Embedded Sensors for Manufacturing

Research Support Service

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Prepared by: **PreScouter**
Sofiane Boukhalfa, PhD
Navneeta Kaul, PhD
Shuo Deng, PhD

PRESCOUTER

How can embedded sensors be applied throughout the manufacturing supply chain?

In order to better understand whether adoption of embedded sensors for manufacturing purposes is an appropriate and sound strategic decision, it is important to highlight:

- **An overview of embedded sensors:**
    - What embedded sensor networks are and how they work
    - Applications of embedded sensors throughout the manufacturing supply chain
    - Types of sensors and their benefits
    - Relevant market trends
- **Case studies highlighting the use of embedded sensors in manufacturing and their benefits**
- **Potential academic partners to help drive innovation internally**

Note: An embedded sensor here refers to sensors (of different types) that are environment-embedded — that is contained in the environment.

Executive Summary

In this report, PreScouter provides a **high level overview** of embedded sensors and the relevant **market trends**, with a focus on their use in manufacturing processes. We highlight the potential benefits of embedded sensors by providing **5 case studies**. This will allow clients to better understand the benefits this technology may pose for an organization's own manufacturing processes, and will be used to guide strategic decisions internally regarding their potential adoption. The report also highlights **5 potential academic partners** that may facilitate an organization's adoption of such technologies through developing/acquiring state-of-the-art technology.

Embedded sensors provide value throughout the manufacturing value chain:

1. To enhance industry process control
2. To aid with real-time inventory tracking
3. To drive operational efficiencies, automation and production lines
4. To improve supply chain and logistics
5. To meet consumer demand
6. To facilitate adherence to regulatory compliance

Advantages by the Numbers

The below illustrates specific examples of how different companies globally have used embedded sensor technology to improve their business and manufacturing operations.

HIROTEC

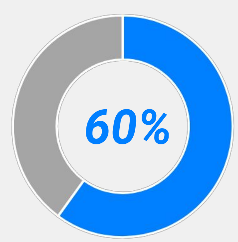
Eliminated cost center:

*Eliminated **100%** of time spent to manually inspect production systems.*

KAESER KOMPRESSOREN

An estimated annual savings of ***$10 million in costs****.*

AND



Reduction in unscheduled system downtime and costly emergency service visits

ERICSSON

Ericsson adopted a mobile IoT system that yields potential savings of approximately ***$230 per added sensor.****

**Accomplished by retrofitting wireless sensors to existing industrial equipment can save the replacement cost of cables, which are prone to connector failures, and can cost up to €200 (US$230) per metre to install and maintain*

Executive Summary

Benefits of Embedded Sensors:

Improving operational efficiency: Sensor-enabled labor monitoring helps reduce idle workforce by optimizing assignments. Sensors used for quality inspection on assembly line closes the physical-digital loop for manufacturing issues in minutes.

Improving asset management: Critical equipment is connected and monitored through sensors to proactively address potential interruptions.

Real-time inventory tracking: RFID sensors used for low-cost, touch-free item identification and tracking can potentially reduce the risk of inventory shrinkage or loss. Smart sensors for omnichannel retailing such as products and packaging embedded with smart sensors make automatic reorders and refills possible.

Product design: Connected products offer insights into customer behaviors and preferences, allowing for a more responsive product development.

References:

1. https://www2.deloitte.com/content/dam/Deloitte/us/Documents/process-and-operations/us-cons-smart-sensors.pdf
2. https://ww2.frost.com/frost-perspectives/sensors-industry-40-market-applications/

An Overview of Embedded Sensors

Introduction

What is an embedded sensor?

An embedded sensor is a type of sensor that is embedded within the environment it is sensing.

What is an embedded sensor network?

An embedded sensor network is a network of small embedded computers, or sensor nodes, integrated into the physical world for communicating with the environment. They are placed very close to the objects for sensing, which allows them to cooperate with each other, monitor the surrounding environment, and produce the appropriate response. The network works with **collaborative signal processing algorithms** to capture relevant data from the environment for real time / post-processing.

References:

1. https://www.isi.edu/~johnh/PAPERS/Heidemann04a.pdf
2. http://engineering.nyu.edu/gk12/amps-cbri/pdf/Intro%20to%20Sensors.pdf
3. https://www.matec-conferences.org/articles/matecconf/pdf/2016/22/matecconf_icfst2016_01002.pdf
4. https://www.centricabusinesssolutions.com/blogpost/5-uses-smart-sensors-manufacturing

The components of an embedded sensor network:

An embedded system consists of a microcomputer and various types of sensors. While sensors detect data, a microcomputer processes the data, and information, the functionality, and performance of the embedded system depends on the sensors.

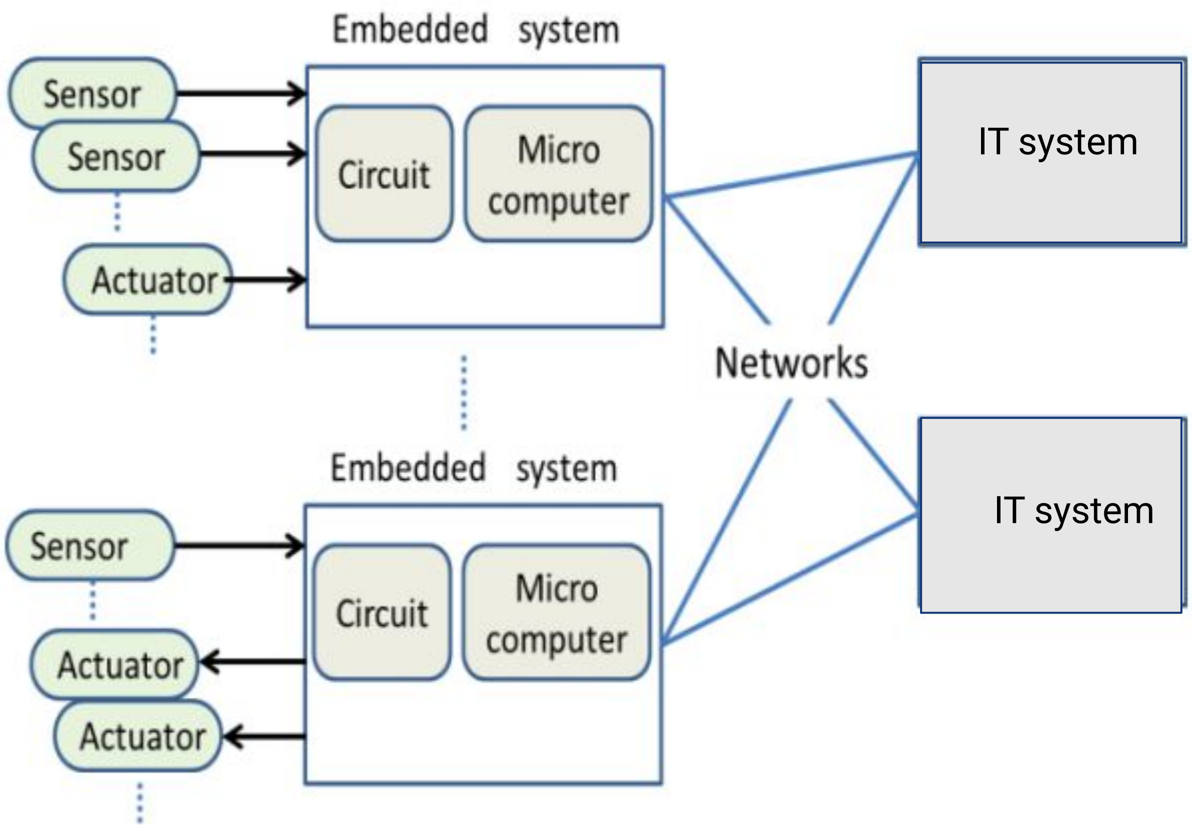
In general, embedded systems consist of the following functions (see page 9 for diagram):

1) A microcomputer unit that **connects** the sensor-driving circuits and stimulates the sensors by transmitting a start signal.
2) Microcomputer unit that **receives** the data captured by sensors via amplifier circuits.
3) Data is **recorded** in the microcomputer's memory space to be **processed** by the embedded software and then transferred to IT systems via data communication networks.

References:

1. https://www.matec-conferences.org/articles/matecconf/pdf/2016/22/matecconf_icfst2016_01002.pdf

Basic Design of an Embedded Sensor Network



References:

1. https://www.matec-conferences.org/articles/matecconf/pdf/2016/22/matecconf_icfst2016_01002.pdf

Introduction

Sensors play a key role in the embedded system architecture:

System sensors play a crucial role in the hardware and software architecture of the embedded system. For example, in cases of low sensed data, amplifier networks are required, and if the data contains noise, then noise-reduction circuits are needed. Sensors also control the timing of the data-sensing and data-collection process with proper software design. Therefore, **for an efficient data-sensing unit, proper sensor selection is crucial**.

Embedded sensors are extensive in use; applications include human bodies, vehicles, planes, phones, digital alarm clocks, washing machines, dishwashers, ACs, radios, industries, agriculture, and military applications. **Ongoing research efforts are working to develop various types of sensors** especially in the embedded system domain.

Impact:

Sensors have helped in optimizing the performance of manufacturing machinery, leading to greater efficiency and productivity gains. With the digitization of factories, analytics, AI and the Internet of things (IoT), **sensors could boost the annual US manufacturing industry by up to $530 billion by 2025**. Industry is adopting 4.0 concepts with the application of IoT and an increased adoption of sensors.

References:

1. https://www.matec-conferences.org/articles/matecconf/pdf/2016/22/matecconf_icfst2016_01002.pdf

Uses of Embedded Sensors in the Manufacturing Value Chain

Industrial process control:

The industrial control, and monitoring application segment, accounts for the highest market share for sensors at 38.6%. Industrial control applications include monitoring of various variables, including pressure, temperature, flow, etc. More than 20 different sensors are used in the IoT industries due to their enhanced monitoring and remote sensing capabilities. Smart sensors or sensors 4.0 enable machines to communicate with each other, collect and analyze data through the cloud and IO link interface leading to continuous monitoring, enhanced connectivity, and optimized system performance. Market growth is expected to further increase with industries shifting towards in-process sensors as a control strategy.

Example:

A leading service supplier for metal cutting, **Sandvik Coromant**, transitioned to embedded sensors inside the company's tools for close monitoring of process attributes such as tool deflection, cutting forces, tool load, and temperature for insight into the manufacturing process. The sensors helped in **reducing scrap rates** and **enhancing productivity**.

Sensors embedded inside a damped turning adaptor communicates current temperature, vibration levels and surface roughness during machining through a wireless protocol.

Source: [Sandvik Coromant]

Uses of Embedded Sensors in the Manufacturing Value Chain

Automation and production lines:

Factory automation enables customized product solutions as well as the self-optimization of the production lines. Many conveyor manufacturers have incorporated sensors and radio frequency identification (RFID) to enhance new features and capabilities. Leading players such as **Mitsubishi** are investing to boost automation systems. Sensors also detect alterations in position, length, height, exterior and dislocation in industrial manufacturing sites. Various sensors including temperature, pressure, MEMS, and torque sensors are being increasingly used in automation.

Real-time inventory tracking:

Real-time inventory tracking RFID sensors, which enable for touch-free identification and tracking of items, have improved traditional inventory management. These sensors allow for **increased traceability**, reducing the risk of inventory loss. Moreover, reliable information generated by sensors strengthens planning capabilities, and reduces out of stock or overstock situations. The automated approach of the sensors leads to more flexible distribution models and protection from inventory theft. Products and packaging embedded with smart sensors allow for automatic reorders and refills.

Uses of Embedded Sensors in the Manufacturing Value Chain

Operational efficiencies:

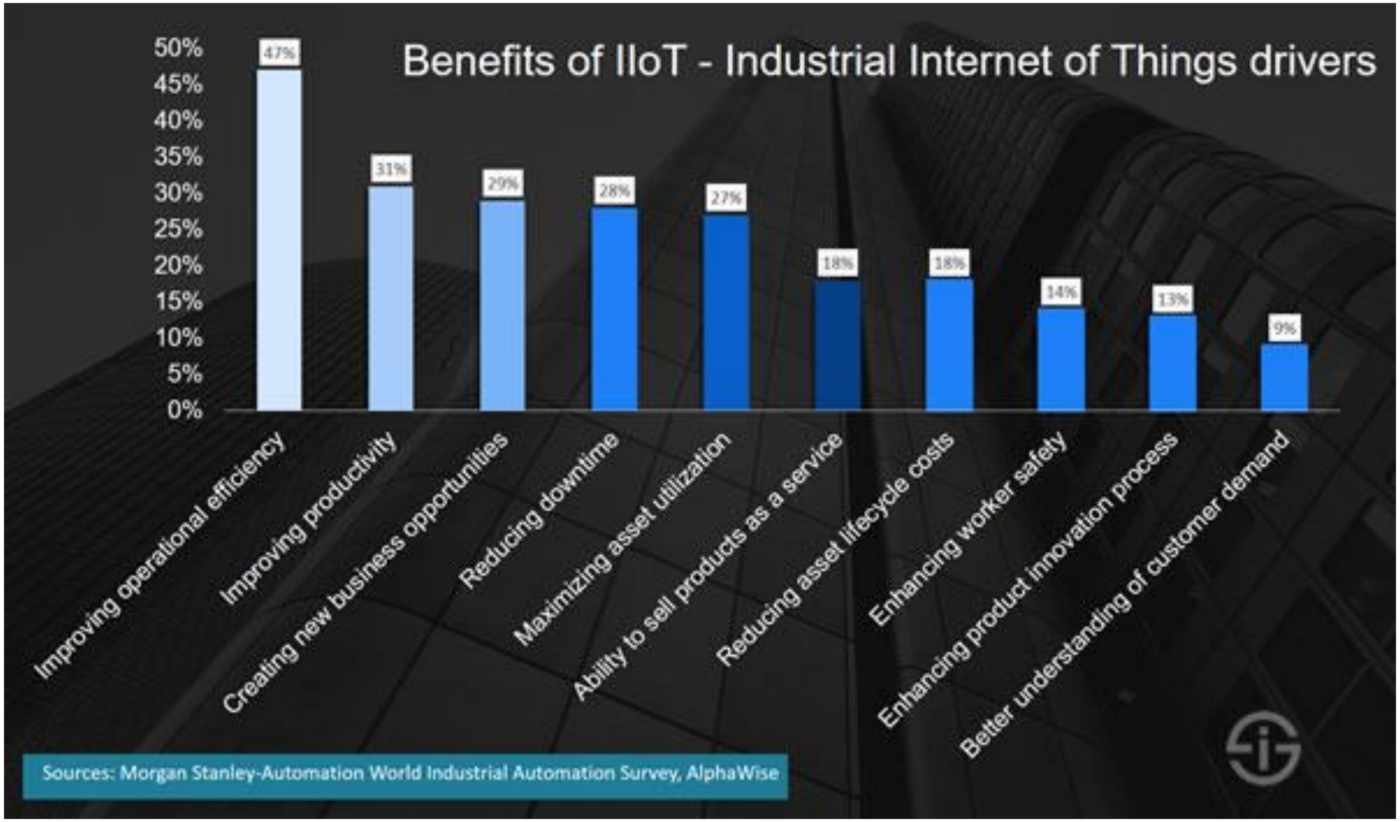
Several operational efficiencies such as labor, logistics, and quality control costs are improved with sensor deployment. Sensors have improved inventory counting, material sorting and automation leading to more productivity. Further, they are also helpful in identifying root errors in manufacturing and drive better product design. For example, assembly lines for wearables during quality inspection can send pictures to design engineers in real-time through smart sensor technology. This allows engineers to identify any manufacturing issues at the time of assembly before they become a point of failure and thus saves a lot of time.

Adherence to regulatory compliance:

Installed sensors in manufacturing equipment with data can help in generating reports to prove the regulatory compliance of industries. Smart sensors with data in the areas of energy consumption, temperature, humidity, operation hours, maintenance, production line outputs are easier to pull and collate. Moreover, sensors are also instrumental in improving production processes by providing output on product quality and real-time notification of such issues.

Uses of Embedded Sensors in the Manufacturing Value Chain

Drivers for IIoT sensors in industrial manufacturing



Source: https://www.i-scoop.eu/internet-of-things-guide/industrial-internet-things-iiot-saving-costs-innovation/

Supply chain and logistics:

Sensors are at the forefront of the supply chain market as 44% of supply chain organizations have already adopted them. Due to improved asset tracking and remote monitoring abilities, sensors in the logistics market have recorded a 15.9% CAGR. Sensors enable a close control, monitoring, and transparency of assets at all levels of the supply chain.

Examples:

Nokia has already applied a conscious supply network concept at factories to allow increased digitization across its supply chains and more transparency in the logistics value chain. These sensors leverage RFID and a neural network to provide enhanced asset tracking solutions and conscious supply chain for inventory management with reduced time to market.

Source: Nokia

Harley-Davidson has applied smart sensors for improved asset management and predictive maintenance of industrial machinery to actively address potential interruptions.

Source: Harley-Davidson

Consumer service:

Connected products also offer **insights into customer preferences and demands** for an effective product development. Sensors provide manufacturers data that could be adopted by the manufacturers for developing agile methods and that can be fed seamlessly into product life cycle management systems **to stimulate innovation**. Product developers with sensors are also saved from over engineering with an optimized R&D expenditure. Finally, having complete understanding of where true bottlenecks exist due to the use of monitoring equipment such as predictive maintenance could **improve problem solving in previously under-addressed areas.**

References:

1. *https://ww2.frost.com/frost-perspectives/sensors-industry-40-market-applications/*
2. *https://www2.deloitte.com/content/dam/Deloitte/us/Documents/process-and-operations/us-cons-smart-sensors.pdf*
3. *https://www.prescouter.com/inquiry/what-companies-are-offering-commercially-available-solutions-in-the-smart-packaging-domain/*
4. *https://www.plantautomation-technology.com/articles/types-of-sensors-used-in-industrial-automation*
5. *https://www.centricabusinesssolutions.com/blogpost/5-uses-smart-sensors-manufacturing*

Types of Embedded Sensors Based on Property

Sensors can be categorized on the basis of property:

PRESSURE SENSORS:

- Sense pressure to transform it into an analog electric signal, the magnitude of which is dependent on applied pressure.
- Required for various industrial applications, including touch screen devices, vehicle manufacturing, biomedical instruments, aviation, air conditioning, and hydraulic measurements.
- Categorized into strain gauge type, capacitive pressure sensor, and piezo sensors.
- Piezo sensors when combined with an IoT solution are able to sense real-time changes in pressure. Many industrial IoT systems with these sensors can monitor changes in pressure in critical types of equipment, including boilers, aerospace, water systems, oil drilling systems, etc.

TEMPERATURE SENSORS:

- One of the most commonly used sensors in industrial IoT systems.
- Detect changes in temperature producing either an analog or digital output.
- Could be categorized into contact temperature sensors, which requires direct contact with the system being sensed, and non-contact temperature sensors, which use convection and radiation to detect the changes in temperature.
- These two sensors could further be classified to electro-mechanical, resistive, and electronic types.
- Thermocouples, a type of electronic sensor, are one of the most routinely used types of sensors, due to their simple design, small size, ease of usage, and quick response to changes in temperature.

References:

1. *https://www.engineersgarage.com/articles/pressure-sensors-types-working*
2. *https://www.embitel.com/blog/embedded-blog/7-most-commonly-used-sensors-for-developing-industrial-iot-solutions*
3. *https://www.electronics-tutorials.ws/io/io_3.html*
4. *https://www.embedded.com/design/real-world-applications/4421319/Sensor-basics--types--functions-and-applications*

Types of Embedded Sensors Based on Property

FLOW SENSORS:

- Detect the flow rate for a liquid or a gas.
- The choice of the most suitable type depends on various factors such as nature, fluid viscosity, flow rate range, and the required accuracy of the measurement.
- Medical industries, HVAC, and various smart energy applications extensively use flow sensors.
- Flow sensors are further categorized into differential pressure flowmeter, positive displacement flowmeter, variable area flowmeter, magnetic flowmeter, vortex flowmeter, thermal flowmeter, multivariable flowmeter, and Airflow sensors.

BIOSENSORS:

- Biosensors generally consist of a biological component as sensor coupled to a transducer for quantitative detection and conversion to an electronic signal.
- Have emerged as a valuable tool in the detection of various biomarkers for disease diagnosis, healthcare, food safety, and the environment.
- Wearable sensors are helpful for non-invasive monitoring of biomarkers from sweat, tear, and saliva.
- Implanted biosensors, on the other hand, provide valuable information about diabetic patients and are easily operated by smartphones and IoT, enabling users to measure physical parameters in real-time.

References:

1. http://what-is-a-sensor.com/what-are-flow-sensors/
2. https://www.pc-control.co.uk/flow_sensors.htm
3. https://www.first-sensor.com/en/products/flow-sensors/
4. https://www.news-medical.net/health/What-are-Biosensors.aspx
5. https://www.mdpi.com/journal/sensors/special_issues/Wearable2018
6. https://www.iotforall.com/top-digital-health-solutions/

Types of Embedded Sensors Based on Property

IMAGE SENSORS:

- Are solid-state devices that can convert photons into an electrical signal for view, analysis, and storage.
- Due to the increasing demand for smartphones, digital cameras, security cameras, and imaging devices, image sensors are used widely in industrial, automotive, media, medical, and various consumer applications.
- Classified based on structure (CCD or CMOS), chroma (color or monochromatic), or shutter type (global or rolling).
- Depending on resolution, frame rate, pixel size, and sensor format, sensors are best chosen for applications.
- Embedded vision systems with sensors could be used for self-driving vehicles with accuracy and reliability.

PROXIMITY SENSORS:

- Detect the presence of nearest objects with no physical contact.
- Emit an electromagnetic field or a beam of electromagnetic radiation to detect changes in the return signal.
- Various types of proximity sensors are used for industrial applications including inductive, capacitive, ultrasonic, photoelectric, magnetic, etc.
- These sensors are best suited to detect motion and track objects in real-time to offset any issues in industrial manufacturing.

References:

1. https://thinklucid.com/tech-briefs/understanding-digital-image-sensors/
2. https://possibility.teledyneimaging.com/embedded-vision-in-2019/
3. http://www.infiniteinformationtechnology.com/iot-devices-proximity-sensors

Types of Embedded Sensors Based on Property

ACCELEROMETER/INERTIAL SENSORS:

- Measure acceleration experienced by an object due to inertial forces or mechanical excitation. A proof mass inside accelerometer structure moves in one direction. Due to inertia, the proof mass remains in place during the acceleration of the surrounding structure in the same direction. Sensing systems within the accelerator monitor the movement of proof mass relative to the neighboring structure, and interface circuits convey a signal for detection.
- Play a key role in applications including automotive air-bag deployment, smartphone motion tracking, and industrial predictive maintenance.

HUMIDITY SENSORS:

- Detect moisture levels in the environment. Monitoring humidity is one of the essential parameters in various industrial applications.
- Controlled moisture levels are necessary for medical equipment, including pharmaceutical processing.
- In recent years, there has been a huge surge in the market for electronic hygrometers/ humidity sensors. They can be divided into two categories: capacitive type and resistive type. Capacitive type sensors consist of a dielectric material sandwiched between a pair of electrodes forming a small capacitor. Resistive type sensors sense changes in the resistance value of the sensor element in response to the changes in the humidity.

References:

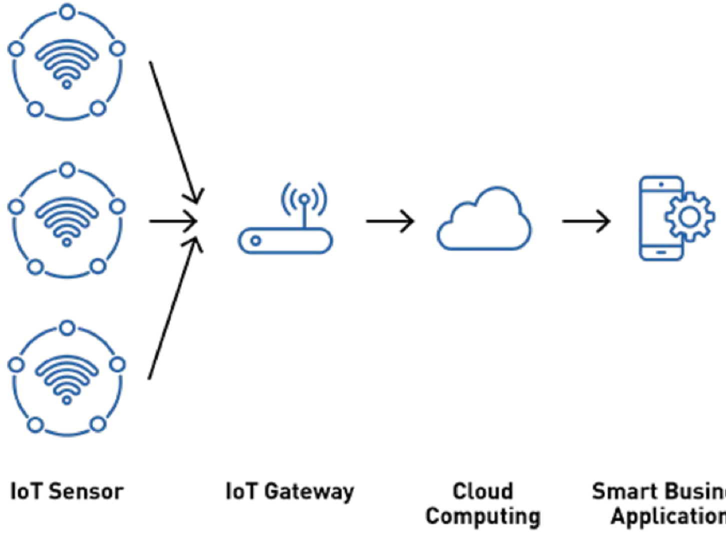
1. *https://www.embedded.com/electronics-products/electronic-product-reviews/system-integration/4461403/Designers-can-find-a-wealth-of-options-for-accelerometer-designs*
2. *https://www.engineersgarage.com/articles/accelerometer*
3. *https://www.engineersgarage.com/articles/humidity-sensor*

Impact of IoT Sensors on Market

Increasing momentum of the IoT sensor market

As embedded systems are now entering in the realm of IoT, technology is being developed to facilitate the connection between the components of the embedded system and the web. IoT's emerging range of software-controlled sensors and other devices allow machines to communicate with each other. Today, most embedded sensors possess connectivity, and can be classified as IoT-type sensors.

Currently, the IoT sensor market is booming and is projected to increase further with stringent government regulations and policies. With continued development in this sector being driven by needs from consumers and businesses alike, embedded sensors will continue to gain new capabilities that will make them relevant in more applications.



Source: [MapR]

References:

1. https://www.globenewswire.com/news-release/2018/04/20/1483291/0/en/Trends-in-Global-IoT-Sensors-Market-Size-to-Reach-USD-27-38-billion-by-2022.html
2. https://www.i-scoop.eu/global-sensor-market-forecast-2022/

Leading the way to digital transformation in manufacturing

Some key applications in industrial manufacturing processes are:

1) **Predictive maintenance:** Predictive Maintenance (PdM) is performed in industries to prevent downtime due to failure or other sources, which can be predicted through analysis of historical data. Typically, only some components are outfitted with sensors as these can be the best indicators of when failure will occur. IoT sensors are efficient at monitoring equipment usage with gathering data about machine operating parameters including run time, speed, output. Sensors provide a cost-effective solution to increase the service life of the machines, which could be a game-changer in industries.
2) **Increased visibility of operations:** For manufacturing, industrial IoT offers a never before seen level of visibility into the shop floor and field operations. In fact, IBM reported a 20% higher product count from the same production line by using the insights by IoT. IoT-driven manufacturing operations provide a detailed view at every point of the production process.
3) **Better product quality control:** IoT sensors are also adept at product quality control. They can monitor machine conditions especially operating beyond normal thresholds.
4) **Increased safety of workers:** Employees can also monitor the safety of the workers in real-time with the data of IoT sensors.

References:

1. https://www.ibm.com/blogs/internet-of-things/digitally-dark-manufacturing-plant/
2. https://www.scnsoft.com/blog/iot-in-manufacturing
3. https://blog.aimultiple.com/predictive-maintenance/

Impact of IoT Sensors on Market

6) **More efficient supply chain management:** Smart supply chain management solutions provide manufacturers with real-time insights into the location, status, and condition of every object (be it an individual inventory item on a warehouse shelf or a truck delivering supplies) at any segment of the manufacturing supply chain. Before IoT, conditions of goods could only be monitored at the delivery point. With IoT, the status of materials, goods could even be monitored en route and offers value esp. for pharmaceutical, food, glassware, and modern nanomaterial companies. The transition towards IoT sensors led to smart chain management solutions that would increase supply chain productivity by 15% and raise cost efficiency by 10%. Moreover, smart chain management with real-time information about location, status and the condition of every object provide optimized solutions and immense value to the manufacturers.

7) **Ensures visibility into remote and outsourced operations In manufacturing:** IoT sensors led monitoring and maintenance offers manufacturers to keep a maintenance check and keep potential failures at bay. Further, the IoT system also allows the company personals to maintain the efficiency of the manufacturing operations without direct access to the location.

8) **Proper asset tracking, investment returns, and management:** Along with improving the manufacturing operations, IoT sensors also help in ensuring proper asset tracking, inventory management, improve reliability, and provide the best returns on assets.

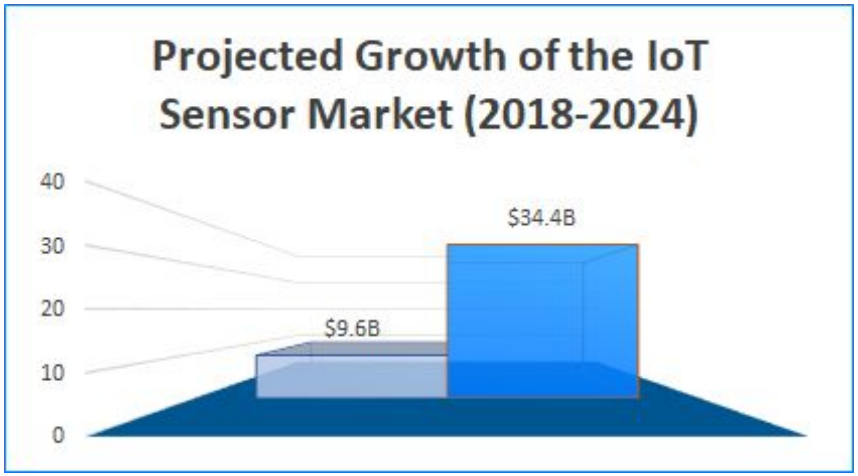
References:

1. *https://www.scnsoft.com/blog/iot-in-manufacturing*

Market Trends

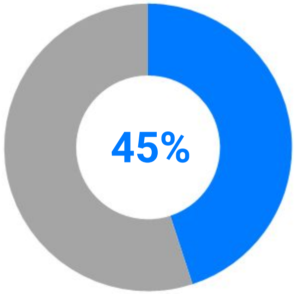
IoT sensor market growth and trends

The IoT sensor market was valued around $9.6 billion in 2018 and is proposed to increase to **$34.4 billion in 2024**. Sensors are extensively incorporated into IoT systems including smart grids, wearables, smart homes, and smart cities. The global market for sensors is projected to grow with a compound annual growth rate (CAGR) of 11.3% until 2022, and would reach $241 billion. From a regional perspective, Asia Pacific region (APAC) generates 45% of total sensor market revenue with emergence of new players including India, China, Japan, Russia, Australia, and Brazil.



The global sensor market is to reach $241B by 2022.

The Asia Pacific region generates nearly half of the total sensor revenue.



References:

1. https://www.globenewswire.com/news-release/2018/04/20/1483291/0/en/Trends-in-Global-IoT-Sensors-Market-Size-to-Reach-USD-27-38-billion-by-2022.html
2. https://www.i-scoop.eu/global-sensor-market-forecast-2022/

Market Trends

CONSUMER ELECTRONICS

Advancements in consumer electronics

AUTOMATION

Strong demand in the automation industries

WEARABLES

Increasing demand for wearables

SMARTPHONES

Growing usage of sensors in smartphones

AUTOMOTIVE

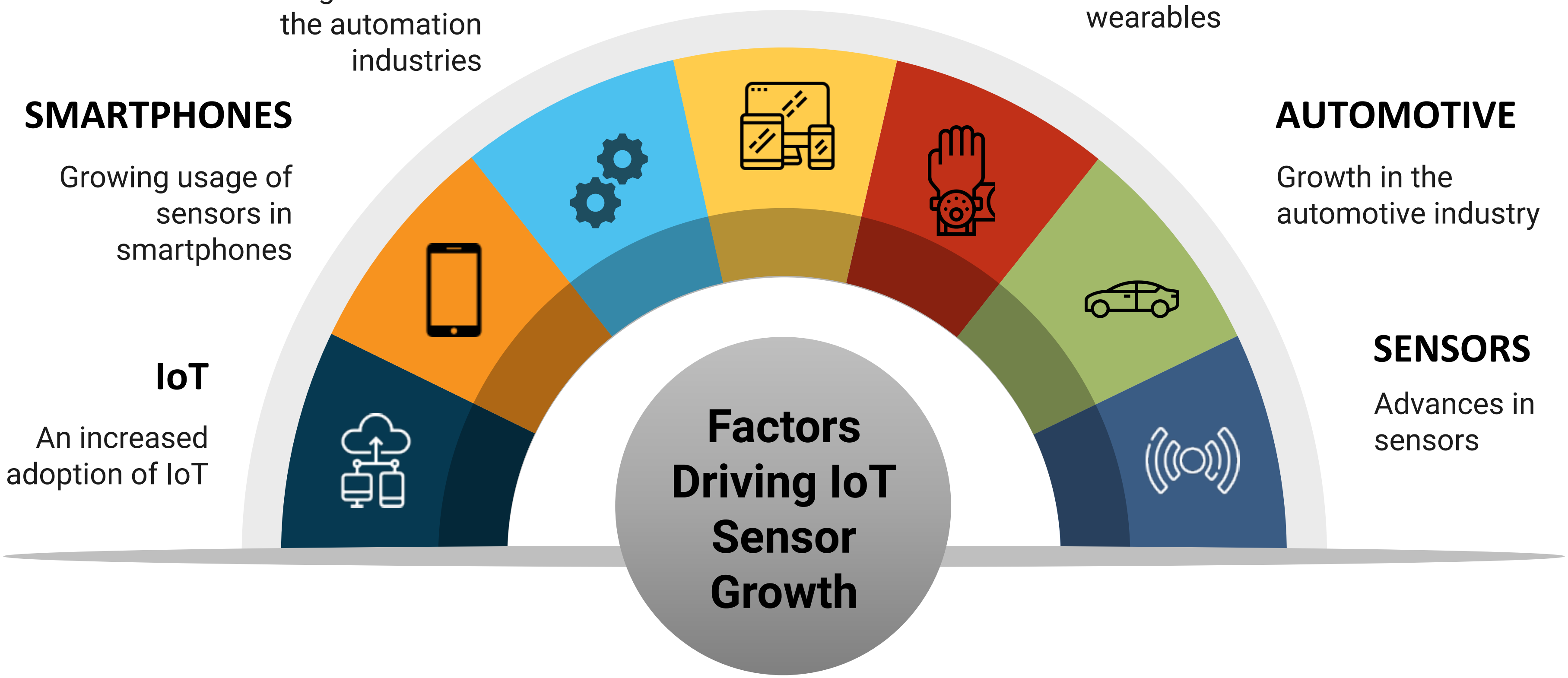
Growth in the automotive industry

IoT

An increased adoption of IoT

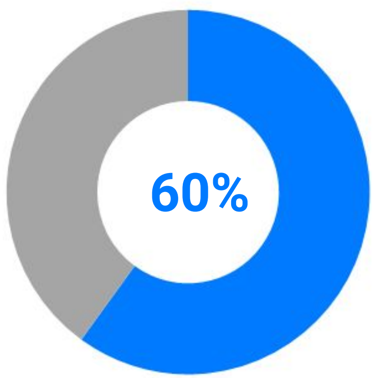
SENSORS

Advances in sensors



Market Trends

About **60% of manufacturing** companies are already working on several IoT projects, **and more than 30%** of them are at an early stage of placement. IoT sensors including **pressure sensors** and **temperature sensors** are projected to hold the major share of the IoT sensor market.



of manufacturing companies are already working on IoT projects

MORE THAN

30%

OF WHICH ARE AT AN EARLY STAGE OF PLACEMENT

Due to extensive uses of temperature sensors in healthcare, automotive, and consumer electronics industries, a rise in demand for automation in these sensors is gathering momentum. Smart cities initiatives are also proposed to drive the demand for IoT sensors.

References:

1. https://www.globenewswire.com/news-release/2018/04/20/1483291/0/en/Trends-in-Global-IoT-Sensors-Market-Size-to-Reach-USD-27-38-billion-by-2022.html

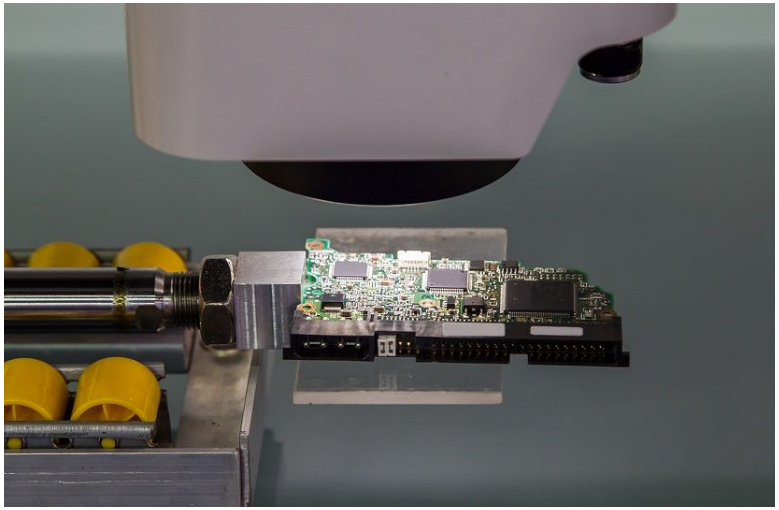
Case Studies

Advantech

Background

Founded in 1983, Advantech is a provider in embedded and automation products and solutions. Advantech offers system integration, hardware, software, customer-centric design services and global logistics support, with a industrial focus on Gaming, Factory Automation, Intelligent Transportation, Digital Healthcare, Digital Retail & Hospitality, and Communications.

Automated optical inspection (AOI) systems integrate optics, mechanics, electronic control, and software -- performing visual inspections of defects and failures of printed circuit boards (PCB) during manufacturing. AOI monitors the quality of PCB production and corrects them in the process flow, which is a key to success in today's competitive PCB production environment.



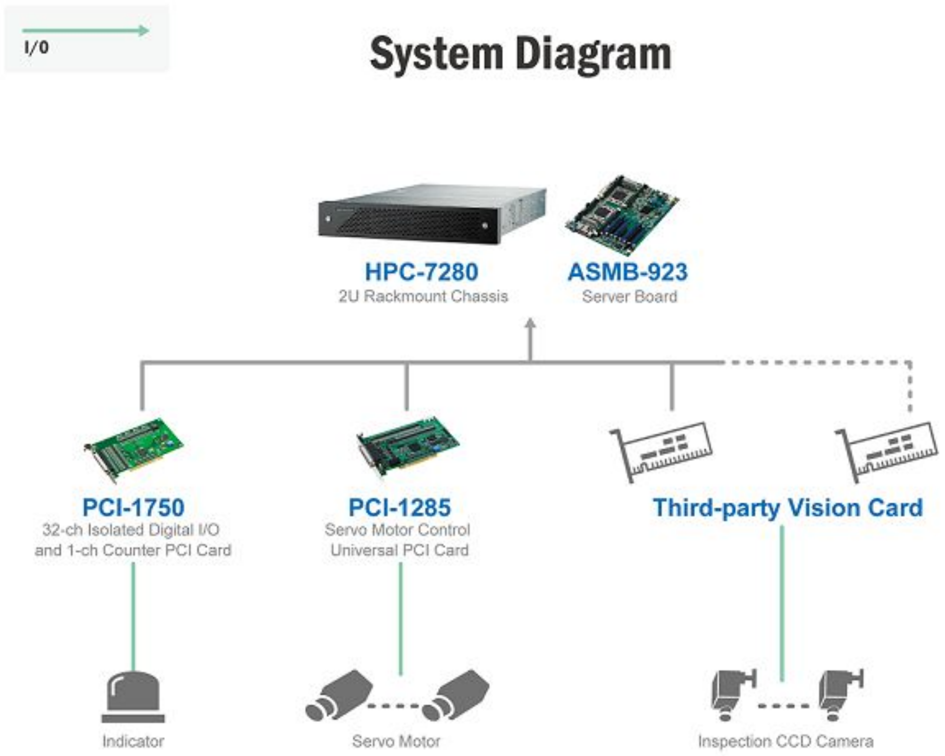
Source: Advantech

System Design

Powerful Graphics Processing Unit (GPU) card is needed for AOI systems to provide real time inspections at production speed. Different types of cards are also needed as AOI systems connect to devices including robotic arms and CCD cameras. (See system diagram in next slide)

Benefits

AOI systems, used for PCB manufacturing monitoring, are able to detect a variety of surface feature defects, such as nodules, scratches, stains, open circuits, and the thinning of soldered joints.



References:

1. https://www2.advantech.com/industrial-automation/casestudies/4d4df996-ed1f-4c32-907e-058f694b1096/

Ericsson

Background

Ericsson, a telecommunications equipment manufacturer, applied a variety of smart factory technologies at its facilities worldwide. Embedded sensors and connected devices are deployed for smart factories to enable self-configurable robotics, augmented reality for testing, autonomous vehicles for material handling, real-time worker and moving assets tracking, digital twins for design and planning, private cloud intelligence, and so on.

Source: Hexagon

System Design

Ericsson uses Narrowband IoT (NB-IoT)-enabled sensors (NB-IoT is a Low Power Wide Area Network - LPWAN - radio technology standard) to connect workstations on its manufacturing lines and to track key moving assets.

Benefits

Ericsson's mobile IoT system is estimated to save $230 per added sensor. With 5G technologies used to connect the sensors and other part of the system with low latency and high reliability, the factories are able to operate at high level of automation.

References:

1. *https://www.rtinsights.com/case-study-iot-makes-ericssons-smart-factories-even-smarter/*
2. *https://www.qualitymag.com/articles/95355-hexagon-ericsson-partner-to-showcase-connected-factory-solutions*

Kaeser Kompressoren

Background

Kaeser Kompressoren is one of the world's leading manufacturers and providers of compressed air systems and services. The company offers products, services, and complete systems for the generation, treatment, and delivery of energy in the form of compressed air. Machine sensors embedded in Kaeser Kompressoren equipment deliver real time analytics that predict and prevent system outages before they occur.

Source: HPE

Kaeser Kompressoren

System Design

Kaeser Kompressoren equipment integrates temperature, humidity, and vibration sensors to capture environmental and performance data. The data is then transmitted in real-time to a system for predictive analytics. Kaeser uses this system to determine if a part might be prone to failure, and faulty parts can be replaced during regularly maintenance.

Benefits

Kaeser Kompressoren's sensor-enabled predictive system **reduces 60% unscheduled system downtime and emergency service visits**, which resulted in an **estimated annual savings of $10 million in break-fix costs**.

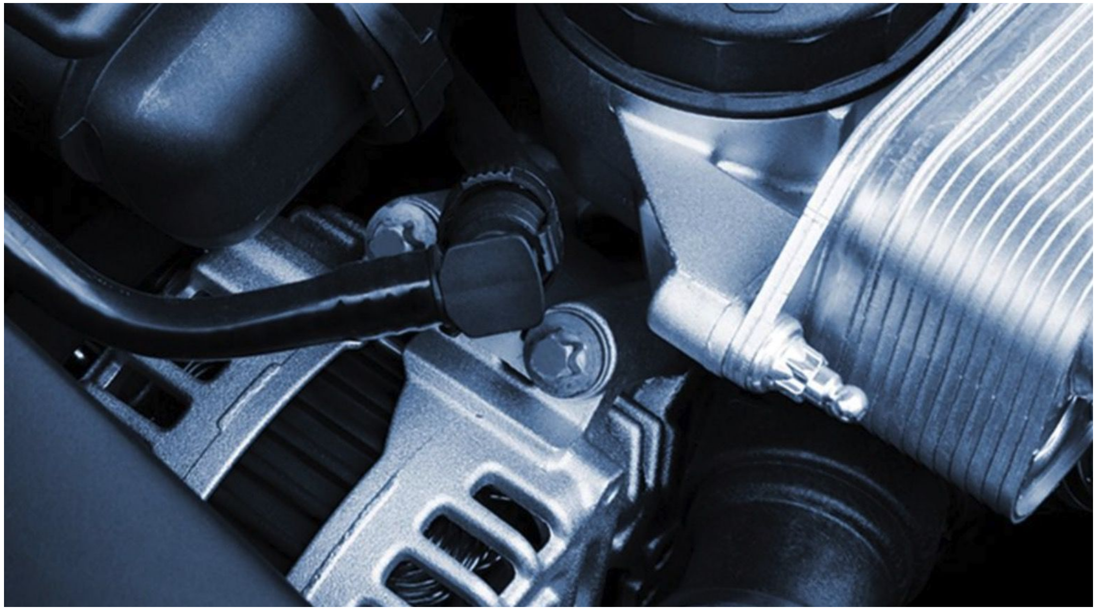
References:

1. *https://www.hpe.com/us/en/customer-case-studies/kaeser-iiot.html*

HIROTEC Group

Background

Headquartered in Japan, HIROTEC Group Companies is a global automotive manufacturing equipment and parts supplier. The company has over 85 years of experience in the industry and 26 facilities in 9 countries. HIROTEC is one of the largest private production companies in global automotive market. HIROTEC is currently focusing on using IoT based technologies to minimize unplanned downtime and ensure continuous operations.



Source: HPE

HIROTEC Group

System Design

HIROTEC implemented an IoT platform pilot to perform remote visualization of an automated exhaust system inspection line. Inspection robots, force sensors, laser measurement devices and cameras are used as data sources for real-time visualization and automatic report generation.

Benefits

The pilot demonstrated that **100% of manual inspection time can be reduced**, thus technicians can focus on tasks that create more value. Based on industry benchmarks, the cost of unplanned downtime to automobile OEM is $361 per second. On an average estimation of 3-minute time spent for technicians to report an issue, HIROTEC is able to **save $70,000** for manual issue reporting.

References:

1. *https://www.hpe.com/us/en/customer-case-studies/hirotec-iot.html*

Johnson & Johnson

Background

Johnson & Johnson is a $70 billion, 130-year old healthcare products manufacturer. Sensor-based technology is having a significant impact on how J&J makes its products as well as on how those products might interact with patients.

System Design

In J&J's pharmaceutical business, in-line sensors are deployed to sample and test tablets and pills in real time, eliminating separate testing and sampling steps.

J&J's healthcare supply chain embeds temperature sensors and monitors into vaccine product, transmitting real-time signals to assure the product is maintained in frozen conditions.

Source: Industry Week

Benefits

The in-line sensors enabled J&J's shift from batch to continuous manufacturing, which provides much greater flexibility, significant reduction in cycle time, and more efficient use of human resources.

The embedded temperature sensors and monitors enabled J&J to track and trace products throughout its extended supply chain as they get handed downstream from manufacturing to a distributor or to a customer.

References:

1. https://www.industryweek.com/supply-chain/healing-power-iot

State-of-the-art in Academia

Top Research Groups and Research Trends

The following table lists the top university groups on embedded sensor research and with a strong industrial focus/connection.

Group	Location	Research Focus	Collaborators
e-WEAR	Stanford University, USA	Wearable sensors	Applied Materials, Samsung, LG, etc.
The Photonics Technology Laboratory	Clemson University, USA	Photonic and microwave sensors and instrumentation	University of Missouri, University of Cincinnati, Habsonic, etc.
Sensor Technology Research Centre	University of Sussex, United Kingdom	Wearable sensors, flexible electronics, Electric Potential Sensor	Plessey Semiconductors, Huawei, etc.
Berkeley Sensor & Actuator Center	University of California, Berkeley, USA	BioMEMS, Microfluidics, NanoPlasmonics, Microphotonics & Imaging, etc.	Marvell, Intel, Bosch, etc.
RFID Lab	Auburn University, Alabama, USA	Technical implementation of RFID sensors in manufacturing.	Amazon, Boeing, Nike, etc.

Stanford Wearable Electronics Initiative (e-WEAR)

Stanford University

Summary:

e-WEAR is a university-wide multi-disciplinary program to bring together Stanford expertise in materials, electronics, systems, data and clinical science, and foster collaborations between Stanford researchers and industry. Current research areas include but are not limited to:

- Flexible and stretchable electronic materials
- Flexible circuit and system design
- Wearable energy harvesting and storage devices
- Wearable sensors
- Wearable applications in robotics
- Wearable applications in automobiles

Commercialization Status:

e-WEAR works closely with diverse industries from various sectors, such as technology, manufacturing, defense, agriculture, communications, social networks, and health care.

Stanford Wearable Electronics Initiative (e-WEAR)

Stanford University

Selected Publications:

- *Modular and Reconfigurable Stretchable Electronic Systems*
- *A highly stretchable, transparent, and conductive polymer*
- *Strain- and Strain-Rate-Invariant Conductance in a Stretchable and Compressible 3D Conducting Polymer Foam*
- *An electrodynamic energy harvester with a 3D printed magnet and optimized topology*

References:

1. https://wearable.stanford.edu/
2. https://mailchi.mp/4b3e23056802/ewear-newsletter-may-2019
3. https://us17.campaign-archive.com/home/?u=0b564b39efb4a303840062b55&id=632cf8c77d

Photonics Technology Laboratory (PTL)

Summary:

PTL at Clemson University conducts fundamental and applied research on design, modeling, fabrication and demonstration of photonic devices and sensors for defense, energy, environmental, and biomedical applications, focusing on the following four thrust areas:

1. Novel micro/nano photonic structures, devices and sensors
2. Fiber optic sensors and instrumentation for applications in harsh environment
3. In situ characterization of nanomaterials and nanostructures using optical methods for chemical and biological sensing
4. Optical biomedical imaging

Commercialization Status:

Research has been funded by NSF, DOE, ONR, NIH, ARO, national laboratories and private companies. Multiple patents are associated with the research group and collaborating companies.

Selected Publications:

- A Fluidic-based High-pressure Sensor Interrogated by Microwave Fabry-Perot Interferometry
- Ultrafast laser ablation of silica optical fibers for fabrication of diaphragm/cantilever-based acoustic sensors
- Local pH monitoring of small cluster of cells using a fiber-optic dual-core micro-probe
- Strain monitoring of bismaleimide composites using embedded microcavity sensor

References:

1. https://haix.people.clemson.edu/
2. https://scholar.google.com/citations?user=c6F1illAAAAJ&hl=en&oi=ao

Sensor Technology Research Center

UNIVERSITY OF SUSSEX

Summary:

The Sensor Technology Research Center at University of Sussex focuses on wearable computing and embedded intelligent systems, flexible and stretchable electronics, mobile and wireless communication, IoT and vehicular networks, electrophysiology and fundamentals of sensors.

The applications domains covered include: remote sensing, forensics, communication, healthcare, rehabilitation, energy management, smart assistance, context-aware systems, vehicular communication, wearable and implantable electronics among others.

Commercialization Status:

The Centre's Electric Potential Sensor (EPS) has been licensed to industrial partners and marketed as an integrated circuit device.

UNIVERSITY OF SUSSEX

Selected Publications:

- *Deep convolutional and LSTM recurrent neural networks for multimodal wearable activity recognition*
- *3D ActionSLAM: wearable person tracking in multi-floor environments*
- *Wireless energy harvesting for Internet of Things*
- *Toward energy and resource efficient Internet-of-Things: a design principle combining computation, communications and protocols*

References:

1. http://www.sussex.ac.uk/strc/index

Berkeley Sensor & Actuator Center (BSAC)

Summary:

BSAC, founded in 1986, conducts industry-relevant, interdisciplinary research on micro- and nano-scale sensors. Major thrust areas of research include:

- Wireless Communication and RF Devices
- Physical Sensors, Actuators, Devices, Circuits, and MicroRobotics
- Packaging, Processes, Materials and Microassembly for MEMS
- MicroMechanical and BioElectroMechanical Power Generation
- Nano Structures and Electro-Mechanical-Bio Interfaces for Nano Technologies
- CAD for MEMS
- BioMEMS and MicroFluidics
- MicroPhotonics

Commercialization Status:

BSAC Researchers pioneered the development of mechanical and electrical structures utilizing lithography and processing capabilities of the semiconductor industry. BSAC research has enabled a series of MEMS approaches into applications, including (but not limited to): MEMS Based Free-Space Optics, Piezoelectric MEMS Silicon-Diaphragm Microphone, MEMS-Scanned Barcode Reader, Microfluidic Host-Fueled Glucose Microbial Power Cell.

Berkeley Sensor & Actuator Center (BSAC)

Selected Publications:

- *All Carbon Based Flexible Humidity Sensor*
- *A Quasi-Static Electrical Measurement Scheme for Probing Gas Reactions on Graphene Surface*
- *Dew Point Measurement Using a Carbon-Based Capacitive Sensor with Active Temperature Control*
- *A New Type of Bionics-Based Piezoelectric Heartbeat Sensor Used in Pulse-Taking for Health Warning*

References:

1. http://www-bsac.eecs.berkeley.edu/about/
2. http://www-bsac.eecs.berkeley.edu/contact/bsac_summary_page.php?URLnode=60

Summary:

The RFID Lab at Auburn University is a research institute focusing on the business case and technical implementation of RFID and other emerging technologies in retail, aviation, supply chain and manufacturing. The lab developed ARC program, which works with end users in retail, aviation, and manufacturing to identify the performance and quality requirement of their use cases and deployment. These are the requirements (Specs) that an RFID tag needs to meet to perform reliably in the deployment. ARC maintains a database that stores comprehensive performance and quality data of market available RFID tags. Lists of tags that meet the requirement of the end users can quickly be generated by comparing the Spec to information in the database.

Commercialization Status:

RFID Lab's ARC program collaborates with appeal manufactures (e.g. Nike), retailers (e.g. Target, Home Depot), as well as RFID technology providers to standardize RFID tag specs being used in inventory management, item tracking use cases.

RFID Lab at Auburn University

Selected Publications:

- *Project Zipper: EPC-Enabled Item-level RFID Supply Chain Brand/Retailer Exchange Study*
- *RFID Item-Level Tagging for Apparel/Footwear: Feasibility Study*
- *RFID As Electronic Article Surveillance EAS: Feasibility Assessment*

References:

1. https://rfid.auburn.edu/arc/
2. http://www-bsac.eecs.berkeley.edu/contact/bsac_summary_page.php?URLnode=60

Appendix

+1.872.222.9225 • info@prescouter.com

Potential Next Steps

Topic	Question
IP Analysis	Uncovering recent patents in this sector to establish technology trends
Market research	Identify relevant market trends, segmentation and analysis to determine whether this market is an attractive investment opportunity
Next generation technologies	Investigate academic literature to identify commercial roadblocks and forecast technology evolution for embedded sensors
Identification of suppliers/partners	Profiles of top 10 relevant suppliers to help client introduce sensors into mfg. line
Data Analysis and Recommendations for Recap Report	

Next Steps

THESE ARE SOME POSSIBILITIES THAT PRESCOUTER CAN OFFER FOR CONTINUATION OF OUR RELATIONSHIP:

PERIODIC TRACKING OF NEW DEVELOPMENTS: quarterly/biyearly scouting on any novel technologies related to the topic of interest.

OUTREACH to companies or research groups for detailed anonymous interviews.

Engagement with **SUBJECT MATTER EXPERTS** to receive an expert opinion.

Engaging with a **CONTRACT RESEARCH ORGANIZATION** for building a prototype, testing an equipment or any other related research service.

CONFERENCE SUPPORT: PreScouter can attend conferences of interest on your behalf.

WRITING ARTICLE: PreScouter can write technical or more public facing articles on your behalf.

For any requests, we welcome your additional questions and custom building a solution for you.

About the Authors

Sofiane Boukhalfa, PhD

Managing Director, High Tech / Aerospace & Defense Practice

Professional Summary:

Sofiane leads the high-tech, aerospace and defense and finance verticals at PreScouter. Sofiane earned his B.S. in Materials Science and Engineering from The University of Illinois at Urbana-Champaign, and his Ph.D. in Materials Science and Engineering from the Georgia Institute of Technology, where his research focused on nanotechnology and energy storage. Since graduating from Georgia Tech, he has worked as an emerging technology and business strategy consultant at several firms and for his own clients.

About the Authors

Navneeta Kaul

University of Denver, United States

Shuo Deng

Massachusetts Institute of Technology, United States

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