track progress during an exercise regimen.

Attach to a keychain or wear around your neck

Steps	Accelerometer	Records the number of steps taken
Calories	Accelerometer	Tracks calorie consumption
Stairs	Accelerometer, Pressure Sensor	Detects when users take the stairs and tracks the number of steps
Vehicle	Accelerometer	Detects when wearers ride a bus, train, car, or other vehicle

Alerts

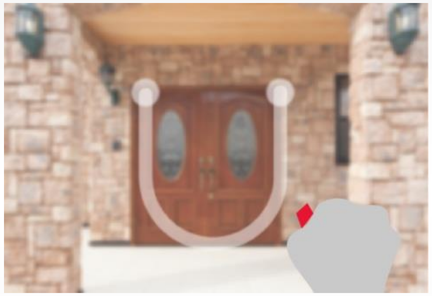
Notifies users if they don't reach their target goals for the day

Motivates

Tracks activity progress and provides extra motivation to get in shape or stay fit

Gesture Control (Lock/Unlock Function)

Lock and unlock doors by holding the Wearable Key Device and simply drawing a 'U' or 'L' in the air.
Plus, users can verify whether the door is locked using a tablet or smartphone, providing greater security and peace of mind.



Unlock

Lock

UV Monitor

Attaching the Wearable Key Device externally makes it possible to measure the amount of UV radiation to prevent sunburn or excessive exposure.

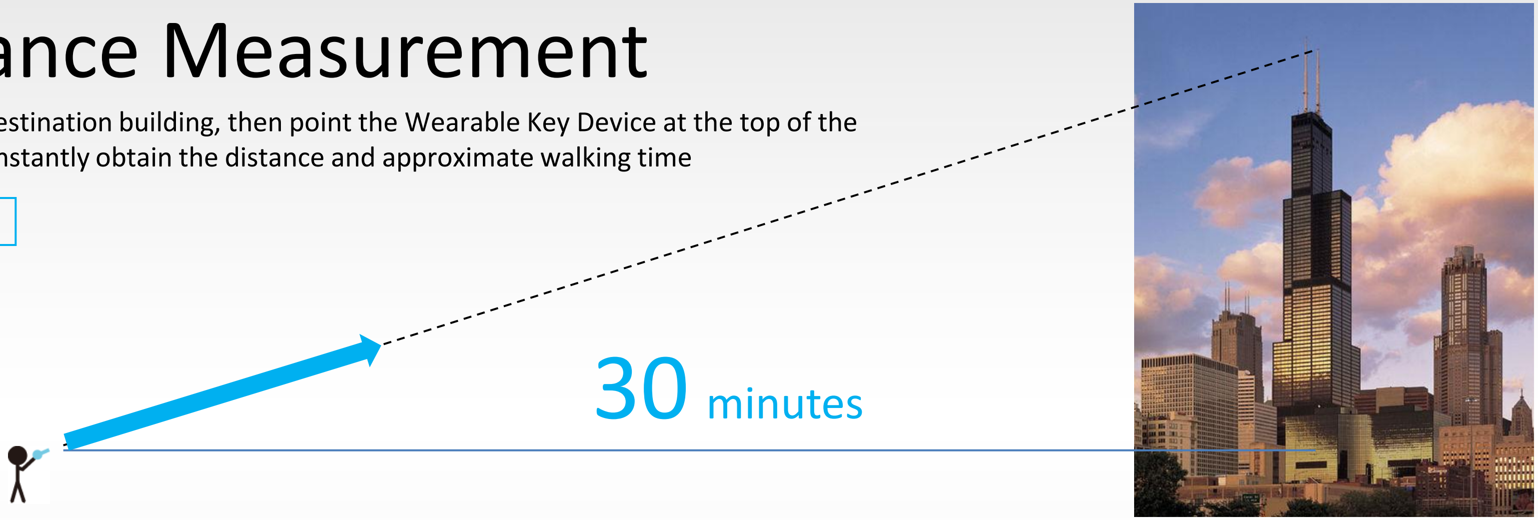
UV Sensor | RGB Sensor

Application Examples

Distance Measurement

Register a destination building, then point the Wearable Key Device at the top of the building to instantly obtain the distance and approximate walking time

Accelerometer



Metal Detector

A high-precision MI sensor is included that can detect foreign metal objects in food and other locations

Magnetometer

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Sensing the Future

John M Chong
jchong@kionix.com