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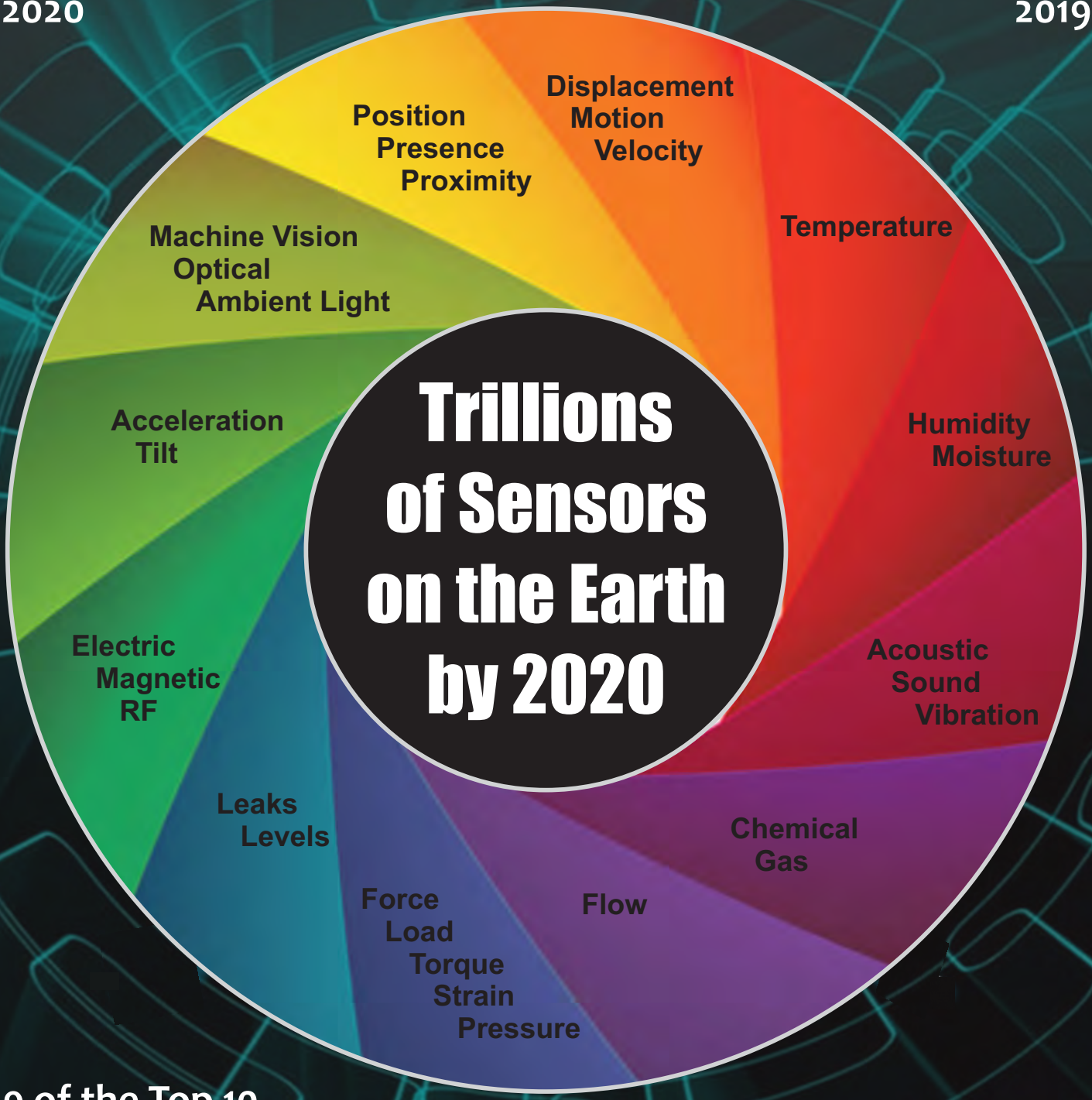
Nov-Dec 2019

Future Impacts of New Sensor Technologies 2020

5 Defining Moments and Trends 2019



9 of the Top 10 Analog IC Vendors Deliver High Volume Tiny Sensors

In this Edition:

Cover Story:
Trillions of Sensors on the Earth by 2020

Headlines:

- **Sensor & MEMS Market "Who is making What"**
  - Two Top Market Segments
  - Low-cost IoT-focused devices "Tiny but includes high accuracy types"
  - Industrial sensing "Mainly Ruggedized Modules"
  - What are Sensors & MEMS sensing?
  - Markets and Applications
  - Arenas with Significant New Sensor innovation Opportunities
  - Products, Technology and Vendor Evolution
  - Where are the missing 41 billion IoT devices of 2019 Forecast?
  - Tables: 35 Vendors by Application with direct links
  - Research Institutes & Universities mentioned in this article
  - Tribute to FAIRCHILD Semiconductor & Dr. Janusz Bryzek
  - Conclusion

- **Small-size and Highly Accurate Sensors from TI**

- **Compairing Sensors & MEMS**

- **Future Impacts of New Sensor Technologies**
  - Sensing Tiny Things
  - Demographic: type of sensors by physical measurement
  - Trillions of Sensors Will Integrate and Inform Future Smart Systems
  - Arenas With Significant New Sensor innovation Opportunities
  - New Sensor Integration Enables New Value Creation Through Complex Interactions
  - Competing Suppliers Target Segments With an Array of Sensor Types

- **Five Defining Moments and Trends in Sensors in 2019**
  - AMS acquires 59% of Osram shares
  - Neuromorphic sensing: A brainy direction
  - Ex-InvenSense execs form UltraSense
  - The influence of the piezo effect
  - At the edge

50 Sensor & MEMS Companies in this Edition

Vendors: ACEINNA, Allegro, AMS, Analog Devices, Avago, Bosch, Broadcom, Canon, Emerson, Epson, eXo Imaging, Fairchild, GE, Honeywell, HP, iniLabs, iniVation, Intel, InvenSense, Libelium, Maxim, MediaTek, Microchip, Monnit, Murata, NXP, ON Semi, Osram, Panasonic, Prophesee, Qualcomm, Renesas, Seiko Epson, STMicroelectronics, TDK Epcos, TE connectivity, Texas Instruments, thinfilm, Toshiba, UltraSense, Vayyar, Vesper, XSENSE

Research Centers: CEA-Leti, ETH Zurich, Fraunhofer, Imec, National Science Foundation, UC-Berkeley Sensor & Actuator Center, Vision Institute (CNRS, UPMC, INSERM)

Daniel Dierickx
CEO & co-Founder
at e2mos
Acting Chief Editor

Over 3 Decades Global Semiconductors & Computer Systems Market Expertise

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Sensor & MEMS Market "Who is making What"

An Update for Experienced Engineers and a Discovery for Beginners

By Daniel Dierickx, e2mos | 30-Dec-2019

There are apparently over 1,000 Sensor and MEMS vendors; yet by 2020, according to the National Science Foundation (USA), there will be trillions of sensors on the earth.

We reviewed about 500 Sensors & MEMS vendors, and we came to the conclusion that we should try to help our readers to demystify the Sensor Market.

Here we go in bullet style:

■ Two Top Market Segments

Competing hardware suppliers are approaching the top segments from two distinct backgrounds: **industrial sensing**, or **low-cost IoT-focused applications**.

■ Low-cost IoT-focused devices "Tiny but includes high accuracy types"

Package size down to: 0.80mm x 0.80mm (DSBGA 4-pins) see below and **page 8**.

TO-92

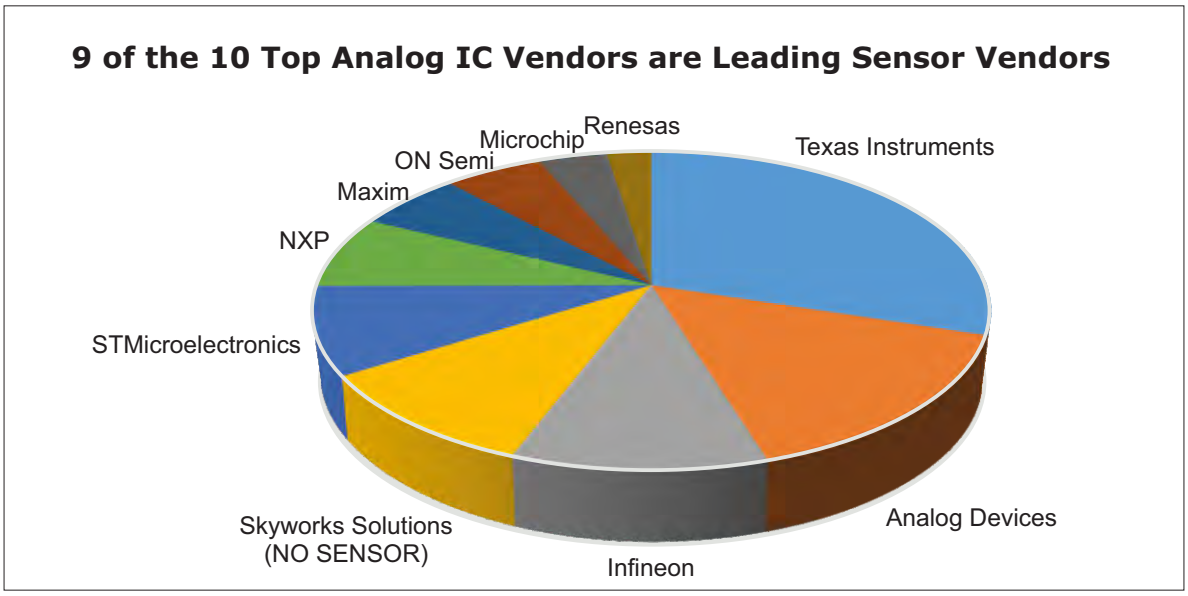
DSBGA

SOT-23

SOIC

FCBGA

These devices are mainly produced by semiconductor vendors, 9 of the 10 Top Analog IC Vendors are offering a range of sensors in traditional and standardized IC packages and as such must be mounted on a PCB and/or in a module. Those 9 Analog IC Vendors are: Texas Instruments, Analog Devices, Infineon, STMicroelectronics, NXP, Maxim, ON Semiconductor, Microchip and Renesas. Skyworks Solutions is not involved in sensors.



Obviously there are other IC vendors with a strong sensor product portfolio like: Bosch, Broadcom (Avago), Qualcomm, Toshiba, MediaTek, and many more. **see table page 5 & 6**.

■ Industrial sensing "Mainly Ruggedized Modules"

Vendor examples: Bosch, Denso, Honeywell, Emerson, TE connectivity, Monnit, Libelium, thinfilm, GE Sensing, Sensata Technologies, and many more. **See table page 5 & 6**.

Light, Vision

Temperture with
Wireless transmitter

Pressure

... to next page

Sensor & MEMS Market "Who is making What"

... from previous page

■ What are Sensors & MEMS sensing?

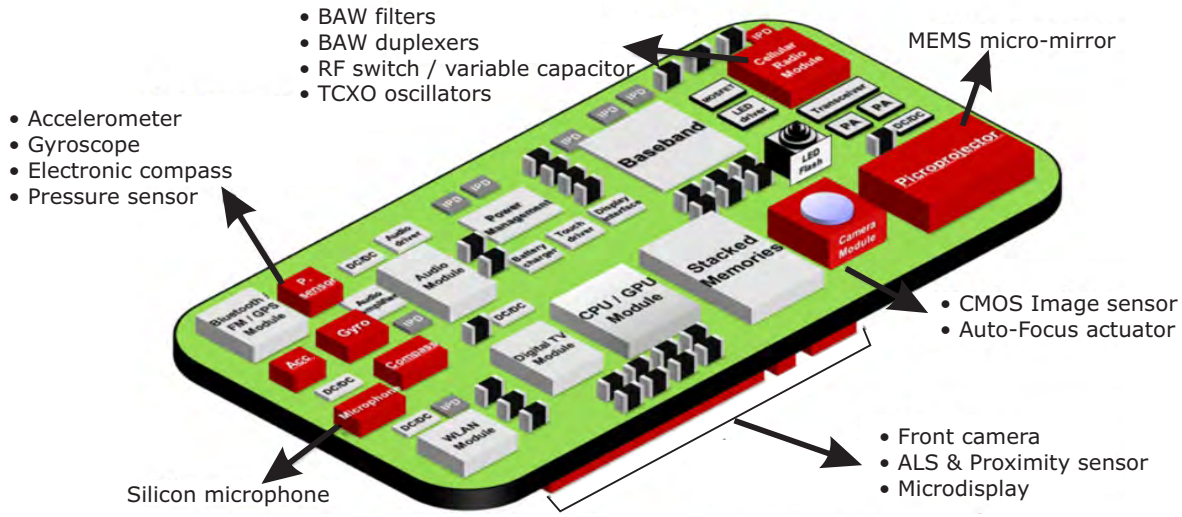
A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure, or any one of a great number of other environmental phenomena. The output is generally a signal that is converted to human-readable display at the sensor location or transmitted electronically over a network for reading or further processing. See infographic page 9.

■ Markets and Applications

Major markets & applications include:

● Agriculture ● Transportation ● Buildings ● Utilities ● Infrastructure ● Public Service and more.

Other important markets: ● Aerospace ● HVAC ● Oil & Gas ● Medical ● Homes ● **Smart Phones (see picture below)** ● Wearables ● Buildings ● Process Mfg. ● Solar Energy ● City ● Security and more



■ Arenas with Significant New Sensor innovation Opportunities

Top opportunities all require better end-to-end sensing solutions:

● **Biopharma** ● **Agriculture** ● **Industrial** ● **Supply Chain** (see page 11)

are the most attractive opportunities for new multi-variate, flexible sensors.

■ Products, Technology and Vendor Evolution

It is obvious that with such high numbers of vendors, products, applications and the huge boost coming from the IoT we will see some changes, so review on time your current suppliers and the innovative startups.

■ The IoT is a huge application field for Sensors But « Where are the missing 41 billion IoT devices of 2019 Forecast? »

It's now accepted that IoT has not achieved the level of success expected by enterprises and analysts, even though growth has been exponential and IoT is here to stay with billions of devices now active. Enthusiasm about the transformative effect of IoT led to projections of tens of billions of IoT connected devices2 but it's now clear that IoT deployments are much harder to do successfully than previously thought and substantial complexities have been glossed over.

See the story in "IoT World" of Nov-Dec 2019

Click Here or on the Picture

... to next page

Sensor & MEMS Market "Who is making What"

... from previous page

■ Application by Vendor: Tables with Direct Links

Table 1: Low-cost IoT-focused devices from the Top Analog IC Vendors (from page 3)

APPLICATION/VENDOR	TI	ADI	Infineon	STMicro	NXP	Maxim	On Semi	Microchip	Renesas
Temperature	X	X			X	X	X	X	
mmWave / RF	X	X							
Electrical	X		X						
Magnetic	X	X	X	X	X				
Humidity	X			X					
Ultrasonic	X								
Pressure	X		X	X	X				
Ambient Light	X						X		X
Distance / Proximity	X		X						X
Position / Tilt	X		X						
Motion / Accelerometer		X		X	X				
Gyroscope		X		X					
Optical		X							
Radar / Image			X				X		
Environmental / Gas			X	X					X
Health						X			
Touch					X	X	X		
MEMS Microphones			X	X					
IMU *	X	X		X		X		X	

* IMU: Inertial Measurement Units

Table 2: Other Major Sensor & MEMS Vendors from IC Vendors

APPLICATION/VENDOR	Allegro	Broadcom	Qualcomm	Tosbiba	MediaTek
3D		X	X		
Image			X		
Environmental			X		
Flow					
LiDAR					
Light		X			
Medical					X
Position	X				
Current	X				
Magnetic	X			X	
Proximity		X			
Ultrasonic			X		
Gas				X	

NOTE: Broadcom (Avago and formerly Hewlett Packard Optoelectronic Division

Click on the Vendor's Names
to go directly to their
Sensor & MEMS Web Page

Table 3: Industrial Sensor & MEMS Vendors (from report page 13)

APPLICATION/VENDOR	Honeywell	Emerson	Bosch	TE	Monnit	Libelium	thinfilm
Temp / Humidity	X	X	X	X	X	X	
Electrical / Magnetic	X		X		X		
Position / Proximity	X			X			
Barcode	X						
Pressure / Flow	X	X	X	X		X	
Gas / Chemical		X	X	X		X	
Liquid Analysis		X					
Luminance		X		X	X		
Accel / Gyro / Motion			X		X		
Image			X				
RFID / NFC					X		X
Vibration / Impact						X	
Vision / Optical			X			X	
IMU *	X		X	X			

... to next page

Sensor & MEMS Market "Who is making What"

... from previous page

Table 4: Ten Other Vendors with Specialties (please visit their sites for details)

APPLICATION/VENDOR	AMS	Osram	ACEINNA	Epson	Murata	TDK-Epcos	Vesper	UltraSense	Vayyar	XSENSE
3D	X							Touch-Force	4D	
Image	X								X	
Environmental	X									
Flow	X									
LiDAR	X									
Light	X				IR					
Medical	X									
Position	X				X	X				
Accelerometer				X	X	X				
Motion										+ Capture
Current			X							
Magnetic					X	X				
Proximity										
Ultrasonic					X	X				
Gas					X					
Flow			X							
Temperature					X	X				
Humidity / Moisture						X			X	
Pressure					X	X				
Optical		X								
Piezoelectric						X	Microphone			
IMU - Inertial			X	X						X

NOTE: TDK Completes Acquisition of InvenSense, PR 18-May-2017

■ Neuromorphic Computing: a New Technology in the Sensors & MEMS Market

Here are some players:

Intel - What Is Neuromorphic Computing? Click Here

The first generation of AI was rules-based and emulated classical logic to draw reasoned conclusions within a specific, narrowly defined problem domain. It was well suited to monitoring processes and improving efficiency, for example. The second, current generation is largely concerned with **sensing and perception**, such as using deep-learning networks to analyze the contents of a video frame.

PROPHESEE - REVEALS THE INVISIBLE Click Here

With the world's most advanced neuromorphic vision systems,
inspired by human vision and built on the foundation of neuromorphic engineering.
PROPHESEE is the revolutionary system that gives Metavision to machines, revealing what was previously invisible to them.

iniLabs - Incubating neuromorphic technologies Click Here

Our founders have invented some of the key foundations of the field, and we continue to lead the world in neuromorphic engineering through our close collaboration with the Institute of Neuroinformatics at the University of Zurich and the ETH Zurich. We also created and sponsor the Misha Mahowald Prize for Neuromorphic Engineering, which recognizes outstanding achievements in the field.

iniVation - Neuromorphic Vision Systems Click Here

At iniVation we create neuromorphic vision systems. Our bio-inspired intelligent technology offers unprecedented advantages over conventional machine vision systems: ultra-low response latency, low data rates, high dynamic range and ultra-low power consumption.
Founded by the inventors of event-based vision, iniVation combines decades of world-leading R&D experience with a deep network of >250 customers and partners across multiple industrial markets. Our customers include global top-10 companies in automotive, consumer electronics and aerospace.

... to next page

Sensor & MEMS Market "Who is making What"

... from previous page

■ Research Institutes & Universities mentioned in this article

- National Science Foundation - USA Click Here
- Fraunhofer Institute – Germany Click Here
- ETH Zurich – Switzerland Click Here
- Vision Institute (CNRS, UPMC, INSERM) – France Click Here
- Imec – Belgium Click Here
- CEA-Leti – France Click Here
- UC - Berkeley Sensor & Actuator Center – USA Click Here

■ Tribute to FAIRCHILD Semiconductor and Dr. Janusz Bryzek

Fairchild has been a key player in the Sensor & MEMS market.

Fairchild was also a leading vendor of Analog IC (I stil have a copy of their famous Linear IC Application Handbook).

Dr. Janusz Bryzek was the VP Development MEMS and Sensing Solutions, he was very often named as the father of the MEMS.

Dr. Janusz Bryzek is now the Executive Chairman, Chief Visionary Officer & Co-founder at eXo Imaging, Inc. pioneering a high-performance ultrasound platform and AI for imaging and therapeutics.

Emergence of Trillion Sensors Movement: please **click on the pictures below** and discover the amazing content of those two presentation dated 2012 and 2014 but still very interesting.

About FAIRCHILD Semiconductor and a bit of history of semiconductor companies

Fairchild Semiconductor International, Inc. was an American semiconductor company based in San Jose, California. Founded in 1957 as a division of Fairchild Camera and Instrument, it became a pioneer in the manufacturing of transistors and of integrated circuits. Schlumberger bought the firm in 1979 and sold it to National Semiconductor in 1987; Fairchild was spun off as an independent company again in 1997. In September 2016, Fairchild was acquired by ON Semiconductor.

■ Conclusion

The Sensor & MEMS products and technology will evolve very fast, and is already a large market. The exponential growth of the IoT with billions of devices now active will also accelerate drastically the number of applications in many market segments. Prices of those sensors have come down to the floor.

Challenge: we have observed that OEMs users of sensors and MEMS are not always well aware of the latest product offering and do not have enough knowledge of vendors. Therefore we intend to publish one or two pages in the next editions including technical details of new products.

I hope that you will find this article useful and will help you to navigate faster in those products & technology.

Daniel Dierickx, CEO & Co-founder at e2mos www.e2mos.com -- Suggestions and comments to mgt@e2mos.com

Small-size and Highly Accurate Sensors from Texas Instruments

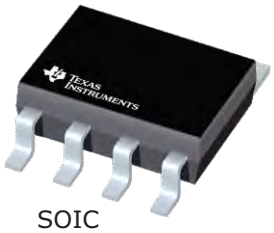
Six examples out of hundreds


TO-92


DSBGA
0.80 x 0.80mm


SOT-563
1.60 x 1.20mm


SOT-23


SOIC

FCBGA

Small-size sensors to enable new form-factor possibilities

- **TMP390: Temperature Switch « Industry's first dual-channel »**
Ultra-small, dual-channel (hot & cold trip), 0.5-µA, resistor-programmable temperature switch

- **DRV5011: Magnetic Sensor - Hall Effect « Industry's smallest low-voltage, digital Hall-effect sensor »**
The DRV5011 device is a digital-latch Hall effect sensor designed for motors and other rotary systems.
Small size (available in WCSP and X2SON), low voltage (up to 5.5-V) Hall effect latch

- **IWR6843: mmWave « Industry's only single-chip sensor with a 75% smaller footprint »**
Single-chip 60-GHz to 64-GHz intelligent mmWave sensor integrating processing capability based on FMCW radar technology. It is built with TI's low power 45-nm RFCMOS process and enables unprecedented levels of integration in an extremely small form factor. The IWR6843 is an ideal solution for low power, self-monitored, ultra-accurate radar systems in the industrial space.

PART NUMBER	PACKAGE	PIN COUNT	BODY SIZE (NOM)
TMP390	SOT-563	6	1.60 mm × 1.20 mm
DRV5011	DSBGA	4	0.80 mm × 0.80 mm
	SOT-23	3	2.92 mm × 1.30 mm
	X2SON	4	1.10 mm × 1.40 mm
	TO-92	3	4.00 mm × 3.15 mm
IWR6843	FCBGA	161	10.4 mm × 10.4 mm
	FCBGA	209	15 mm × 15 mm
TMP61	X1SON	2	0.60 mm × 1.00 mm
	TO-92S	2	4.00 mm × 3.15 mm
	SOT-5×3	2	0.80 mm × 1.20 mm
TMP117	WSON	6	2.00 mm × 2.00 mm
	DSBGA	6	1.53 mm × 1.00 mm
TMCS1100	SOIC	8	4.90 mm x 3.90 mm

Direct Link to TI Sensors - Demo Boards - App Notes

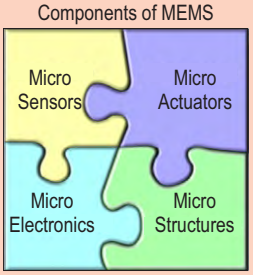
Highly accurate sensors to achieve automation you can trust

- **TMP61: Thermistor**
±1% tolerance 10kΩ silicon-based linear thermistor with 0.6 s thermal response time and 0.5% typical long-term sensor drift starting at US $0.05 in 1,000-unit quantities

- **TMP117: Temperature Sensor**
CMOS single-chip mmWave sensor that enables implementation of short-and-medium range automotive radar applications such as automated parking and obstacle detection using 76 to 81 GHz band

- **TMCS1100: Magnetic Current Sensor - High-Precision, Isolated Current Sensor With External Reference**
« Industry's highest accuracy (0.5%), zerø-drift, galvanically isolated magnetic current sensor »
Galvanically isolated Hall-effect current sensor capable of dc or ac current measurement with high accuracy, excellent linearity, and temperature stability. A low-drift, temperature-compensated signal chain provides < 1% full-scale error across the entire device temperature range.

Comparing Sensors & MEMS (see also MEMSnet)



Sensors: In the broadest definition, a sensor is a device, module, machine, or subsystem whose purpose is to detect events or changes in its environment and send the information to other electronics, frequently a computer processor. A sensor is always used with other electronics.

MEMS: Micro-**E**lectro-**M**echanical **S**ystems is a technology that in its most general form can be defined as miniaturized mechanical and electro-mechanical elements that are made using the techniques of microfabrication. The critical physical dimensions of MEMS devices can vary from well below one micron on the lower end of the dimensional spectrum, all the way to several mm. Likewise, the types of MEMS devices can vary from relatively simple structures having no moving elements, to extremely complex electromechanical systems with multiple moving elements under the control of integrated microelectronics. The one main criterion of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move. Microsensors and microactuators are appropriately categorized as "transducers", which are defined as devices that convert energy from one form to another (mechanical signal to electrical signal).

Future Impacts of New Sensor Technologies

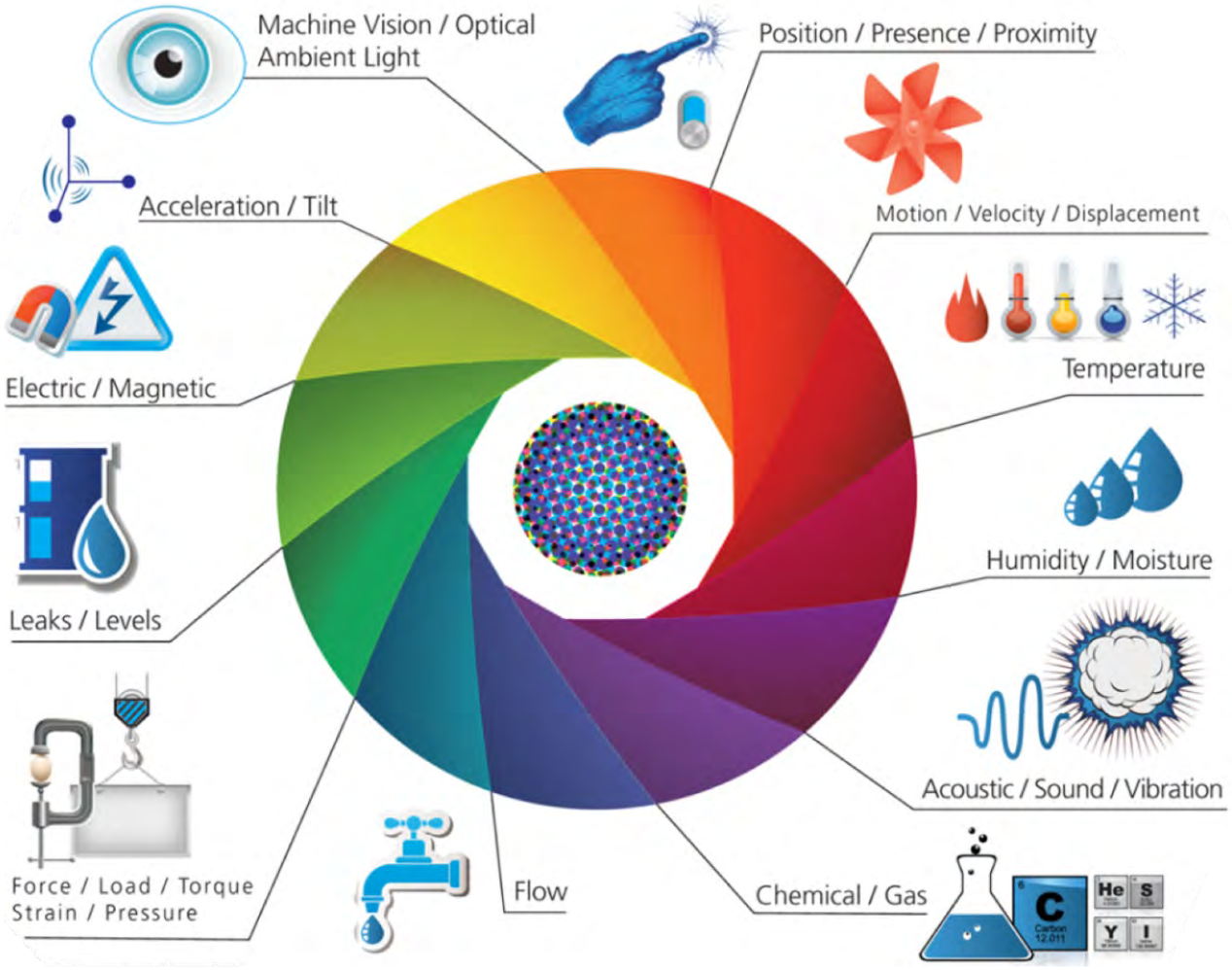
As more and more companies delve into developing smart systems, they are quickly finding that competitive differentiation shifts away from unique, vertically focused product features. The new focus will be on how the product is actually used—how it fosters interactions between and among users in a networked context.

SENSING TINY THINGS

Do you understand how fast the world is changing? One indication of the speed is the fact that we're drowning in unprocessed information. We're creating data at 2X the rate we're deploying traditional bandwidth to carry it, but almost all the data created to date has never been analyzed. More than half the data created by physical or operational systems loses any value that could be derived through analysis in less than a single second.

Yet by 2020, according to the National Science Foundation, there will be trillions of sensors on the earth. And forecasters predict that in just a few more years there will be more processing power in smart phones than in all the servers and storage devices in data centers on the earth today. Ready or not, we're rushing into the future of truly distributed systems and intelligence.

We are giving our World a Digital Nervous System



Source: Habor Research

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Revolutions always begin by sensing small things and drawing inferences. For example, there is great value in knowing how people use "white goods" like home appliances. If you embedded a microprocessor in the plastic of an electrical outlet, you'd have true local processing as opposed to processing in a remote cloud. From there, you could infer almost anything by sensing the electrical current "signature" and its usage profile—not just energy used, and whether a washing machine's motor is about to fail, but the fact that the consumer just washed a load of whites versus a load of colored clothes. If you had an inkjet printer plugged into that same outlet, you could know whether the consumer was printing colored pages versus black-and-white.

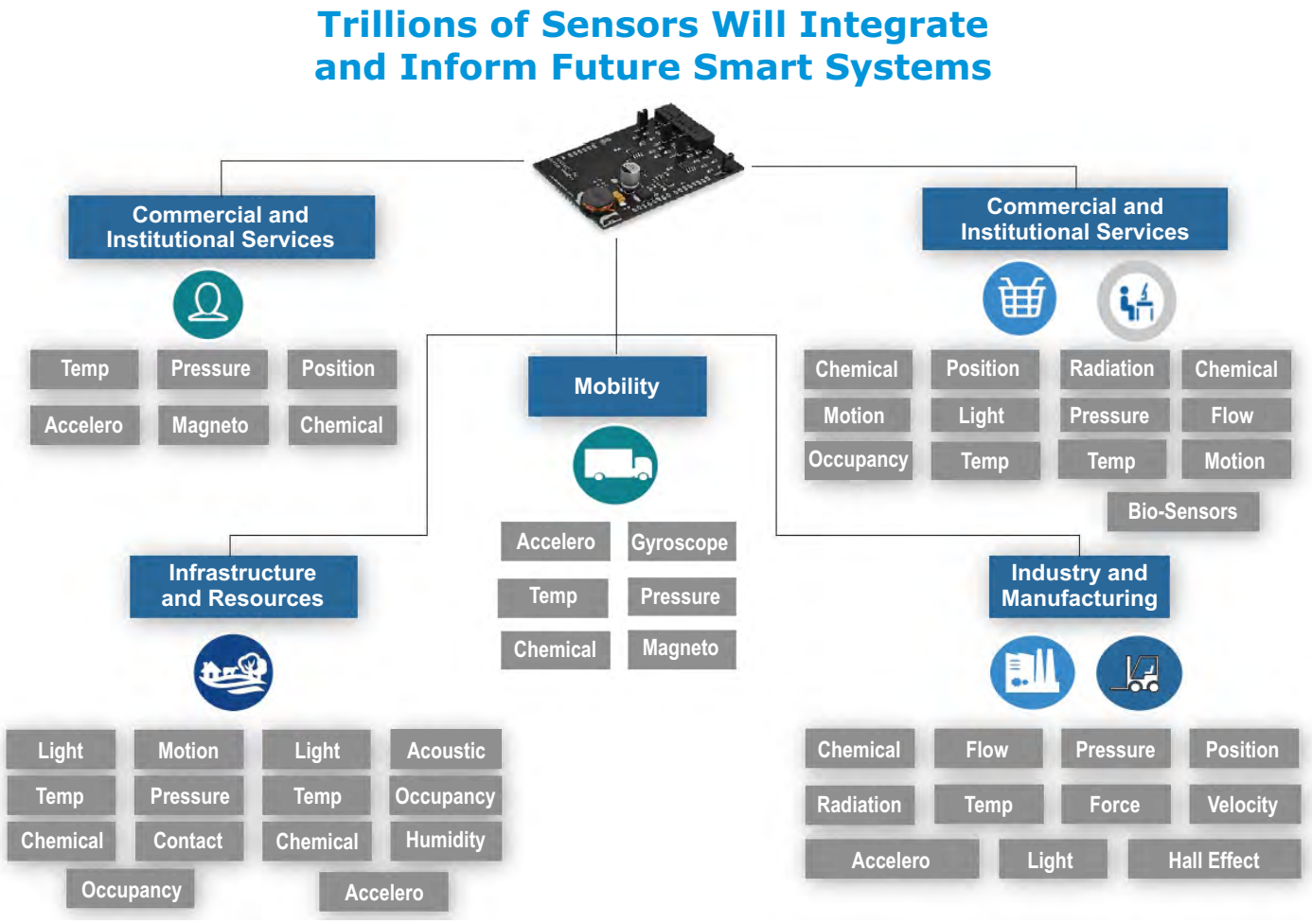
Analysis of data from a "sweat patch" for measuring human perspiration can reveal the emotional state of an athlete wearing it, as well as the level of physical stress she's under. If a worker is wearing the patch, you can see if they're being exposed to the many dangerous substances that exist in factories, farms, and other workplaces.

Weather is another complex phenomenon that can be greatly understood by correlating data values collected from simple pressure, temperature, and moisture sensors with additional spatial and temporal parameters that place the data into a richer context. I could be running a fleet based on weather forecasts, but if I add the data from sensor packs mounted directly on my vehicles, I'm less likely to be impacted by unexpected weather conditions. The closer that systems are to real-time, the more efficient and cost effective they can be. All such data, with its related context, has extraordinary value to everyone.

NEW VALUE FROM GROWING INTERACTION

As networks have invaded the "physical" world, system and solution designers are seeing the new values that come from the growing interactions between sensors, machines, systems and people. Electronic, mechanical and other related systems that used to have unique physical interfaces and components are now becoming digital and standardized.

The convergence of collaborative systems and machine communications will enable entirely new modes of services delivery and customer interactions, and the implications are enormous. No product development organization will be able to ignore these forces, nor will their suppliers. Product and service design will increasingly be influenced by the use of common components and subsystems. Vertically defined, stand-alone products and application markets will become part of a larger "horizontal" set of standards for hardware, software and communications.



Source: Habor Research

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Future Impacts of New Sensor Technologies

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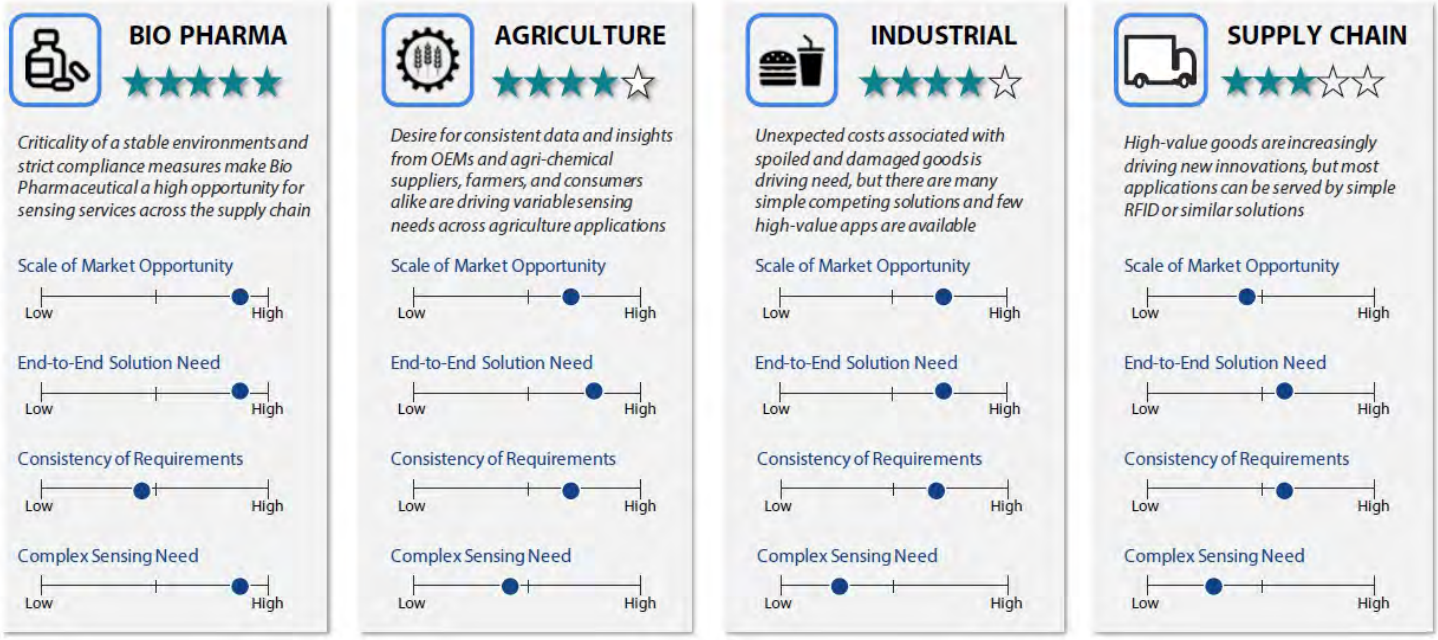
Further, efficient support of products and equipment is only the first benefit of this trend. To conserve precious resources on this tiny planet, the world desperately needs better sensing, and soon. But it's not happening because the big attention and glamor continues to reside with IT, and IT wouldn't know a sensor if it tripped over one. They understand the data that runs the corporation, but not the gargantuan accumulation of tiny data emanated by the systems that run the world. All those systems interact, which creates context, which adds to the value. It's not that the IT guys are stopping the world from innovating, it's that they have no interest in integrating real-time inputs.

All of these trends lead us to the simple question: How well-prepared are manufacturers for the advent of smart systems and services, sometimes called the Internet of Things? We may think we know how to design smart systems, but many companies are finding this to be a serious challenge. For all the talk about silicon-based "intelligence" permeating every aspect our lives, we still live in a brutally dumb world.

Arenas With Significant New Sensor innovation Opportunities

Top opportunities all require better end-to-end sensing solutions.
Biopharma and agriculture are the most attractive opportunities
for new multi-variate, flexible sensors



Source: Habor Research

TOO MUCH DISCONNECTION

We believe that in most companies there is too much disconnection between people, functions, processes and knowledge to design and create organic smart systems growth opportunities. Large organizations have many rules and policies that often seem completely disconnected. They have been creating language, processes and systems that seem to be a triumph of technique over originality. General managers, like cost accountants, claim to have developed uniform approaches for just about everything–including "organic" growth.

Mounting evidence suggests that most of the existing approaches to creating new growth businesses are of little value when it comes to emergent and disruptive opportunities like the Internet of Things. These days all large manufacturers have a so-called "business system" which seems to have severely diminished managers' ability to focus on new smart systems opportunities, take risks, or do just about anything creative. These robotic processes lead organizations further and further away from any kind of innovation and blur management's vision.

Most knowledge comes from human experience and expertise. But today, knowledge and expertise largely reside in functional silos dispersed across organizations. Acting singularly, those siloed systems are constrained by the resources under their control. Legacy processes and habits inhibit any natural ability to communicate and collaborate on solving big problems or creating new solutions. In many companies, lean practices have been applied so aggressively that people are simply consumed by "running the business." They fail to harness the collective intelligence available throughout the company and its networks. Thus, they fail to develop creative products, systems and solutions.

So how have manufacturers been able to continue to grow and create value in the equity markets? Several ways: global expansion, re-engineering, lean practices, mergers and acquisitions—all reasonable strategies for growth and value creation. But the marketplace is rapidly consolidating, and the world is increasingly driven by new and unfamiliar technologies. What worked in the past is less likely to work now or in the future. For many companies, those strategies have already reached the point of diminishing returns. Besides which, almost every major manufacturing segment has gone through twenty plus years of consolidation and there are not enough acquisition candidates left to "move the value needle."

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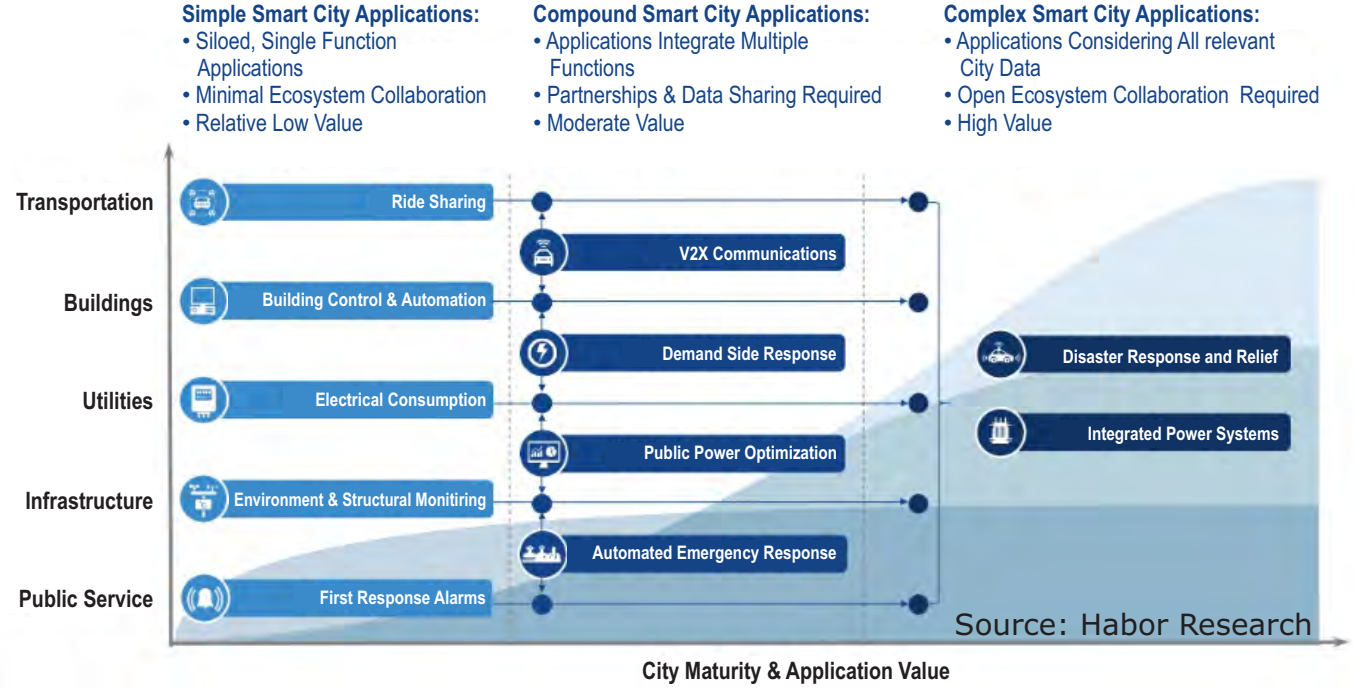
THE BLIND LEADING THE VISION-IMPAIRED

This evolution reminds us of a story by H. G. Wells, "The Country of the Blind." The story concerns a group of people living in total isolation in a valley of the Andes Mountains. For an unknown reason, the inhabitants of the valley have been congenitally blind for two or three generations.

The people in the valley have re-evaluated much of the information handed down through oral tradition. New impressions have been forged based on subjective experience. For example, they have decided there is no difference between angels and birds. The people have reasoned that they can hear both birds and angels sing, and they can feel the wings of both brush their faces—so there must be no difference.

The story depicts a group of people who, as long as they remain in isolation, can rationalize any type of behavior—no matter how absurd the behavior appears to an outsider. Isolation and blindness lead the inhabitants further and further away from the truth.

New Sensor Integration Enables New Value Creation Through Complex Interactions



In our opinion, existing schemas, institutions and approaches for new growth development are, for the most part, broken. In the Internet of Things arena, the complexity of interdependent relationships required for new growth ventures only compounds the challenges. In this environment, growth depends on interacting in new and creative ways. Linking functions by breaking down the barriers to communication is the first step, but it can't stop there. The key is building truly collaborative networks.

LESS MANAGERIAL HIERARCHY, MORE CUSTOMER VALUE

For those brave enough to have invested in smart systems and services opportunities, progress has been slow to come. In many ways, most of the larger diversified industrials have not gone beyond "first base" in capitalizing on the value of connected smart systems and services.

We believe they have focused too much attention on captive OEM services. While many manufacturers have begun to build remote services programs, they are mostly directed at productivity and efficiency. These remote services programs are focused inwardly; they're not focused on creating new customer value.

Based on Harbor Research analysis, many of these systems barely utilize the data they collect. While many players are talking a "Big Data" game, few are realizing any significant new value from machine data and analytics. To date, the remote services opportunity has been comprised of monitoring applications and related tracking and location services—what we like to call the "alerts and alarms" syndrome. Manufacturers are stalled, wondering how to get to a future focused on collaboration between devices, data, people and systems.

Given the apparent speed that corporate leadership can absorb new management theories maybe this isn't a real problem; just a work in progress. With all the fads and fashion of management concepts, from empowerment to re-engineering to innovation and, more recently, design thinking, it's a wonder we haven't met the challenge of Smart Systems Design by now. Just observe how many consulting firms have acquired design firms in the last three years. Help is surely on the way.

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Compared to what is evolving in the marketplace—design thinking or not— the solutions we are describing here will have far less managerial hierarchy, less command-and-control decision-making, less stage gate process, and less proprietary ownership of ideas. These networked—that is, "smart"—systems will be self-organized by manufacturers, partners and customers who are motivated to explore and develop ideas they care deeply about. Collaborative innovation will go beyond ideas a bout new products and services. They will extend to ideas about the very manner in which business is conducted.

WHAT ARE SMART SYSTEMS?

Our practice focuses on what we've come to call "Smart Systems," the convergence of pervasive and embedded computing with the Internet; what many refer to as "the Internet of Things (IoT)." We prefer Smart Systems over other terms in common use because it captures the profound enormity of the phenomenon; something much greater in scale, scope and impact than just machine connectivity.

"Smart Systems" is a new generation of computing and information architecture that looks very different from classical information, computing, and telecom (ICT) paradigms. In Smart Systems, the physical world dovetails with machine learning and artificial intelligence to produce previously unimagined capabilities for both the B2B and B2C worlds. After years of frustrating fits and starts, the technology is here to integrate people, processes, and data in ways that enable collective awareness and better decision making.

Competing Suppliers Target Segments With an Array of Sensor Types

Competing hardware suppliers are approaching the top segments from two distinct backgrounds: **industrial sensing**, or **low-cost IoT-focused applications**. Few offer multi-sensing solutions in a single device

	Honeywell	EMERSON	BOSCH	TE connectivity	MONNIT	libelium	thinfilm
Sensor Types Provided (Relevant Examples)	• Temp/Hum. • Current • Position/Prox. • Barcode • Pressure/Flow	• Temp/Hum. • Gas/Chem. • Liquid Analysis • Luminance • Pressure/Flow	• Temp/Hum. • Simple Gas • Pressure • Accel/Gyro. • Image	• Temp/Hum. • Position/Prox. • Pressure/Flow • Luminance • Simple Gas	• Temp/Hum. • Luminance • Accel/Gyro. • Volt/Current • RFID	• Temp/Hum. • SimpleGas/Chem. • Pressure • Vibration/Impact • Vision	• RFID/NFC
Relative Price Point	$$$	$$	$$	$$$	$	$$	$
Market Presence: Biopharma.	●	●	○	○	●	●	●
Agriculture	●	○	●	●	●	●	●
Food & Bev.	●	●	●	●	●	●	●
Luxury Goods	○	●	○	○	○	○	○
General Transport	●	●	○	●	●	●	○
Other Markets & Apps.	• Aerospace • HVAC • Oil & Gas • Medical	• Oil & Gas • Process Mfg.	• Homes • Smart Phones • Wearables	• Oil & Gas • Buildings • Homes • Wearables	• Buildings • Homes • Solar Energy • City	• Buildings • Security • Process Mfg. • City	

● Primary Target ○ Secondary Target/ Has Capabilities ⬚ Similar multi-variate sensing packages

Source: Habor Research

ABOUT HARBOR RESEARCH

An internationally recognized strategy consulting, design and technology research firm, Harbor Research has predicted, tracked, and driven the development of Smart Systems, Services and the Internet of Things since our inception in 1984.

While our history is long, our strategy is simple: create value for our clients by combining creative facilitation with structured methods, rigorous analysis and systems-focused thinking. It is this mindset that has given us the privilege of working with leaders in some of the greatest companies in the world. We work with clients in a variety of ways including growth strategy consulting, business model development, and solution design services supported by our independent research focused on emerging technologies and human sciences.

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Five Defining Moments and Trends in Sensors in 2019

29-Dec-2019 | By Anne-Françoise Pelé | Source EETimes

The internet of things (IoT) is becoming the internet of everything. More industries are looking to connect their machines and applications, and more users are enjoying the functionality of their smart devices. Market research firm McKinsey predicts IoT's economic impact will be in the range of $4 trillion to $11 trillion per year by 2025. Microelectromechanical systems (MEMS) and sensors are an essential part of the IoT phenomenon.

The best way to grasp the nature of this growing market is to look back at the world events and trends that topped the news in 2019 and are most likely to change the course of action in 2020, if not over the next several decades. The five most influential events in sensors this year were a long-debated acquisition, the resurfacing of a compute concept that's set to become the cornerstone of artificial intelligence (AI), the launch of a promising new player by sensor industry veterans, a market-rejuvenating technology based on an effect discovered more than 100 years ago, and a push to think and act "locally."

1. AMS acquires 59% of Osram shares

(Image: Osram)

After months of negotiations and speculation, Austrian sensor company AMS AG finally acquired enough shares to take over photonics specialist Osram Light AG.

In December, AMS said the acceptance rate in its $5.1 billion (€4.6 billion) takeover offer was 59.3 percent and exceeded the minimum acceptance threshold of 55 percent.

"Our goal is to create a global leader in sensor solutions and photonics, based on European technology," Amy Flécher, vice president marketing communications for AMS, told EE Times. Stressing the complementary nature of the two businesses, she added: "Osram is the leader in visible- and invisible-light emitters and aspires to develop IC-design, optics, and optical-packaging capabilities," while AMS has "IC-design, optics, and optical-packaging capabilities and aspires to add a leadership position in emitters."

An underlying reason for the takeover bid is that AMS is heavily reliant on a single customer: Apple. Acquiring Osram expands AMS's business and diversifies its revenue mix. In the first half of 2019, AMS's consumer business accounted for 75% of its total revenue, while the automotive business and the industrial and medical businesses accounted for 10% and 15%, respectively. The long-term goal is to generate 35% to 40% revenue in both the automotive and consumer businesses and 20% to 30% in the industrial/medical business.

Calling the deal "a Christmas tale in which the rising star is acquiring the falling giant," research and strategy consulting firm Yole Développement said AMS would now be able to take a strategic foothold on the European semiconductor scene. The companies' revenue was a combined $6 billion in 2019, comparable to other big European players such as Infineon, STMicroelectronics, and NXP.

AMS said it aims to close the transaction in the first half of 2020.

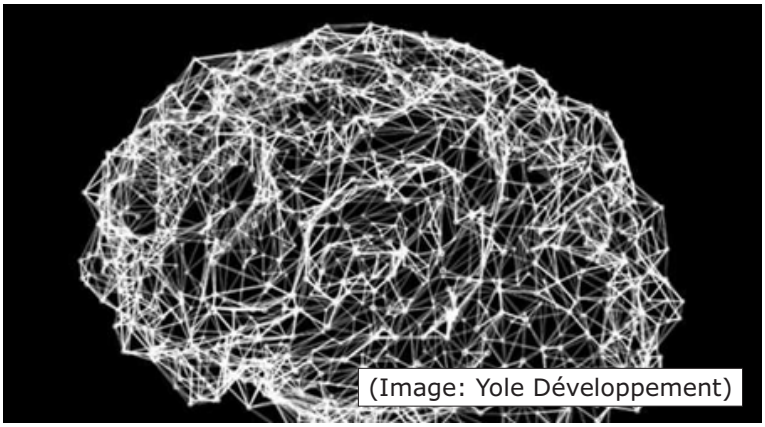
2. Neuromorphic sensing: A brainy direction

Deep learning is "not actually learning," said Mike Davies, head of Intel's neuromorphic computing unit, at this year's International Solid-State Circuits Conference. His words revived the neuromorphic-compute debate in the AI community at a time when both data-bandwidth constraints and computational requirements are escalating.

Neuromorphic means "taking the form of the brain." Introduced by Carver Mead in the 1980s, neuromorphic engineering, also known as neuromorphic computing, uses very large-scale–integration systems containing analog circuits to mimic neurobiological architectures present in the human nervous system.

... to next page

In an interview with EE Times, Pierre Cambou, principal analyst for imaging at Yole, said that neuromorphic sensing and computing could solve most of AI's current issues while opening new application perspectives in the next decades. "Neuromorphic engineering is the next step toward biomimicry and drives the progress toward AI," he said.

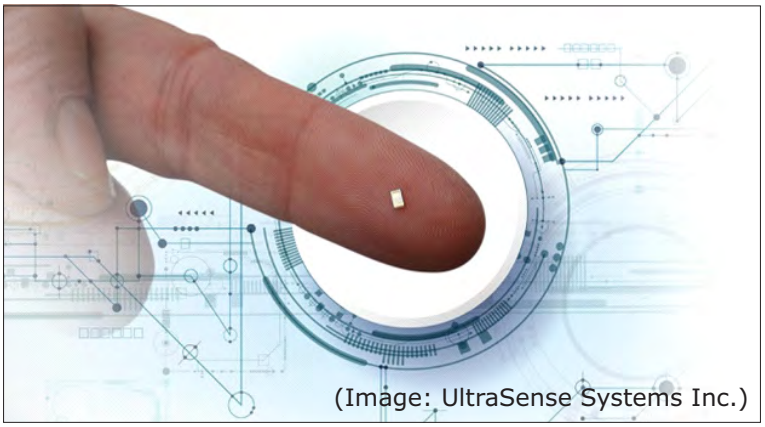

(Image: Yole Développement)

An ecosystem of neuromorphic-sensing startups has indeed emerged, with roots that date back to the invention of a silicon retina by Carver Mead's student Misha Mahowald at the Institute of Neuroinformatics and ETH Zurich in 1991. Insightness was founded in 2014 as a spinoff of ETH Zurich and the University of Zurich. It designs vision sensors that allow motion detection within milliseconds even if the sensor itself is moving. Other spinoffs from ETH Zurich include iniLabs, an event-driven–camera developer, and iniVation, a developer of neuromorphic event-driven vision systems.

Similarly, Prophesee, formerly known as Chronocam, bloomed from breakthrough research conducted by France's Vision Institute (CNRS, UPMC, INSERM) on the human brain and eye over the past 20 years. Prophesee recently rolled out what it claims is the first event-based vision sensor, in an industry-standard package.

At the packaged-semiconductor level, Yole said it expects neuromorphic sensing to grow from $43 million in 2024 to $2 billion in 2029 and $4.7 billion in 2034.

3. Ex-InvenSense execs form UltraSense


(Image: UltraSense Systems Inc.)

Mo Maghsoudnia, Dan Goehl, Sina Akhbari, Stan Liu, and Hao-Yen Tang have more than 10 years of experience in commercializing ultrasonic products and own more than four technology patents. They all worked for InvenSense and left the company around the time of its acquisition by TDK Corp. for $1.3 billion. In mid-December, they formally announced the launch of UltraSense Systems Inc. and introduced what they claim is the smallest ultrasound sensor-on-chip for touch and gestures through any material of any thickness, including metal, glass, wood, ceramic, and plastic.

UltraSense has made mobile handsets its primary focus because "adoption is relatively quick, and we are hitting the market at the right time with the launch of 5G technology, in particular millimeter-wave 5G," said Dan Goehl, chief business officer at UltraSense. The startup also sees prospects in the consumer and automotive spheres, with "a lot of proofs-of-concept going on with several automotive suppliers for various types of applications," he said.

Although UltraSense is not the only one to develop this kind of ultrasound technology, its contributions could hasten the demise of mechanical buttons and shape the future of user interfaces.

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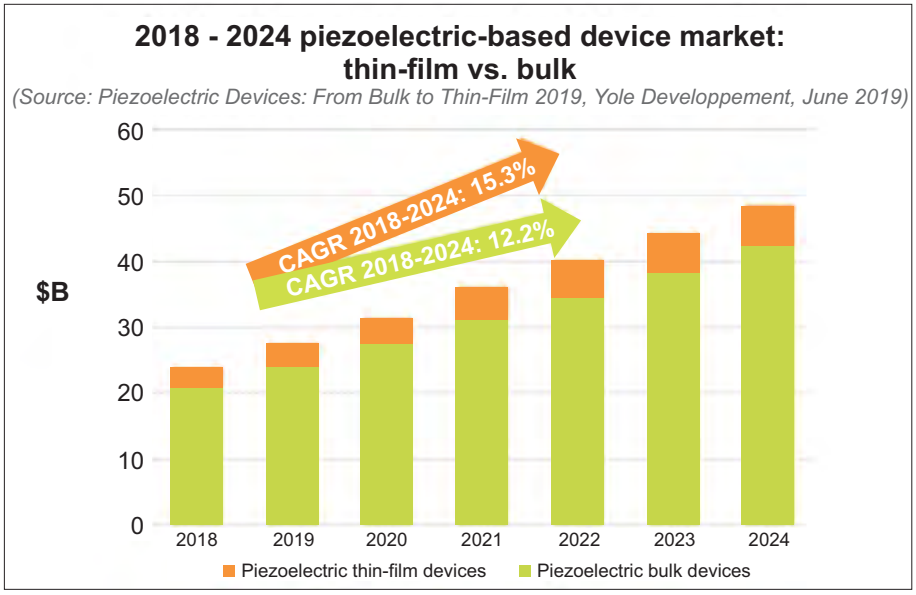
4. The influence of the piezo effect



(Image Yole Développement)

The universe of applications for piezoelectricity has been expanding ever since French brothers Paul-Jacques and Pierre Curie discovered the piezoelectric effect more than a century ago. According to Yole Développement, the market for piezoelectric sensors, actuators, and transducers is expected to reach $48.5 billion in 2024, with a 12.6% CAGR from 2018 to 2024.

"Piezoelectric MEMS are disrupting the traditional, capacitive-microphone approach thanks to [piezo MEMS'] waterproof, dust-proof and ultra-low power consumption" characteristics, Dimitrios Damianos, technology market analyst with Yole Développment, told EE Times. What's more, "piezoelectric MEMS technology has started rejuvenating the MEMS market, spreading to other devices such as micro-speakers, piezoelectric micromachined ultrasonic transducers, autofocus, etc."

Vesper Technologies Inc., a Boston-based provider of piezoelectric MEMS microphones, recently announced that its ZeroPower Listening technology had been certified by Amazon for extended battery life and far-field voice interactions. The certification follows Amazon's financial backing of Vesper's technology in 2018 and underscores the tech giant's faith in the piezoelectric approach.

On the research front, thin-film piezoelectric architectures are seen as promising candidates as they offer enhanced process uniformity, higher reliability and yields, and a smaller footprint and chip size. The Fraunhofer Institute for Silicon Technology is focusing on multilayer aluminum nitride, a material with very high piezoelectric coefficient, and CEA-Leti has figured out a way to transfer thin-film PZT to a transparent glass substrate in order to obtain a transparent piezoelectric structure.

5. At the edge

Sensors are getting smaller and smarter. They can now perform much more than just converting physical parameters such as moisture, dust, heat, and motion to analog electrical signals or digital data.

For example, Vayyar claims it has designed a small, sensor-based chip that, with its 72 transmitters and 72 receivers, tracks and maps everything without a camera. The technology can detect obstacles and monitor people's location, movement, height, posture, and vital signs wirelessly, in all lighting and weather conditions and in real time. A key differentiator is its ability to "see" through walls, closed doors, and other solid objects, the company said. And because Vayyar's approach uses radio-frequency waves — rather than cameras and optics — to detect objects, its sensors do not collect any optical data, protecting users' privacy.

Because sensors collect massive amounts of unstructured data, it often makes more sense to process the data locally rather than send it to the cloud. Running AI algorithms at the edge, directly in the sensor, indeed offers several user benefits, Markus Ulm, CTO of Bosch Sensortec, told EE Times. The first one is personalization; because the calculation is performed locally, it can be optimized for the user based on that person's behavior. Second, edge data processing without cloud involvement safeguards the privacy of user data, Ulm noted.

The third benefit is real-time feedback, said Ulm. "By passing stuff to the cloud and getting it back, you experience some latency and, in many cases, it is unwanted." Executing at the edge avoids data transfer and thereby reduces latency. Fourth, local processing extends battery life.

Edge AI is still at an early stage of development. Various challenges have not yet been overcome, as the machine-learning community has been mainly focused on cloud-based solutions to address big-data requirements and large-scale problems. But the potential is there.