White Paper

The Role of Sensor Fusion and Remote Emotive Computing (REC) in the Internet of Things

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Abstract

The age of sensor technology is upon us. These days, it's unusual to experience an electronic consumer product that doesn't use sensors to create new experiences for its users. Sensors are experiencing a renaissance of sorts as micro-electromechanical systems (MEMS) technology becomes less expensive and further miniaturized, in turn fueling penetration of sensors into new applications and creating new potential for the sensor market.

Table of Contents

2 Introduction
2 Human Beings: The Ultimate Sensing Example
3 Evolving Sensor Technology to Improve Everyday Life
4 How Sensor Fusion Works
6 Other Examples of Sensor Fusion
7 Leveraging Sensor Fusion for the Internet of Things
9 Context Awareness
11 Sensor Fusion/Context-Aware and Remote Emotive Computing-Related Services

Introduction

Sensors are now found in a wide variety of applications, such as smart mobile devices, automotive systems, industrial control, healthcare, oil exploration and climate monitoring. Sensors are used almost everywhere, and now sensor technology is beginning to closely mimic the ultimate sensing machine … the human being. The technology that allows this to happen is *sensor fusion*, which leverages a microcontroller (a "brain") to fuse the individual data collected from multiple sensors to get a more accurate and reliable view of the data than one would get by using the data from each discrete sensor on its own. Sensor fusion creates a situation in which *the whole is much greater than the sum of its parts*.

Sensor fusion enables **context awareness**, which has huge potential for the Internet of Things (IoT). Advances in sensor fusion for *remote emotive computing* (emotion sensing and processing) could also lead to exciting new applications in the future, including smart healthcare. However, these capabilities spark significant privacy concerns that IoT governance will need to address. Massive amounts of context-aware data will become available as use of sensor fusion and REC technologies increases. This data, along with the IoT's access to the "global neural network in the sky" and cloud-based processing resources, will lead to a tremendous expansion in the delivery of context-aware services customized for any given situation. Services could be based on the context of what an individual user is doing, what machines are doing, what the infrastructure is doing, what nature is doing, or all of the above in various combinations.

Human Beings: The Ultimate Sensing Example

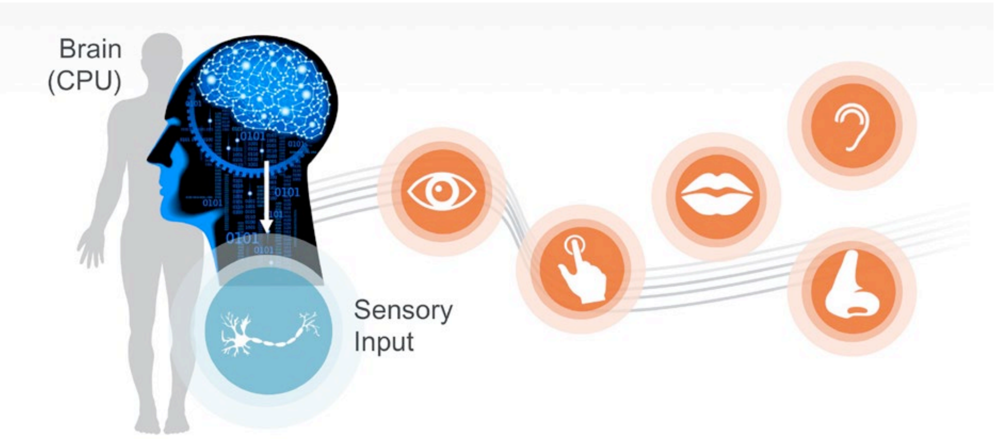
To understand how sensor fusion works, let's take a look at how sensing works in the human body. A human being experiences the external environment in many ways. Vision, hearing, chemical sensation (senses of smell and taste) and surface sensation (sense of touch) all provide sensory information about one's surroundings, which travels through the peripheral nervous system (PNS) to the brain. The brain then decides how to respond to a given condition or experience.

The PNS doesn't make complex decisions about the information it transports; these decisions are made by the brain. In response to sensory input, the brain sends out motor information—a human being's response to the input. For example, a pedestrian sees a car driving toward him, and his brain tells his muscles to walk faster to the other side of the road to avoid an accident. Human beings also receive information from their internal organs, some of which is noticeable, such as a stomach ache. There are also other kinds of internal information a person isn't aware of, such as blood pressure, that are used to regulate the body's internal environment.

The brain is the ultimate decision maker. However, without the peripheral nervous system's ability to bring in sensory information and send out motor information, one would not be able to walk, talk or do many of the other functions we often take for granted.

The brain often uses several sources of sensory input to validate an event and compensate for a lack of "complete" information to make a decision. For example, a person may not see flames under the hood of a car, but the smell of burning rubber and heat coming from the dash would tell the brain it's time to leave the car because the engine is on fire. In this case, the information causing the brain to react is greater than the sum of the disparate sensory inputs.

Sensor Fusion: The Human Model



Sensory information (vision, hearing, smell, taste and touch) is gathered from one's surroundings and travels through the peripheral nervous system to the brain for processing and response.

"The Whole Is Greater Than the Sum of Its Parts"

In the world of technology, sensor fusion plays a similar role. By integrating inputs from multiple sensors for more accurate and reliable sensing, sensor fusion can produce much higher levels of recognition and offer new responses. Individual sensors have inherent limitations and can err, which can be corrected or compensated for by complementary sensing nodes. For instance, gyroscopes suffer from offset drifts over time, which can be compensated for using a companion accelerometer. The conclusion is that fused sensor information (from multiple sensors) is more accurate and reliable than individual sensor data.

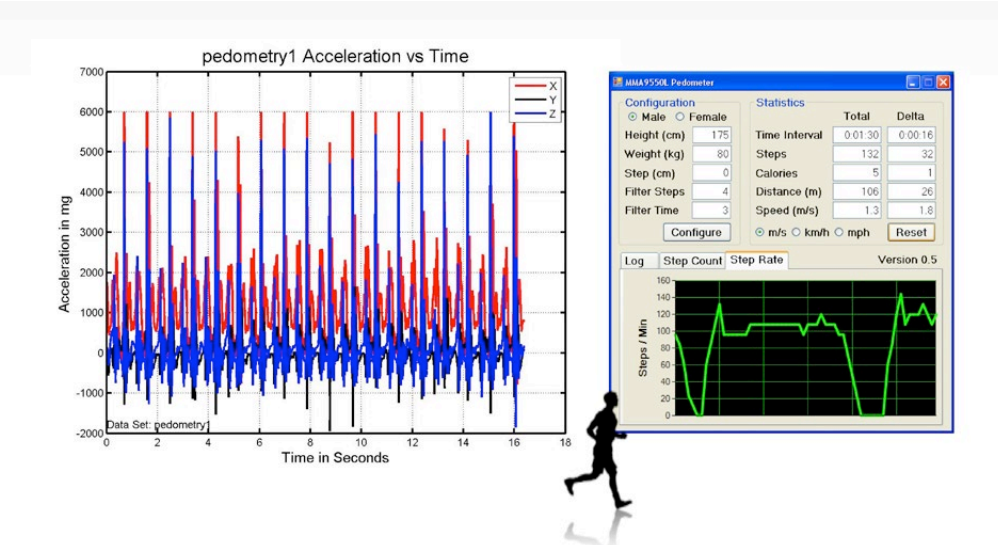
Evolving Sensor Technology to Improve Everyday Life

Let's take a look at a simple example of the pedometer. Traditional pedometers used a pendulum and had to be worn at the hip at a vertical angle to avoid false readings. As the user walked, the pedometer counted each step by keeping track of the pendulum swinging back and forth with the hip motion and hitting a counter each time. However, false readings were common due to variations in stride, the angle of climb/walk or incorrectly counting steps when a user was driving a car or making other motions.

MEMS-based inertial sensors led to big improvements. The first generation of MEMS-based pedometers used accelerometers that performed 1-, 2- or 3-axis (3D) detection of a person's acceleration, more accurately measuring step counts. And, unlike the old-fashioned mechanical pedometers that simply recorded a step with every swing, an accelerometer measured a person's movements many times every second.

But, what if you wanted to not only count the number of steps, but also accurately calculate calories burned when moving up and down stairs or hills? The next generation of pedometers added altimeters to measure and account for the changes in the altitude of an object above a fixed reference point (elevation) while a person is walking. Altimeter technology senses absolute air pressure in altimeter or barometer (BAP) applications. Accurate pressure readings

Pedometer Example



Configuration

● Male ○ Female

Height (cm) 175

Weight (kg) 80

Step (cm) 0

Filter Steps 4

Filter Time 3

Statistics

	Total	Delta
Time Interval	0:01:30	0:00:16
Steps	132	32
Calories	5	1
Distance (m)	106	26
Speed (m/s)	1.3	1.8

● m/s ○ km/h ○ mph

also require temperature measurement, so some kind of temperature compensation circuitry is typically added for accuracy.

Following the success of early portable music players that hung on a jogger's arm, today there are many standalone pedometers and cell phones with pedometer functionality that are designed to be worn on the arm (as opposed to hanging on a belt at the hip). With this use case, the arm motion introduces parasitic movement. A gyroscope can measure the rotational movement of the arm and compensate for it.

The combination of three types of sensors (accelerometer, altimeter and gyroscope) with an MCU to measure and process the readings results in a highly accurate pedometer.

How Sensor Fusion Works

The most basic sensor fusion example is an e-compass, in which the combination of a 3D magnetometer and 3D accelerometer provides compass functionality. More complex sensor fusion technologies give users an enhanced experience, leveraging and combining 3D accelerometers, 3D gyroscopes and 3D magnetometers (which measure the components of the magnetic field in a particular direction, relative to the spatial orientation of a given device). Each of these sensor types provides unique functionality, but also has limitations:

- Accelerometer: x-, y- and z-axis linear motion sensing, but sensitive to vibration

- Gyroscope: pitch, roll and yaw rotational sensing, but zero bias drift

- Magnetometer: x-, y- and z-axis magnetic field sensing, but sensitive to magnetic interference

When combining all of these technologies, sensor fusion takes the simultaneous input from the multiple sensors, processes the input and creates an output that is greater than the sum of its parts (i.e., by using special algorithms and filtering techniques, sensor fusion eliminates the deficiencies of each individual sensor—similarly to how the human body functions, as described above).

Sensor fusion provides a whole host of capabilities that can make our lives easier and enables a variety of services that can leverage these capabilities.

One of the issues facing the sensor industry today is lack of standardization across various operating systems (OSs). Today, most OS drivers ask for the most basic sensor data, which limits the use of the full capabilities of the sensors.

Sensor fusion is a part of Microsoft® strategy, so the Windows® 8 OS supports sensors in a cohesive manner, using sensor-class drivers based on industry standards developed in collaboration with Microsoft's ecosystem partners (Human Interface Device specification 2011). The Windows Runtime programming module allows for lightweight executive calls that enable sensor processing at the hardware level.

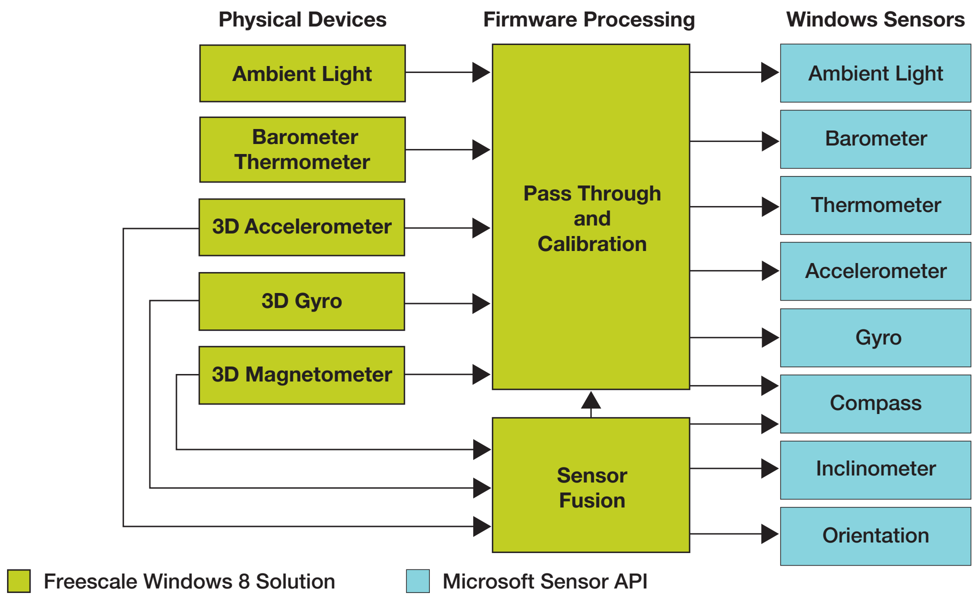
Sensor fusion often refers to a combination of a 3D accelerometer, a 3D gyroscope and a 3D magnetometer. This configuration is called a nine-axis system, which affords the user nine degrees of freedom (9-DoF). In 2012, Freescale introduced a 12-axis Xtrinsic sensor platform for Windows 8 that offers a 12-DoF sensor fusion solution. This is accomplished by including a barometer sensor, a thermometer sensor and ambient light sensing functionality.

Freescale 12-axis Xtrinsic Sensor Platform for the Windows 8 OS

This comprehensive hardware and software solution fuses accelerometer, magnetometer and gyroscope data using a Freescale 32-bit MCU (the "brain" of the operation) and provides ease of integration for streamlined development. Targeted for use in tablets, slates, laptops and other mobile devices, Microsoft's Windows 8 OS expands capabilities for running smartphone and tablet applications with the computing power of a personal computer. Freescale was one of the first companies to receive Windows 8 certification from Microsoft for its sensor fusion platform.

Basic sensor fusion processing requires 10–12 MIPS. For a 9-DoF sensor fusion, the requirement can easily reach 18–20 MIPS of processing cycle. There are various approaches to meeting these processing needs (with pros and cons for each), including

12-Axis Xtrinsic Sensor Data Flow for Windows® 8



adding a dedicated coprocessor for sensor processing or using a robust MCU with enough performance headroom to allow the addition of new functionality over time. If an MCU was already needed to perform embedded processing for an IoT application, then the MCU option would be advantageous, as it would “kill two birds with one stone.”

Other Examples of Sensor Fusion

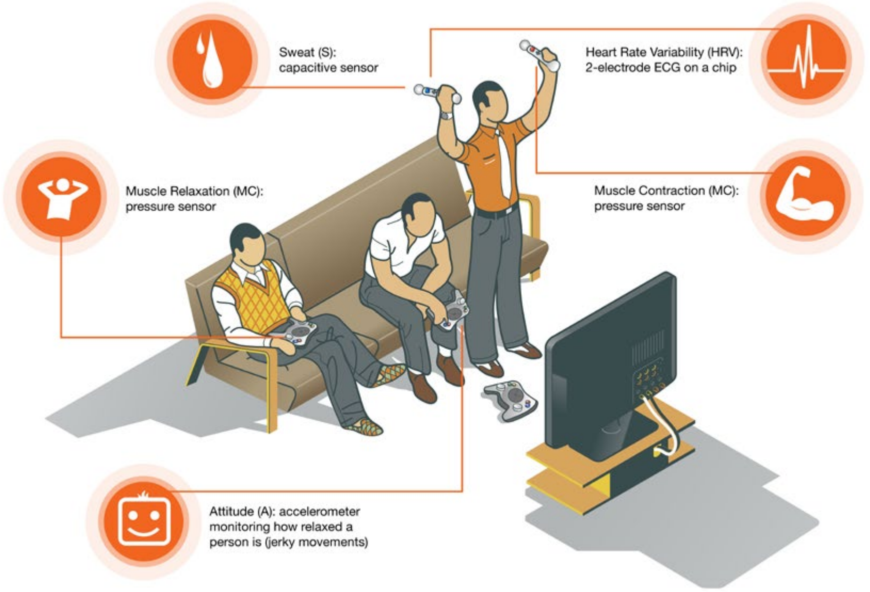
Freescale is doing research regarding the use of sensors in medical electronics and multi-sensor processing for non-medical applications. Dr. José Fernández Villaseñor is a medical doctor and electrical engineer combining his work as a Freescale medical product marketer and a hospital physician in his study of the field of emotion analysis using sensors (a large building block of REC technology). Research shows that heart rate increases due to physical activities have a different pattern and slope than increases due to adrenalin from excitation. Hence, one can use algorithms and analyze sensor data to electronically detect the types of emotion a person is displaying.

Here’s an example of a gaming platform that can detect emotions electronically by monitoring and data acquisition from physiological variables and states, such as:

- Muscle relaxation (MR)—via a pressure sensor
- Heart rate variability (HRV)—via a two-electrode ECG on a chip
- Sweat (S)—via a capacitive sensor
- Attitude (A)—via an accelerometer monitoring a person’s state of relaxation (jerky movements vs. steady hands)
- Muscle contraction (MC)—via a pressure sensor

Using the sensor data collected, an MCU in the game platform could, for example, detect emotions and give the gamer feedback during game situations to make the game more exciting. How about making turns faster and more difficult to maneuver in a driving game

Context Awareness Using Emotion Sensing



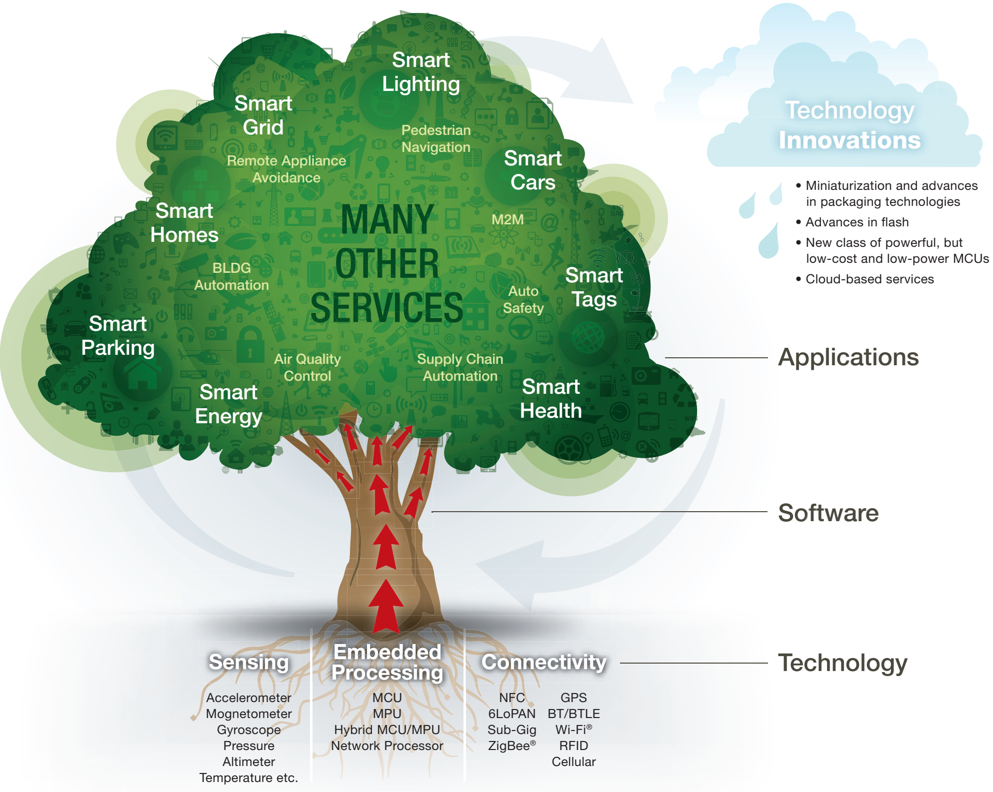
until the gamer shows a more relaxed state (a less jerky reading from the accelerometer)? Hence, the calm driver with better command over his/her emotions will have a better score (similar to real life). This would be considered *local emotive computing* if the local console's MCU provided the processing function or *remote emotive computing* if a cloud-based system provided the processing function. In a cloud-based system, sophisticated "big data" algorithms can be leveraged to provide a more elaborate response to the gaming scenario.

In another example, sensors could be used to detect emotion by measuring the way a user holds a cell phone to type or make a call. Furthermore, software algorithms could be used to provide additional context as to the state of mind of the individual by analyzing the way the person texts, how jerky the phone movement is or how many mistakes are made while typing (use of backspace key).

Leveraging Sensor Fusion for the Internet of Things

As discussed in the white paper **"What the Internet of Things Needs to Become a Reality,"** the IoT encompasses many use cases—from connected homes and cities to connected cars and roads to devices that track an individual's behavior and use the data collected for "push" services. The IoT is a sort of universal "global neural network in the sky" that will touch every aspect of our lives. From a technology perspective, the IoT is being defined as smart machines interacting and communicating with other machines, objects, environments and infrastructures, resulting in volumes of data generated and processing of that data into useful actions that can "command and control" things and make life much easier for human beings.

Internet of Things



Requirements common to all IoT use cases include:

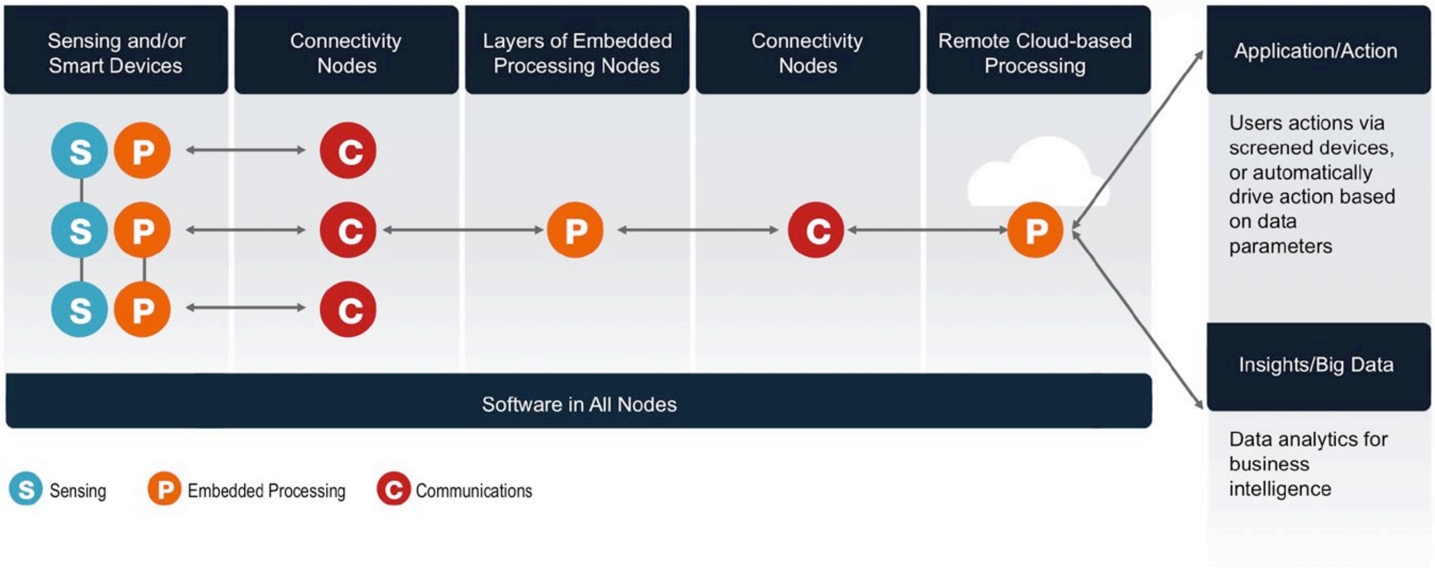
- Sensing and data collection capability (sensing nodes)
- Layers of local embedded processing capability (local embedded processing nodes)
- Wired and/or wireless communication capability (connectivity nodes)
- Software to automate tasks and enable new classes of services
- Remote network/cloud-based embedded processing capability (remote embedded processing nodes)
- Full security across the signal path

The types of sensing nodes needed for the IoT vary widely, depending on the applications involved. Sensing nodes could include a camera system for image monitoring, water or gas flow meters for smart energy, radar vision when active safety is needed, RFID readers sensing the presence of an object or person, doors and locks with open/close circuits that indicate a building intrusion or a simple thermometer measuring temperature. Who could forget the heat-seeking mechanical bugs that kept track of the population of a building in the movie *Minority Report?* Those mechanical bugs represent potential sensing nodes of the future. (I assume they'll be used for fighting crime.)

These nodes all will carry a unique ID and can be controlled separately via a remote command and control topology. Use cases exist today in which a smartphone with RFID and/or near field communication (NFC) and GPS functionality can approach individual RFID/NFC-enabled "things" in a building, communicate with them and register their physical locations on the network. Hence, RFID and NFC will have a place in remote registration, and, ultimately, command and control of the IoT.

The addition of sensor fusion platforms and remote emotive computing dramatically increases the capability of the sensing nodes in the IoT.

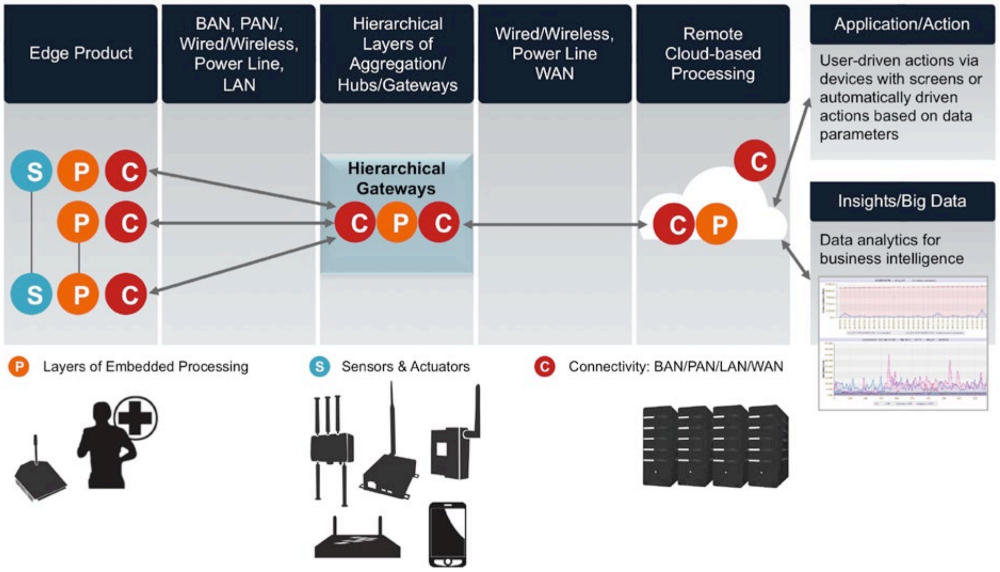
Functional View of Internet of Things Technologies



‘Box-level’ View of IoT Building Blocks

If we convert the building blocks of the IoT from simple nodes to a box/product-level view, we end up with sensing/edge nodes that use PAN/BAN/LAN types of communications topologies, connected to gateways with different levels of hierarchy.

‘Box-level’ View of IoT Building Blocks



These gateways, in turn, communicate to the cloud via WAN communication technology. Once connected to the cloud through an access network, data will be routed through a server for application/action, as well as big data analysis.

Context Awareness

Sensor fusion, along with embedded processing and connectivity, enables context awareness, and context awareness enables a new world of services.

What is “Context?”

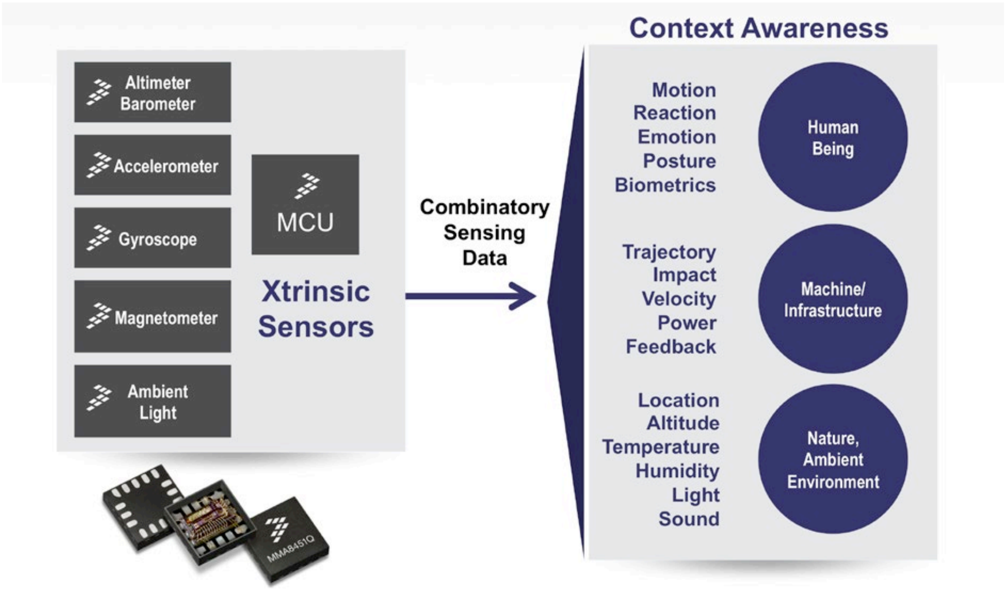
Context is defined as the circumstances or facts that form the setting for an event, statement, situation or idea. In software programming, the idea of developing context-aware applications has been around for awhile. *Context-aware* apps examine *who, where, when* and *what,* and the software designer uses this contextual information to determine why a situation is happening and then encodes some action in the application.

Based on this definition, the four most important categories of information to formulate a context-aware action are:

- Identity
- Location
- Time
- Activity

In using contextual information to formulate a deterministic action, context interfaces occur within (and in between) first a human being, then the environment and, lastly, machine and infrastructure elements. The same way that a canvas, a collection of paint tubes and a brush allow an artist to create a masterpiece, context awareness and these interfaces are the tools for enabling a variety of services that otherwise would not be meaningful. This is where incremental improvements in technology can lead to the whole being much greater than the sum of its parts. Nothing detects and provides the readout of human beings' emotions the way sensors do. Sensors provide access to the human mindset, making an experience more "personal."

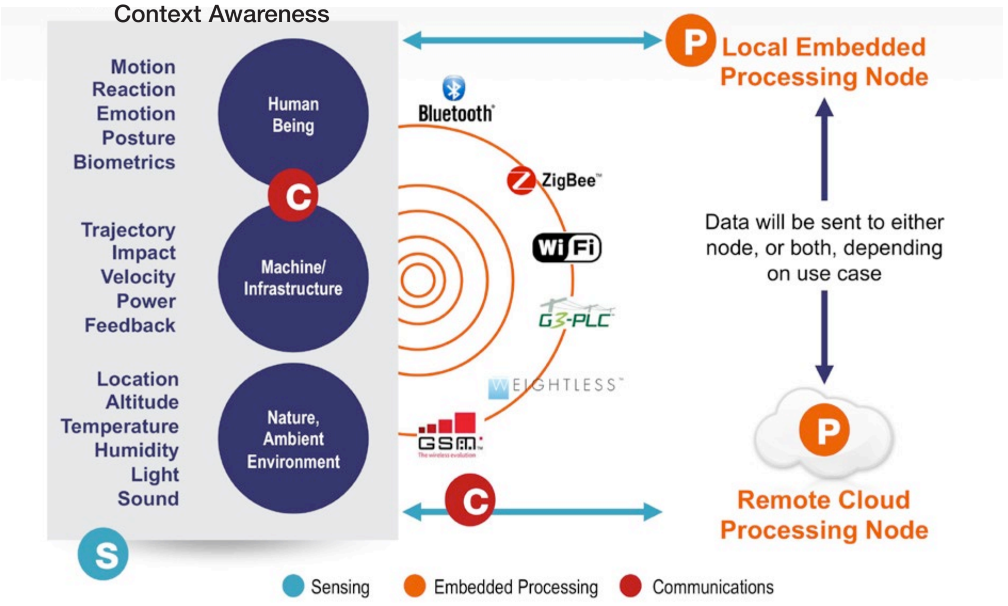
Sensor Fusion Enables Context Awareness



The interactions (and interfaces) between human being, nature and environment and machine/infrastructure provide valuable data points for determining context awareness, including:

1. The human being
   - Motion, posture and strides
   - Reaction to stimuli
   - Emotions under given conditions
   - Biometrics at any given time
2. The ambient environment
   - Location
   - Altitude
   - Temperature
   - Humidity
   - Light
   - Sound
   - Smell
3. Infrastructure/machines being used by the person
   - Trajectory
   - Impact
   - Velocity
   - Feedback
   - Vibration and gyration
   - Structural integrity related changes

Context Data Transferred for Processing



In the IoT, after inputs are collected by the sensing nodes, an embedded processing node processes the context-aware data and either provides feedback for immediate action or passes it on for cloud/network-based processing. In the latter scenario, various connectivity mechanisms are needed to get the data to the core network. For example, within this context, a cellular phone or a connected tablet becomes a “gateway” to connect to a wide area network (WAN).

Sensor Fusion/Context-Aware and Remote Emotive Computing-Related Services

Imagine a situation in which a sensor fusion platform is used, leveraging local embedded processing as well as cloud-based software techniques (such as pattern recognition and machine learning used in Internet searches and online advertising) to remotely monitor a variety of conditions and provide completely new classes of services—and all of this is done automatically by a cloud-based command and control center without any human interaction needed. The variety of these services is only limited by one’s imagination, and scenarios could include:

- Sensors on fruit and vegetable cartons could track location, temperature, vibration and jerkiness of the ride and sniff the produce, warning in advance of spoilage. Then a cloud-based command and control center could automatically communicate with the transporting truck or train to reroute the shipment and save the food. Imagine the economic benefits of this in a greater scale.

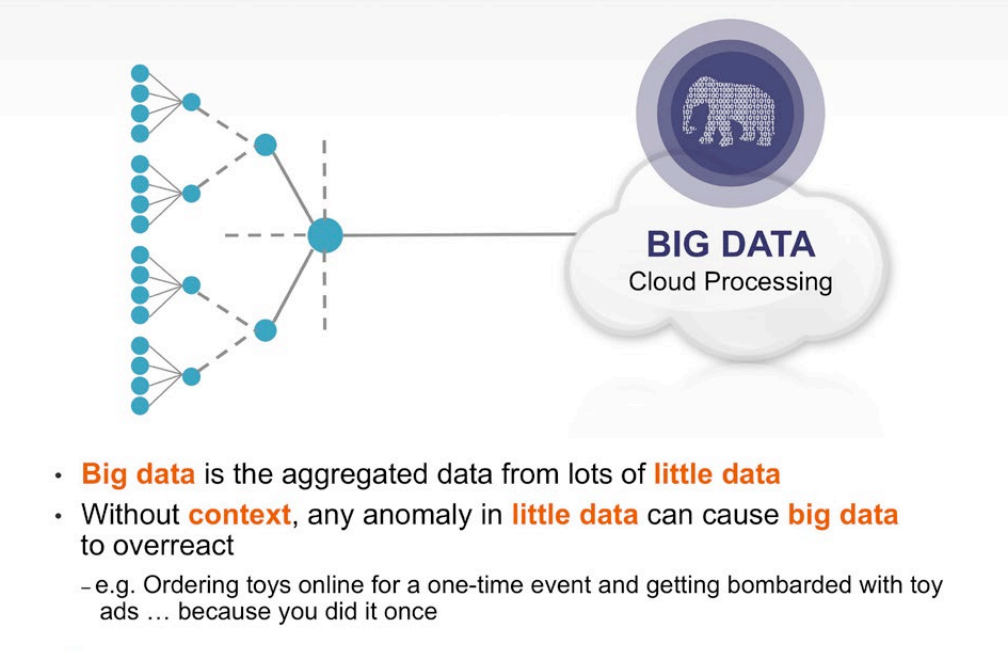
- Helping an individual in a mall have a much better shopping experience by providing directions, coupons, augmented reality maps and recommendations for deals, free concerts, movies and other entertainment, social networking and places to eat based on the shopper's health history.

I recently spent a few days at a local children's hospital, and couldn't help but wonder how the system could be improved.

- A sensor fusion platform could be used to reduce the number of times a hospital nurse has to check patients' vital signs, reducing healthcare costs. How about also using it to remotely monitor a patient and avoid the need for a hospital visit altogether by recommending or providing preventive care when needed?
- Imagine combining a variety of sensor fusion platforms and RFID tag readers behind hospital room sinks to monitor movements by doctors and nurses, alerting them if they forget to wash their hands before and after touching patients (one of the biggest causes of hospital-acquired infections).
- REC example: A person's vital signs, emotions and movements could be tracked 24 hours a day. That data could then be used to alert the individual to be more vigilant about his or her eating, driving, etc. to help prevent health issues and/or accidents. The person's phone could call a predetermined emergency contact if the person was severely intoxicated and provide the location of the person for sending help. Imagine how many parents of teenagers would sign up for that service!
- A bridge experiencing structural issues that becomes unfit to drive on due to environmental conditions automatically alerts a cloud-based command and control center, which, in turn, alerts all of the cars (not just the drivers) on the way to that bridge to stay away and take alternate routes.
- The vehicle of an intoxicated driver alerts the police and nearby vehicles to help avoid an accident.
- And lots of other types of services that leverage sensor fusion to provide context-aware services.

For most part, no major technological breakthroughs are required at a device level to make any of these scenarios happen, and there is already a great deal of attention being given to the use of “big data” processing, analytical tools and mechanisms to generate those types of services. Only incremental improvements are needed to bring the ecosystem of technologies and players together, setting the rules of the game, and moving away from little silo clouds to that “global neural network in the sky.”

Context Helping Big Data



- **Big data** is the aggregated data from lots of **little data**
- Without **context**, any anomaly in **little data** can cause **big data** to overreact
  - e.g. Ordering toys online for a one-time event and getting bombarded with toy ads … because you did it once

The information collected by sensors can be used for services that benefit and simplify people’s lives, or it can be used for data mining and other use cases that raise security and privacy concerns—hence, the IoT dilemma. With sensor fusion and REC technologies, even more capabilities can be added to the mix. Just as the Internet phenomenon happened not so long ago and caught like a wildfire, the IoT will touch every aspect of our lives in less than a decade, with sensor fusion having a front row seat for the phenomenon. Are you ready for it?

To contact Kaivan Karimi or to view more IoT-related material he has authored, visit https://community.freescale.com/people/kaivankarimi/content

For more information about Freescale sensing solutions, visit freescale.com/Xtrinsic

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