Hype Cycle for Sensing Technologies and Applications, 2020

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Sensing is critical in improving situation awareness and intelligence in Internet of Things, playing an increasing role in artificial intelligence enabled applications. IT leaders must leverage and evaluate the emerging sensing technologies and applications for sustainable competitive advantage.

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What You Need to Know

Fast adoption of sensors across end markets is driving innovation in sensor performance, size and integration. These improvements, combined with analytics and artificial intelligence (AI)-driven platforms — going from an on/off operation to a greater degree of measurement and fusion —

create opportunities for improved situational awareness. However, emerging application requirements demand low-latency response times with higher precision; for example, multiexperience, human augmentation, autonomous vehicles, digital twins and so on. This trend has also resulted in processing decentralizing to the edge — where sensor data would be directly analyzed and processed. IT leaders need to understand the different sensing technologies and their applications to include in their roadmaps and evaluate trade-offs between factors such as cost, precision, coverage, scalability and interoperability for the technology selected.

The Hype Cycle

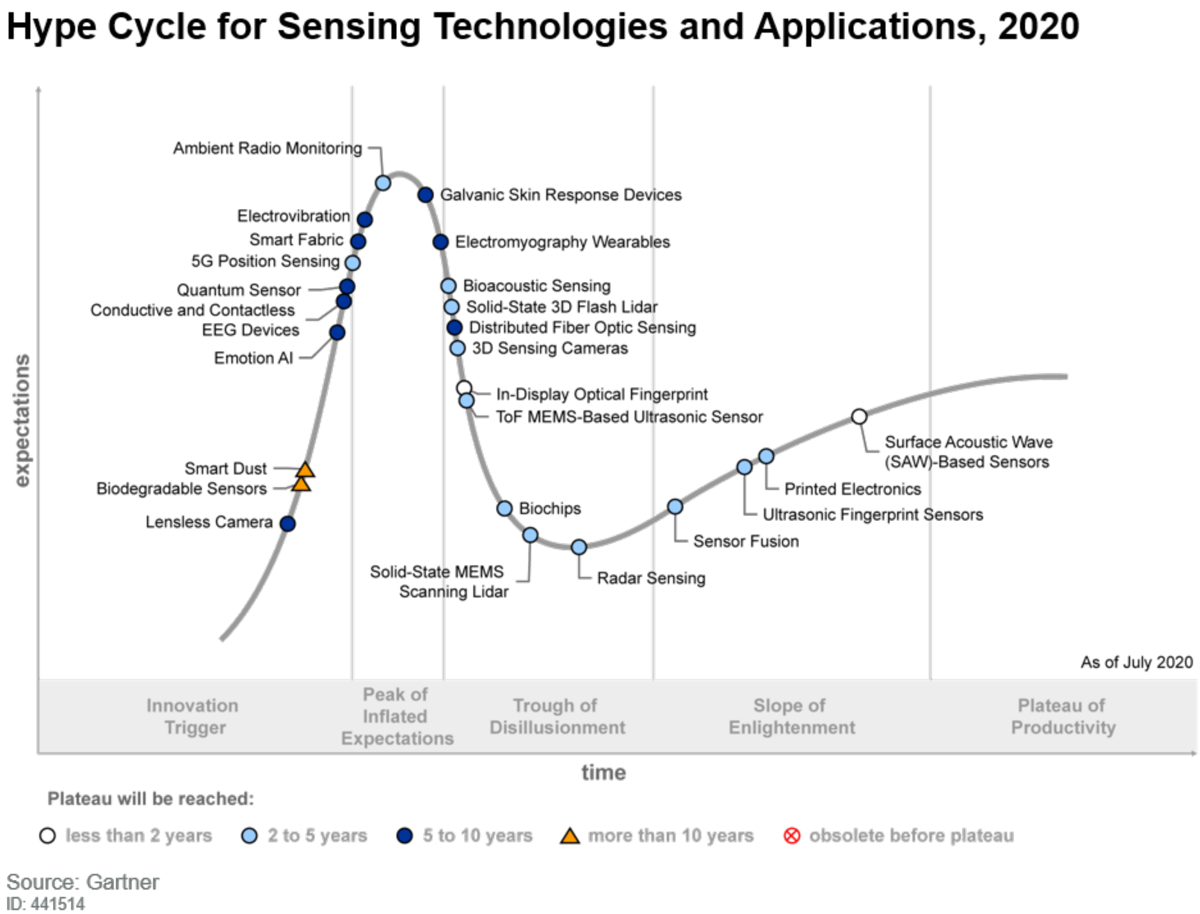
This Hype Cycle for Sensing Technologies and Applications coupled with an understanding of the situational awareness needs can be used to develop a comprehensive view for the timely investment to gain competitive advantage. Device miniaturization and low power consumption have been driving the development of sensors for some time now. Sensors are also becoming batteryless by harnessing ambient energy to become self-powered systems. The profiles in this Hype Cycle range across several applications like medical, automotive, consumer, industrial, communications and so on, to be used for tracking an asset, sending coordinates, monitoring the health and condition of an equipment or system, and monitoring a process in manufacturing or nonmanufacturing. Around half of the entries are around the Innovation Trigger and Peak of Inflated Expectations, which are intended to be seen as an investment from a long-term perspective since they will take more than five years to reach the Plateau of Productivity. The position of **Biochips** has been corrected and advanced to the Trough of Disillusionment in this Hype Cycle. **In-Display Optical Fingerprint** and **Surface Acoustic Wave (SAW)-Based Sensors** are expected to reach the Plateau of Productivity in the next two years.

The following new profiles have been added based on their hype and interest in their respective applications:

- **Sensors: Biodegradable Sensors, Printed Electronics**
- **Sensing Technologies: Radar Sensing**
- **Sensing Applications: Smart Fabric, Galvanic Skin Response Devices, 5G Position Sensing, Distributed Fiber Optic Sensing (DFOS)**

The scope of head-mounted electroencephalography (EEG) has been expanded to include contactless EEG known as **Conductive and Contactless EEG Devices** in this Hype Cycle and its position defined accordingly.

Figure 1. Hype Cycle for Sensing Technologies and Applications, 2020



The Priority Matrix

The Priority Matrix combines "position in the Hype Cycle," "benefit rating" and, most importantly, "time to mainstream adoption" for each profile in this Hype Cycle. It is useful for ranking which technologies an organization should examine first based on maturity and business impact.

The innovations that are located near the Peak of Inflated Expectations means that the market has great expectations for these sensors and believes that these innovative sensors can bring new applications for the Internet of Things (IoT) or AI.

Transformational Benefit

The 2020 Priority Matrix for sensing technologies and applications indicates that the entries like **Emotion AI, Quantum Sensor, Smart Dust** with potentially transformational benefits will not reach mainstream adoption in the near term (less than two years). Technology innovation leaders adopting these elements should be either in more mature organizations or explicitly willing to assume the risks of earlier adoption, perhaps starting by piloting them in parts of their organization.

High Benefit

Sensor Fusion, 3D Sensing Cameras, 5G Position Sensing, Biochips, Printed Electronics, Radar Sensing, Solid-State 3D Flash Lidar, Solid-State Micro-Electromechanical Systems (MEMS) Scanning Lidar are expected to be of high benefit within two to five years. **Lensless Camera** and **Biodegradable Sensors** have a higher time horizon.

Less mature and risk-averse organizations should focus on the business impact and consider more proven technologies with moderate to high benefit and a shorter time frame to mainstream adoption.

Figure 2. Priority Matrix for Sensing Technologies and Applications, 2020

Priority Matrix for Sensing Technologies and Applications, 2020

benefit	years to mainstream adoption			
	less than two years	two to five years	five to 10 years	more than 10 years
transformational			Emotion AI Quantum Sensor	Smart Dust
high		3D Sensing Cameras 5G Position Sensing Biochips Printed Electronics Radar Sensing Sensor Fusion Solid-State 3D Flash Lidar Solid-State MEMS Scanning Lidar	Lensless Camera	Biodegradable Sensors
moderate	In-Display Optical Fingerprint	Ambient Radio Monitoring Bioacoustic Sensing ToF MEMS-Based Ultrasonic Sensor Ultrasonic Fingerprint Sensors	Conductive and Contactless EEG Devices Distributed Fiber Optic Sensing Electromyography Wearables Electrovibration Galvanic Skin Response Devices Smart Fabric	
low	Surface Acoustic Wave (SAW)-Based Sensors			

As of July 2020

Source: Gartner
ID: 441514

Off the Hype Cycle

Piezoelectric MEMS Microphone has moved beyond the scope of this Hype Cycle since it is now relatively mature, having reached the Plateau of Productivity.

The scope of **Head-Mounted EEG** has been expanded to incorporate contactless EEG, known as **Conductive and Contactless EEG Devices** in this Hype Cycle with its position defined accordingly.

On the Rise

Lensless Camera

Analysis By: Juhi Gupta

Definition: Lensless cameras have no lens assembly and capture the image directly on the sensor. Without the quality focusing and filtering provided by a normal lens assembly, the captured image requires digital processing to reconstruct the captured lower-grade images.

Position and Adoption Speed Justification: Lensless cameras will be smaller and thinner, because they don't need lenses and modules. The form factor will be completely changed from cubic to flat, allowing the camera to be easily installed into any small, thin, light and/or flexible electronic equipment. The cost of a lensless camera will be greatly reduced, because there is no lens or complex assembly work required. Also, using different software algorithms can achieve altering field views (wide angle or tele) or different resolution with the same image setup, because this technology isn't limited by the lens' focal length. In addition, lensless cameras can also be modified to capture a wide spectrum, including near-infrared, millimeter or ultraviolet wavelengths, thus further extending their applications and use.

There is no mainstream approach to developing lensless cameras. A few notable approaches include:

- Using a unique film, mask or aperture assembly (such as a liquid crystal panel) on top of a conventional image sensor to capture visible and invisible light
- Using silicon photonics to mimic the lens and sensors of a conventional camera, with a much thinner form factor. These are aligned as large arrays of light receivers, each of which can independently add a tightly controlled time delay (or phase shift) to the light received, providing a controlled time-delay. This optical phased array (OPA) enables the camera to have a selective and directional focus.
- Using conventional glass to mimic the lens. The benefit of this approach is that the glass can be the windows in a house, which can be turned into security cameras. Or a windshield in a vehicle can become a dash camera.

No matter the approach used, computational work is required to reconstruct the captured lower-grade images. The computational workload for better image quality will be high, resulting in high power consumption and/or slow image output. However, early traction can be found in high-volume

Internet of Things (IoT) applications, where absolute image quality can be traded for a low cost and a small form factor.

Lensless technology is still in infancy stage, and during last year, different research labs have made continuous progress, working on prototypes. The improvements focus on improving the image quality, including better resolution, and reducing signal noise. Thus, the position on the Hype Cycle has moved forward slightly.

User Advice: Electronic equipment can be easily installed with multiple lensless cameras at a low cost. With this design, electronic equipment will be able to collect all light/image/environment information surrounding the electronic equipment as an input for machine vision.

The computational work for image reconstruction needs to improve, because it's still high, resulting in high power consumption and/or slow image output. Improvements for the image quality enhancement and faster real-time response needs to be done by employing artificial intelligence (AI) chips with machine learning (ML) capability. Or they can use alternative mechanisms for better light capture or design better sensors that enable much larger receivers with higher resolution and sensitivity.

Electronics OEMs should monitor the technology's improvements and look to form strategic partners to stay ahead of the competition.

Business Impact: Lensless cameras will allow IoT products to adopt multiple lensless cameras to collect detailed information about depth and visible/invisible light at low cost. In addition, no further weight will be added, because the camera doesn't have a lens. These cameras can be used in security or disaster relief applications that employ cameras as sensors, such as cars, drones or household security systems.

Lensless cameras will benefit the medical industry and life sciences with their architecture of small form factor, inexpensive and lightweight designs. This will aid their usage in applications such as digital in-line holography, 3D fluorescence microscopy, and portable or in-vivo imaging. This will also decrease the pain that occurs during human body inspection and their applications in point-of-care diagnostics devices.

Today's smartphones are thinner than camera modules. Thus, they have camera bumps in the back. Smartphone OEMs will have more product design flexibility enabled by the small and thin form factor of lensless cameras

Lensless cameras can also be used for 3D photography, and recent research studies are also exploring their applications, such as in food safety and forensics. This is based on their ability to be tuned to capture a wide spectrum of wavelengths, including near-infrared and ultraviolet, and to reveal indications of materials, such as chemicals or microorganisms, and everything else that remains invisible to the naked eye.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Caltech; Harbin Institute of Technology; Hitachi; Rambus; Rice University; Tsinghua University of Shenzhen; University of California at Berkeley; University of Utah

Biodegradable Sensors

Analysis By: Michael Shanler

Definition: Biodegradable sensors are thin-film sensors manufactured using nontoxic materials that can go into common waste streams. The primary application is for microsensing for food monitoring. Some of these sensors are bioresorbable, meaning they can be ingested. Others are biocompatible, meaning they can be implanted into medical devices or pharmaceutical products before dissolving or harmlessly passing after ingestion.

Position and Adoption Speed Justification: This is a new Hype Cycle entry for 2020. Biodegradable sensors are a relatively old concept within academia, dating back to the 1950's, but few research institutions were able to manufacture and design them for the right price points for use in products at scale until recently. Over the last five years, multiple research institutions in Switzerland, the U.S., the U.K., Japan and Korea have pushed biodegradable sensors to the point where they are ready for industry use. Leveraging advanced design and simulation principles, polymer science, and green technologies made this advance possible.

Today, biodegradable sensors can be designed to perform a variety of specific functions. They operate as detectors for changes to pH, humidity, oxidization, gasses, glucose, antibodies, and chemicals. Others are manufactured as RFID tags — with carbon electrodes printed on paper. Some circuits are printed to be used as repeaters for both active and passive sensor technology. These sensors are often manufactured by embedding chips or sandwiching sensors in between thin-film polylactic acid (PLA) or dissolvable silicon, and are produced using corn and potato starch. PLA and related biofilm and green plastics are harmless and biodegrade over time. Compositions comply with U.S. and EU food legislation and label requirements.

The sensors embedded into the material may not be fully biodegradable, but they are designed using nontoxic materials that can exist within the human body at low levels, even when accumulating over time (such as molybdenum, magnesium, zinc, silicon dioxide and nitride). Some use RFID-related technologies. Others are powered by the substrate or products in which they are embedded. The sensors often can operate for a few weeks before eroding. They are designed to go to waste in traditional landfills. Most of these sensor formats are smaller than a grain of rice; however, research organizations are actively miniaturizing them even further.

Gartner has observed several prototypes at companies and some initial use cases, but beyond small commercial offerings (such as Proteus Digital Health), the technology has yet to be scaled to the masses. These sensors have a lot of potential to change the way food, retail and medical devices are monitored and used; however, we only envision success for when used at scale when manufacturers hit the right price points and margins.

This is a newly commercialized technology by a handful of vendors; thus, Gartner places this embryonic technology in the Innovation Trigger phase.

User Advice: Evaluate the advantage of biodegradable sensors and how they may dovetail with smart product or Internet of Things (IoT)-enabled product strategies. Drivers could be product quality, tracing, authenticity or performance. CIOs must also plan building in the IoT data ingestion and analytics capabilities required to deliver business value from sensors. Specifically:

- CIOs and CTOs in the food and beverage, consumer, and retail industries should evaluate using these sensors for tracking product quality "use by dates," locations, unique identifiers and performance (such as pH, oxidation, taste and degradation) of fruits, meats, grains and vegetables. This activity must also include potential impacts on product margins and the cost of goods sold. These sensors can be affixed to the inside of outer packaging (cereal boxes), affixed to product labels (such as biocompatible RFID stickers on premium apples) or even embedded into the products themselves (inside ground beef).
- CIOs and CTOs in the healthcare and life science space should evaluate bioabsorbable and biocompatible iterations for the IoT and sensing potential for both drugs and devices. CIOs and technology leaders must evaluate the sensors while accounting for the downstream device regulatory requirements (for example, 510K class I, II, and III submission) and determine what is required to put them into production.

Before investing, life science companies must outline with a clear vision what is required to make these sensors work in their highly regulated manufacturing, supply chain and distribution channels. Teams must determine where new policy, systems and business processes are needed to support serialization, unique identifiers and safety systems. They also must determine early on whether the sensors are considered part of software as a medical device, companion device and/or digital therapeutics.

Business Impact: These sensors can add data to augment the customer or distribution channel, and have effects on smart supply and logistics, with added capabilities for measuring real-time physical, chemical and biologic functions.

These sensors could help streamline the product life cycle and provide data for location, serialization, product quality, tampering and product performance. There will be useful benefits from combining sensor data with informatics and operational systems for R&D, quality, regulatory, manufacturing and supply chain, or other specialized areas (such as clinical, diagnostics and safety). Specifically, these sensors can dovetail with smart products, IoT analytics and sensor-enabled business models. These sensors can also be used to support smart manufacturing, as well as adaptive supply chains and distribution channels.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: c2renew; EPFL; ETH Zurich; Grolltex; imec; Murata; NanoScale Systems; Proteus Digital Health

Recommended Reading: "Top Consumer Food and Beverage Trends for 2020"

"Major Consumer Value Shifts Driving Marketing Changes in the Food and Beverage Industry"

"Scaling Digital Commerce Into a Digital Platform Business"

"The Gartner Supply Chain Top 25 for 2019"

Smart Dust

Analysis By: George Brocklehurst

Definition: Smart dust is a type of distributed sense and control network, consisting of self-contained "motes," targeting a volume of less than 1 cubic millimeter. These motes have the capability to sense, compute, communicate and power their own activities. They support a distributed sensing network, such as temperature, pressure, movement and humidity sensing, using mesh networking to achieve communication coverage.

Position and Adoption Speed Justification: The aspired size of these motes presents two key challenges, in power and communication. Self-powering motes using energy harvesting will be key in reaching the full potential of smart dust, but their small size limits the energy that can be recovered and stored. Similarly, RF communications face power as well as transmission range challenges due to the tiny antennae. Smart dust proponents have embraced these limitations by finding high value use cases that value size over connectivity range.

We witnessed an activity peak when IBM (in March 2018) announced a 1m3 x86 equivalent mote with applications in supply chain tracking supported through block chain. Two months later, University of Michigan announced a 0.03m3 precision temperature monitoring mote with medical applications including tumor monitoring. One month later MIT announced a graphene-enabled 0.01m3 mote grafted onto a colloid particle for diagnostic journeys through anything from human digestive systems to oil and gas pipelines.

In terms of commercialization, CubeWorks, a University of Michigan spin out has established three products ranging in size and capability. They have focused on high value use cases addressing environmental and security monitoring as well as applications in pharmaceutical and biomedical science. While these solutions are larger than 1 mm3, ranging from 14 mm3 up to 1.6 cm3, they are a significant step forward in understanding the challenges of productizing smart dust.

While most of the announcements still come from lab-based research we are seeing signs of early commercialization and Gartner expects this to grow over the next one to two years. Initial routes to market are fairly modest but they pave the way for the more transformational applications of the technology to come. Consequently, this innovation profile takes another step up the Peak of Inflated Expectations.

User Advice: Research into smart dust should be viewed as a vehicle for innovations that will also benefit other operational and market activities. Most near-term return on investments will come from commercialization of these innovations, including transfer to the somewhat larger IoT endpoint technologies.

- Smart dust is embryonic and should be tracked within innovation teams. Tracking should examine both smart dust research activity and trajectories of the associated technologies within industry.
- Lead adopters should consider taking equity stakes in university commercialization efforts. Early successes and adjacent commercialization opportunities will be enabled by hardware innovations where IP protection will create barriers.
- Consideration must be given to the complexity of mass data communication and processing. The density of wirelessly communicating things will present new challenges in cross-channel interference and coordinated transmissions that will require new protocols and techniques to address possibly the use of biologically inspired algorithms (for example., swarm research).
- Motes have limited communication range and processing so gateway architecture — how to collect and aggregate data — is critical to scale.

IoT use-case characteristics that benefit from emerging products are applications that need:

- Very high sensor density over a small area.
- Very tiny sensors that are either covert or don't disrupt a sensitive process
- Migratory sensors, for example, in liquid flows.

Which can also accept:

- Very short range communications.
- Fairly simple processing and somewhat limited data storage in each node.

Business Impact: The potential benefits of smart dust are wide-ranging, compelling and transformational extending the Internet of Things' "situational awareness." The concept of this technology transitions the Internet of Things into the Internet of Everything, which carries profound implications for the architecture of collecting, processing and interpreting data. A world with widespread adoption of smart dust will require radical innovations in all the systems that would convert captured data into some useful action. A further generational step, with innovations such as neural dust, will transform the way humans interact with their surroundings, emerging initially through medical advancements, such as prosthetic control, and then into broader possibilities.

In the medium term, the breakthroughs from pursuing this research will also have high impact and will help the IoT to meet its potential for lowering cost and power while increasing local processing and endpoint intelligence.

Equal to smart dust's transformational potential are its legal, ethical, security and privacy ramifications.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Cornell University; CubeWorks; EPIC Semiconductor; HP Inc.; IBM; MonoLets; University of California; University of Michigan

Emotion AI

Analysis By: Annette Zimmermann

Definition: Emotion artificial intelligence (AI) technologies (also called affective computing) use AI to analyze the emotional state of a user (via computer vision, audio/voice input, sensors and/or software logic). It can initiate responses by performing specific, personalized actions to fit the mood of the customer.

Position and Adoption Speed Justification: One of the benefits of detecting emotions/states is for a system to act more sympathetically. It creates anthropomorphic qualities for personal assistant robots (PARs), making them appear more “human.” This “emotional capability” is an important element in enhancing the communication and interaction between users and a PAR. People’s daily behavior, communication and decisions are based on emotions — our nonverbal responses in a one-on-one communication are an inseparable element from our dialogues and need to be considered in the human-machine interface (HMI) concept.

The first step in detecting human emotions is to define the different types of emotions, from angry, sad, happy and insecure. AI is a critical part of some, although not all, emotion AI solutions. Computer vision (CV)-based emotion AI requires a collection of imaging/video data and preparing it to be fed into an artificial neural network (ANN). Vendors using CV technology to detect emotions primarily apply convolutional neural networks (CNNs), a deep-learning technique.

Several new commercial deployments occurred in 2019 for emotion AI and new vendors entered the market. At the same time, we did not see any evidence for great advancements in technological capabilities. Therefore, the position of this profile on the Hype Cycle was stagnant.

There are several vendors, including Beyond Verbal, audEERING and Intelligent Voice, that have developed emotion AI systems based on audio analysis. Phonetic attributes and the understanding of words do not play a primary role here, and the most sophisticated systems are completely language-agnostic, including tonal languages. Vendors have developed algorithms that attribute the different pieces of sound waves to emotional states. The main type of neural networks (NNs) used for audio-based emotion AI are recurrent neural networks (RNNs).

Data quality (lab-based versus real-life data) and machine learning (ML) techniques determine the reliability of the technology to detect emotions. The better the data and the more data there is, the higher the probability of detecting different nuances of human emotions. Combinations of CV-based, audio-based and sensor-supported technologies make sense in certain use cases, but is not always required to gain a better result.

User Advice: As the market is currently very immature, most vendors are focused on two or three use cases in two or three industries. Hence, when selecting a vendor, it is important to review their capabilities and reference cases. As discussed above, the context and environment of the use case will determine the type of emotion AI to be used. Organizations should make lists of use cases that apply to them.

- Be use-case-driven. The use case will determine the emotion AI technology to be used and vendor selection.
- Appoint responsibility for data privacy in your organization, a chief data privacy officer or equivalent.
- Work with your vendor on change management in order to avoid user backlash due to sensitive data being collected.

At the same time, identifying and processing human emotion is currently a gray area, especially in the EU. The EU Commission has started an initiative to review the ethical aspects of AI technologies, and emotion AI will certainly be part of this debate.

Business Impact: Emotion AI technologies have already been adopted by various business functions in different industries, including call centers, PARs and high-end cars. CV-based emotion AI has already been used for more than a decade in market research — testing how consumers react to products and commercials. For about two years, many vendors have moved into completely new industries and use cases such as automotive, robotics, medical diagnostics, education and the public sector.

- Insurance companies are using audio-based emotion AI for fraud detection.
- In call centers, voice-based emotion AI can be used for intelligent routing for a better customer experience.
- Software exists that helps physicians with diagnosing depression and dementia.
- Dubai's Road and Transport Authority (RTA) announced the use of CV-based emotion recognition in four of its "customer happiness centers." When the "happiness level" among visitors drops below a certain threshold (maybe due to long queues) employees are notified and can act upon it.
- Inside the car, audio and CV-based emotion AI helps to understand what is going on and detects whether passengers are emotionally distracted.
- In retail, stores are adopting camera-based facial and emotional recognition to understand demographics and moods of visitors, enhancing the retail experience. Similar trends are emerging in the hospitality industry (in hotel lobbies) where cameras are used to recognize frequent guests and recognize their emotions.
- In education, we have seen prototypes of learning software that adapts to the user's emotional state. Another opportunity is in training and workshops, where emotions of the training participants are captured to see how they are experiencing the training.

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: audEERING; Affectiva; Behavioral Signals; Eyeris; Google; Intelligent Voice; Microsoft; Voicesense

Recommended Reading: “Competitive Landscape: Emotion AI Technologies, Worldwide”

“Competitive Landscape: Customer Analytics”

Conductive and Contactless EEG Devices

Analysis By: Annette Jump

Definition: Electroencephalography is a technology used to monitor and record brain activity. An EEG cap is typically worn requiring electrical conductivity with the skin, usually with the application of a conducting gel. Contactless EEG electrodes do not require electrical conductivity with the skin and can be integrated in a cap or in close proximity with the head. These devices, when used for brain-machine interfaces, typically are employed for simple feature selection, and some exploratory use cases include navigation of more complex software controls.

Position and Adoption Speed Justification: EEG devices have diversified from lab-only EEG caps with visible electrode wiring requiring electromagnetic conductivity with the wearer’s skin, to headbands and other form-factors using contactless electrodes sensors marketed for nonmedical use. Contactless electrode EEG devices have a variety of experimental form factors such as the more traditional cap and head-mounted products, to headrests or other close proximity form factors.

Medical and research based applications of EEG technology for temporal resolution (when brain activity occurs) is well founded, but spatial resolution (where the signal occurs) is much more limited than other techniques such as FMRI. EEG offers milisecond accuracy of activity, with a general regional view of where the activity occurred. FMRI while providing accurate spatial data provides results after a few seconds. Outside of medical research there is rudimentary understanding and use for EEG signals today. The technology remains in the prepeak area, but the position has changed due to the inclusion of contactless EEG in 2020 (which is even more emerging versus conductive EEG).

Potentially, the largest market for contactless EEG devices is healthcare and consumer wellness, especially using EEG headbands to help maintain a desired mental state during meditation or while relaxing. However, the value proposition is not strong enough for mass-consumer adoption. Other more advanced use cases will be for BMI interfaces and ability to control devices and things in real and digital world with brain waves (thoughts). The research is currently expanding beyond only reading brain activity, as DARPA who has been a long term investor in brainwave technology and is currently funding noncontact research that can both read from and write to the brain.

For now, any head-mounted EEG form factors (conductive electrodes with gels, or nonconductive electrodes) presents a challenge to use and adoption, these devices are difficult to set up (for a variety of practical and scientific reasons — such as the use of gels and environment-specific electro interference) and generally are uncomfortable to wear. We expect contactless electrode EEG devices to be integrated into more user-friendly form factors such as helmets, headbands and caps to support more mainstream adoption.

User Advice: EEGs are used to collect temporal data of the brain and in combination with the real intelligence of software to convert EEG data into relevant information, for example to understand a wearer's current state of health/alertness or a reaction toward a product or service. The use of EEG data has moved into business organizations in recent years, with applications in market research, healthcare, remote health monitoring and safe worker environments. Various form factors are commercially available from different vendors such as SmartCap Tech and EMOTIV.

- CTOs and COOs should explore how the use of EEG-based solutions can prevent or reduce serious errors, accidents and injuries for employees working in hazardous environments. For example, EEG data may be more useful to detect the onset of drowsiness, reducing the ability to focus, than alternative methods that include monitoring eyelid motion with cameras and changes in respiration or heart rate. SmartCap's solution triggers alerts based on EEG data to prevent microsleeps for mining workers, for example, when they reach a certain fatigue level. Employers are unsure what legal responsibility they will have to remove a worker from a task if they have drowsiness data.
- Product marketers should investigate how EEG solutions can be used for complementary studies to dig deeper into consumer attitudes. It is also worth exploring current use case of EEG solutions for gaming that are currently revolutionalizing gaming inputs and interactivity; such as playing and controlling the game where the user only needs their mind. This application in gaming can be an indication of other possible consumer use cases for the future.
- Consider the practical drawbacks versus reward of implementation EEG solutions: EEG solutions are helping people improve their ability to concentrate on tasks for greater productivity, or helping people with attention deficit hyperactivity disorders to practice concentration through biofeedback, music and games that use input from EEG devices. However, the social hurdles of wearing a device on the head in an office setting or in the classroom are likely to curb adoption outside of the home.

Business Impact: Mining, healthcare, transportation and manufacturing are areas where this technology can be applied in the safe-worker context. Main user-related challenges to adoption revolve around user hesitation to adopt such a device, especially when worn for eight or more hours. However, users may feel uncomfortable about employers collecting and using this personal data. EEG monitors can also be used for medical applications, such as neurorehabilitation for physically disabled people (for instance, paralyzed patients and amputees) and patients with brain injuries (like stroke patients).

In the context of measuring attitude, any consumer goods organization wanting to understand product or brand attitude, or wanting to enhance CRM, the technology can be applied in laboratory research as well as real-life situations, for example, call centers. For market research applications, vendors can differentiate between several states of mind, including excitement, interest, stress and boredom, to understand users' reactions toward products or services. The vendor EMOTIV captures EEG data, along with facial expressions via computer vision technologies, by analyzing movement of the eye and specific muscle groups, which, in combination, can be used for better results or translated into nonverbal commands.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: BrainCo; EMOTIV; InteraXon; Myndlift; Neuralink; Neuroelectrics; SmartCap Tech

Recommended Reading: "Hype Cycle for Sensing Technologies, 2019"

"Maverick* Research: Mass Adoption of Brain-Monitoring and -Altering Wearables Creates Risk of Mind Control"

"Emerging Technologies: Combinatorial Digital Innovation Delivers Product and Service Leadership"

Quantum Sensor

Analysis By: Anushree Verma

Definition: A quantum sensor is composed of two parts, the sensitive component that generates the signal and the auxiliary device that processes the signal. Quantum sensors are used to measure PAR (photosynthetically active radiation), which measures light in the range of 400 nm to 700 nm. This range typically corresponds to the range visible to the human eye.

Position and Adoption Speed Justification: Quantum sensors have been around for a decade, but advancement has been relatively slow. The field is expected to provide new opportunities due to its sensitivity and precision in various fields like medical and healthcare, industrial applications or enhancing positioning capabilities in autonomous cars.

Quantum sensors are capable of providing highly accurate information and can sustain in extreme climatic conditions, this should cause the global quantum sensors market to gain traction.

There have been some advancements (thereby moving up in this Hype Cycle) in Quantum sensors using Rydberg atoms in measuring radio frequency (RF), terahertz electric fields, millimeter-wave, among others, for communication equipment in military. Rydberg atoms could offer higher sensitivity than generally used electro-optic crystals and dipole antenna-coupled passive electronics, although this is still immature.

User Advice: Vendors in this field and ones looking to use quantum sensors must try to keep themselves up to date with the advancements in this technology and potential new opportunities.

They must exploit the fact that quantum mechanics can enhance the precise sensitivity of a device beyond the classical or conventional shot noise limit in areas such as:

- Food safety analysis: Quantum-based sensing technologies are used in the detection of food contaminants, including pathogen detection, pesticides, toxic elements, antibiotic and metal contaminants.
- Environmental monitoring: Quantum-enhanced sensors are the ideal candidate for the environmental pollution monitoring in a precise, authentic, real-time and sensitive manner.
- Communications receiver: Rydberg-atoms-based quantum sensing offer higher sensitivity and can detect entire radio frequency spectrum, from 0 to 100 GHz enabling detection of RF signals for geolocation.

Business Impact: A quantum sensor exploits quantum correlations like quantum entanglement to achieve better sensitivity or resolution than conventional systems, which can have a positive market impact if exploited. A new quantum sensor developed by researchers has proven it can outperform existing technologies and promises significant advancements in long-range 3D imaging and monitoring the success of cancer treatments. The sensors are the first of their kind and are based on semiconductor nanowires that can detect single particles of light with high timing resolution, speed and efficiency over an unparalleled wavelength range, from ultraviolet to near infrared.

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: ADVA; Apogee Instruments; LI-COR Biosciences; Rydberg Technologies; Skye Instruments; Spectrum Technologies

5G Position Sensing

Analysis By: Nick Jones

Definition: Future releases of the 5G cellular standard are intended to support location sensing, initially to around 3M accuracy indoors and 10M outdoors in Third Generation Partnership Project (3GPP) Release 16, with further precision improvements planned in the longer term.

Position and Adoption Speed Justification: A key goal of the Third Generation Partnership Project (3GPP) standard for 5G telecommunications is to enable the network to sense the location of connected devices. The next release of 5G (Release 16, also known as R16) has a goal of achieving approximately 3M precision indoors and 10M outdoors, in the longer-term Release 17 (R17) intends to improve this to approximately 1M indoors and 3M outdoors. In 2020, the R16 standard is still under development with the earliest deployments of R16 equipment likely to start in 2021 and R17 around 2023. However, actual deployment dates will depend on individual cellular's operator decisions, and, in some regions, R16 may not be available for several years. Also, the achievable precision is likely to vary, depending on which frequency bands each operator owns, the type of network equipment they deploy, and the geographic layout of their network. Maturity will also be driven by national regulators requiring better network location for emergency call handling.

User Advice: Precise location information provided by the cellular network is attractive. It will be available indoors and out, it won't require the organization to install location tracking infrastructure and it doesn't require the client device to have any additional components, beyond its wireless module. Network-based location hardware has the potential to be less expensive and use less battery power than GPS, offering the potential for low-cost tracking devices that can sense and report on their location using few components. Organizations contemplating private 5G R16 networks for low-latency sensing and control purposes are likely to benefit from location-sensing integrated with the network. In 2020, all 5G location tracking consists of prestandard experimental deployments.

However, 5G location sensing is unproven, because it won't be available until R16 networks are deployed, which is likely to happen most rapidly in parts of the Asia/Pacific (APAC) region and Europe starting around 2021. However, this might not occur for five years or more in parts of Africa, where operators have less need for 5G. As noted above, many factors could affect the actual (as opposed to theoretical) precision. The best results are likely to be obtained on private networks, where frequency bands, equipment and network design can be optimized for the task.

In 2020, it's uncertain how operators will charge for future 5G location information, and how issues such as privacy and General Data Protection Regulation (GDPR) compliance will be managed.

Business Impact: When 5G location sensing becomes widely available, organizations likely to benefit include:

- Large campus sites, such as industrial manufacturing plants, ports, airports and process plants that install private 5G networks and have mobile assets to track (for example, on-site vehicles and drones, robots and members of staff).
- Companies that need nationwide, medium-precision tracking, with seamless indoor and outdoor coverage (for example, logistics companies tracking parcels or shipments).
- Vendors that want to create low-cost tracking devices and services with good battery life and nationwide coverage (such as for asset tracking, pet tracking or anti-theft purposes).
- Emergency services that need more-precise position information about 911 calls from mobile devices.

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Sample Vendors: Ericsson; Huawei

Recommended Reading: “Unlock the Innovation Potential of Future Location-Sensing Technologies”

“Innovation Opportunities Will Be Enabled as 5G Evolves Through 2025”

At the Peak

Smart Fabric

Analysis By: Nick Jones

Definition: Smart fabrics are woven materials that, at a minimum, integrate conductors and sensors. Advanced smart fabrics might also include displays, power generation/harvesting and haptic actuators. Smart fabrics can sense and report on the user and his or her environment and, in some cases, implement user interface (UI) components, communicate with the user and display information. Smart fabrics are also finding applications beyond clothing — in furniture, medical, and automotive areas, for example.

Position and Adoption Speed Justification: Smart fabrics blend electronic and textile technologies, such as printed conductors, woven conductors, thread sensors, flexible solar cells, LEDs and a wide variety of electronics, in small-enough form factors to be integrated into garments and textile products. A few smart-fabric technologies are commercially available, if rather niche. Many are still the subject of academic research. Challenges involve robustness, washability, cost, flexible batteries to supply power to fabric and garments, networking, and communications.

User Advice: Smart fabrics tend to find applications when an existing fabric or flexible product can be enhanced with sensing, active behavior or user experience capabilities. Examples include clothing, furniture, bedding and similar fabric products. We've also seen alliances between personal electronics manufacturers and garment manufacturers — for instance, to integrate control interfaces for electronic devices into garments or to add sensing (for example, for sports analytics). However, many of the applications in 2020 are rather niche and expensive, usually high-value premium products or professional medical applications. The wide range of technologies falling into the smart-fabric category means that different products and applications may have very different levels of maturity. Smart-fabric technologies will evolve relatively slowly through 2030.

Many of the biometric sensors integrated into smart fabrics are adequate for noncritical monitoring, but are not medical-grade products approved for use in treatment programs.

Business Impact: Examples of areas in which smart fabric can be successful include markets that are price-insensitive or applications in which the extra value justifies the relatively high cost, including:

- Fashion products, such as garments with integrated displays, or UIs to control consumer electronics, such as smartphones
- Sportswear with integrated biometric monitoring, clothes that monitor UV exposure or running shoe insoles (such as ambiotex cycling garments)
- Medical and healthcare products, such as baby monitors, smart mattresses, smart socks that monitor gait and bandages that monitor wound compression

- Military applications for sensing injury, or clothes that generate electricity to recharge soldier's equipment
- Smart furniture with integrated UIs to control home equipment

Makers and hobbyists have used smart-fabric principles to create innovative experimental products. Most smart fabric applications are novel products, but often in areas where there are alternative ways to achieve the same goals. We rate the benefit of the technology as generally moderate.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: adidas; ambiotex; CuteCircuit; Google (Jacquard); Xenoma

Electrovibration

Analysis By: Roberta Cozza

Definition: Electrovibration is a haptic technology based on an effect in which touch receptors in the skin can be duped into perceiving texture. Differing voltages and frequencies can create the illusion of different surface textures, simulate the feeling of localized vibration and friction, mimicking shapes, contours (such as the feel of a keyboard key or button) on touchscreens. A periodic electrostatic force is created that "deforms" the skin on the fingers.

Position and Adoption Speed Justification: At present, developments are happening slowly and remain mainly in labs this is why despite all the effort mentioned below the technology has not moved faster along the Hype Cycle. More research is being done around multitouch vibration. In addition, alternative technologies, such as ultrahaptics that use ultrasound to create the sensation of touch, are grabbing technology investor attention as vendors drive more personalization in their offerings.

Many research groups have developed different electrovibration techniques to enhance the touch display experience with tactile sensation. The most notable comes from researchers at Disney Research in the U.S. and the University of Paris-Sud, France, all of which have used and developed an existing electrovibration technique called electrostatic vibration. Finnish company Senseg (acquired by OFILM) generates tactile feedback by using a solution that charges a conductive film on a touch panel to create an electric field that causes vibration on the skin. This solution is based on independent tactile elements (tixels) providing localized sensations, specifically, different textures for each finger or different areas of a surface.

More recently, researchers from the Korea Electronics and Telecommunications Research Institute have developed a display solution delivering glass-free 3D visuals with electrovibration for a touch experience in museum applications where users have the illusion of touching the artifact. Electrovibration has also been prototyped for styluses to replicate the sensory touch experience of a real pen on paper. More research has been done for example by Go Touch VR to create electrostatic vibrations for 3D surfaces in VR applications to convey a realistic sensation of object touch or grasp.

User Advice: Touch interfaces are a key element driving rich user experiences across immersive technology scenarios and touch device categories. Manufacturers of consumer electronics and touch devices or wearables should explore the opportunities provided by electrovibration techniques for new forms of tactile feedback, touchscreens and other surface types. They should explore this technology to enable realistic sensations in VR or mixed reality applications to differentiate and enhance user experiences.

Business Impact: On-screen touch experiences are becoming more complex. More focus on mobile devices has enabled new touch interactions with pressure-sensing technology, such as Apple's 3D Touch. Mechanical solutions are limited in their ability to differentiate and provide rich experiences based on multitouch and new gestures. Electrovibration solutions can considerably enhance the touch feedback currently delivered by mechanical vibration, which uses moving parts that wear out over time and has motors that drain battery life, generate noise and cause excessive vibration of the entire device.

Electrovibration solutions could greatly affect the way users interact with touch interfaces and screens on tablets, smartphones, handheld gaming devices, 3D surfaces in VR, advanced in-vehicle controls, and other consumer and industrial products.

Different levels of simulated friction can augment the manipulation of icons, files and other "draggable" items in drawing/painting applications. For example, in the TeslaTouch experiment, various levels of friction were associated with file size when files were dragged to a folder or when items needed to be aligned.

Different textures can be applied to virtual objects, and applications can be implemented for blind or visually impaired consumers (current touchscreens still largely require users to locate objects visually on the screen).

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: Disney Research; OFILM

Recommended Reading: "Top 10 User Experience Technologies That Will Drive Innovation"

"Plan Your Hardware Product Roadmap Around Top 5 UX Trends and Technologies"

Ambient Radio Monitoring

Analysis By: Bill Ray

Definition: Ambient radio monitoring is environmental monitoring through detailed analysis of reflected and absorbed ambient radio signals. Mostly demonstrated with Wi-Fi, ambient radio monitoring can be used to detect people (including fall detection) through walls and buildings, without compromising privacy.

Position and Adoption Speed Justification: Early demonstrations from MIT were followed, in 2018, by a system that can track people through a partition wall without using a dedicated radio transmitter. In 2019, the first mass-market product was launched by Belkin International (branded Linksys Aware), providing basic motion sensing by analyzing disturbance in the Wi-Fi mesh network, for a monthly subscription. In 2020, this capability was extended to in-vehicle Wi-Fi — the resolution remains low but body forms and movement can be recognized, and it should be possible to identify types of traffic (pedestrians, cars and so on).

More advanced systems, including fall detection and gesture recognition (such as using a pointing gesture to turn lights on), remain under development. Commercial products are now available from companies such as Origin Wireless AI and XANDEM, with the former increasing resolution to the point where it can establish if people are breathing properly from small movements. Future systems will offer increased accuracy and greater integration with existing Wi-Fi infrastructure. Competition comes from mmWave radar systems and video analysis.

With half a dozen companies marketing ambient radio monitoring systems, the technology is quickly scaling the Peak of Inflated Expectations, though mainstream adoption is still more than two years off.

User Advice: In many markets (such as the U.S. and South Africa), home security offers high revenue potential, and existing CSPs are keen to enter that market, as well as differentiate their offerings. By providing a Wi-Fi access point that is compatible with specific ambient sensors, the CSP can offer a degree of customer lock-in that will be attractive. End users may be reluctant to place cameras around their homes, particularly when those cameras are connected to a cloud-based security system, but a system based on ambient radio signals is often more acceptable.

Those building Wi-Fi infrastructure should test access points with popular sensors and consider if a partnership with one of the companies pioneering the space would be valuable. Public Wi-Fi operators should consider if ambient radio monitoring could provide value-added information on traffic flow or enhanced security.

Business Impact: Ambient radio monitoring can provide security monitoring of both public and private spaces with minimal privacy concerns. Initial deployments are targeted at home security and elder monitoring (specifically fall detection), and the acceptability of ambient radio monitoring in a private home (when compared with cameras) should not be underestimated. Ambient radio monitoring is unlikely to supplant camera systems, as it can't offer the resolution or human readability of visible light systems, but it will expand into niche applications.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: Belkin International; Cognitive Systems; Origin Wireless AI

Recommended Reading: "Competitive Landscape: Outdoor Mapping and Location Services"

"3 Critical Technologies for In-Store Customer Tracking That Tech CEOs Need to Exploit"

Galvanic Skin Response Devices

Analysis By: Anshul Gupta; Roberta Cozza

Definition: A galvanic skin response (GSR) device, also known as electrodermal activity (EDA), is used to measure electrical conductivity of the skin to help understand a user's physiological and psychological condition. The electrophysiological signal is generated by the sweat glands, and sweat may cause measurable variations in conductivity and resistance, though vascular dilatation and constriction may also contribute. These sensors differ from perspiration analysis patches, which use different hardware and are exclusively focused on sweat analysis.

Position and Adoption Speed Justification: GSR sensors alone can only track emotional arousal but tracking degree of emotions or quality of emotion requires combination with other complementary technologies like electroencephalography (EEG), electrocardiogram (ECG), electromyographic (EMG) sensors, audio and video sensors. New use cases beyond emotion tracking, lie detection and facial expression are possible with the integration of GSR sensors with other technologies. Fatigue and stress levels can be measured by integrating GSR sensors with heart rate, temperature and respiration rate sensors. Similarly, integrating with audio- and video-based emotion tracking sensors will help measure effectiveness of marketing campaigns.

Though GSR sensor's size continues to contract, their adoption in the mobile and wearable devices remains limited due to reluctance to use multiple sensors and lack of general purpose use case. GSR sensor as a technology continues to evolve but struggles to match user's expectations leading to limited adoption.

User Advice: GSR sensors evolved from two electrode form factors to small sensors easily integrated into a small form-factor-like ring to bring new use cases supporting more natural, mobile and wireless applications. However, need of a combination of sensors to build effective use cases adds challenge of integrating data and interpretation. Multimodel technology solution also raises costs and impacts device size expectation in case of wearable devices. GSR sensors measure skin conductivity so effectiveness is dependent on placing sensors on the tip of fingers, between the fingers, palm or bottom of the feet.

Business Impact: Given the placement of GSR sensors, requirement of multimodel technology, their applications or uses cases are more in the areas of health related benefits, treating patients and assistive care. However, a GSR-sensor-equipped device will also find use cases in the areas of emergency services, professional sports and public transportation. GSR-sensor-equipped devices could be used within healthcare to monitor and treat patients suffering from trauma, depression, phobia or mental health problems. Understanding what causes a person to feel happy or sad can be used during treatment or aftercare. GSR sensor equipped devices can be used monitor, manage and prevent epileptic seizures.

GSR sensor equipped devices could also find use cases for emergency responders, fire personnel and police/law enforcement officers to enhance performance and safety. Employees working within public transportation, such as airlines, trains and buses, could also use GSR sensor equipped devices to be alerted for stress and fatigue levels to better serve and maintain public safety. Similarly, GSR sensors can be used to monitor stress, fatigue and performance in professional athletes. Other use cases include tracking of emotional responses to assess interactions with consumer product for marketing, usability testing purposes.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: Empatica; Mindfield Biosystems; Moodmetric; NeuLog; Sentio Solutions; Shimmer

Recommended Reading: "Market Trends: How AI and Affective Computing Deliver More Personalized Interactions With Devices"

"Competitive Landscape: Emotion AI Technologies, Worldwide"

Electromyography Wearables

Analysis By: Roberta Cozza

Definition: Electromyography (EMG) wearables refer to devices equipped with electromyographic sensors that measure muscle activity. Muscular contraction generates electrical signals that can be measured from the skin surface with sensors placed on a single part or multiple parts of the body. This information is analyzed and shown in an application that can provide real-time feedback and recommendations around muscle activity, fatigue or coordination.

Position and Adoption Speed Justification: EMG has been used extensively by medical experts and exercise physiologists. Some wearable categories, such as smart garments, have seen the inclusion of EMG sensors to complement the ever-growing interest in biosensing data monitoring. The EMG wearables segment has moved further along the Peak of Inflated Expectations given the increased availability of commercial products, most for medical applications. However, adoption of EMG wearables remains limited because they still appeal to a niche user base.

EMG sensors have been implemented in a number of smart garments — from vendors such as Athos and Myontec — that help focus training in the right zones of the user's body, avoid injury and optimize workouts. Acceptance in the EMG wearables market will be greatly helped by advances in design and size for greater wearability and comfort, as well as by more integration with smart coaching feedback and personalized analytics. Myontec is offering for example an analytics service to enterprises (ErgoAnalysis) which aims at improving performance and well-being for workers in industrial settings by analyzing and advising on physical load via special smart fabrics.

One of the most active areas of applications is in the medical space in conjunction with prosthetics or assisted living; for example, companies such as Ottobock commercialize myoelectric prosthetic wearable hands for amputees. Products, such as Control Bionics' NeuroNode Systems, offer assistive wearables that use EMG sensors to provide a communication system to physically impaired patients with conditions such as ALS, cerebral palsy or spinal cord injuries.

Beyond fitness, sport, health and medical applications, we also see EMG sensors used in wearables to enable control of computing devices and electronics as a novel hands-free UI proposition. EMG sensors from Advancer Technologies' MyoWare Muscle Sensor are commercialized with this purpose. EMG wearables for new UI experiences to control devices still need to prove their usability versus existing UI propositions, as many efforts remain experimental.

User Advice: EMG wearables can deliver value in smart garment applications, though adoption remains limited to elite and professional athletes and high-performance fitness enthusiasts. However, more adoption in healthcare to assist patients for example with severe disabilities or improve safety and performance of workers in vertical applications. When considering adopting EMG sensors in garments, focus on the quality of analytics and intelligence, as well as technology.

EMG wearables as alternative UI mechanisms to enrich interaction in gaming remain mainly in labs, as research groups investigate implementations in the emerging virtual reality (VR) gaming arena.

Business Impact: Dedicated EMG sensors in smart garments have an immediate impact on fitness and professional sport applications. EMG wearables are emerging as additional fitness, performance and healthcare devices to analyze efficiency of training; prevent injuries; improve training; and improve other fitness, sports, industrial and medical applications. The ability of EMG wearables to learn from specific user muscular activity to provide intelligent feedback will be a key value and differentiator factor.

The implementation of EMG sensors, in conjunction with prosthetics, can help amputees control bionic prostheses and provide more efficient gestures and movements. EMG also will provide hands-free UI mechanisms for future VR gaming or industrial applications.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Advancer Technologies; Athos; Myontec

Recommended Reading: "Create a Clear Vision for Your Digital Health Product"

"Plan Your Hardware Product Roadmap Around Top 5 UX Trends and Technologies"

Sliding Into the Trough

Bioacoustic Sensing

Analysis By: Roberta Cozza

Definition: Bioacoustic sensing captures natural acoustic conduction properties in the human body using different sensing technologies. Variations in bone density, size and the different filtering effects created by soft tissues and joints create distinct acoustic locations of signals, which are sensed, processed and classified by software.

Position and Adoption Speed Justification: This technology has been moved further along the Hype Cycle as it is featured now in a number of commercial wearable products, such as smart headphones, which exploit both muscle and bone conduction.

Already, bone conduction is present in clinical hearing aid devices and headphones used in vertical applications such as the military for field communications. Today, several consumer mainstream devices are available as commercial products featuring bone conduction, such as smartglasses with bone conduction speakers that enable users to receive calls or listen to music. Deed S.r.l. has developed a bone conduction solution where smartphone users can listen to calls by holding a fingertip to the ear, leveraging a wristband called GET that transmits audio from the phone to the user's forearm. Other examples of bone conduction are glasses from Zungle, DigiOptix, VocalSkull.

Bone conduction is mainly used today in a new wave of commercial headsets and earphones that transmit sound to the inner ear via the bones of the skull. This allows users to listen to music while still being able to hear their surroundings, leaving ears unobstructed. Examples of these are headphones from AfterShokz, WinnerGear, Sony and Panasonic. Another application is user authentication, for example the Huawei Free Buds 3 collect bioacoustic waveform to identify wearer to unlock the headset paired smartphone when user put them on.

Companies such as Otolith Labs are integrating bone conduction technology into VR HMDs to alleviate the sense of nausea typical in VR experiences. Another use is sound programs for sleep management wearables, such as headbands from companies like Dreem.

User Advice: Advances in this technology should be monitored and considered in consumer or vertical app scenarios where users can benefit from audible ambient sound and easily accessible or hands-free input, such as law enforcement, military field workers or for outdoor fitness.

Explore bioacoustic sensing technology to extend the UI mechanism for entertainment and gaming applications, virtual and augmented reality scenarios, or as novel ways to authenticate users.

Explore bioacoustic sensing technology for medical and healthcare applications where, for example, medical professionals need novel UIs that enable hands-free access to patient information.

Business Impact: Bone conduction has the potential to disrupt human interaction with devices, for example, by using the human body as an input surface. Unlike other external input devices, most interactions could be performed without looking at the surface of a device. When integrated in

VR/AR head-mounted display or smart helmets, it can improve communications and collaboration within teams in noisy harsh environments as information is exchanged, but ears remain uncovered and alert. Bioacoustic sensing technology and wearables enabling gesture recognition and control can impact a number of applications, such as gaming, and offer new ways of iteration with media and connected devices.

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: AfterShokz; Deed S.r.l.; DigiOptix; Huawei; Innomdle Lab; Zungle

Recommended Reading: "Plan Your Hardware Product Roadmap Around Top 5 UX Trends and Technologies"

"Top 10 User Experience Technologies That Will Drive Innovation"

"Top Five User Experience Technologies Tech CEOs Must Plan to Drive Innovation"

Solid-State 3D Flash Lidar

Analysis By: Masatsune Yamaji

Definition: Solid-state 3D flash lidars contain arrays of laser emitters and optical receivers. In principle, solid-state 3D flash lidar operates similar to a camera with a flash. Wherein, the laser lights emit from the lidar, spread into objects and surroundings, are captured by photo diode arrays or image sensors and are finally processed to form a 3D mapping point cloud using time-of-flight algorithm.

Position and Adoption Speed Justification: Solid-state 3D flash lidars have emerged to solve the cost, size and complexity issues of scanning lidars. Solid-state 3D flash lidars are semiconductor-based with no moving parts. The result is a small device, that is less complex to manufacture and is better packaged for mass production, thus improving yields and reducing costs. The critical issue with solid-state 3D flash lidars is the limited field of view (FOV) because it cannot rotate and scan the surroundings like a scanning-type lidar does. The solution for limited FOV is having multiple solid-state 3D flash lidars in a car, and this requires advanced and faster image processing capability.

Mechanical lidar is currently very expensive and the capability of mass production determines the cost. With many vendors developing solid-state 3D flash lidars, further improvements in scale will increase the yield rates, speed up mass production lead time and thus reduce costs. Therefore, over time it will be more affordable for mass market vehicles to have multiple solid-state 3D flash lidars. In addition, range with flash lidar is significantly shorter than the scanning lidar. Solid-state flash 3D lidar will be used with MEMS-based lidar to cover longer distance.

The position of solid-state 3D flash lidars on this Hype Cycle is moving towards maturity, Sliding Into the Trough because vendors are continuously improving performance with new releases; however, the size and cost have reduced over the past year.

User Advice: Automotive makers should include solid-state 3D flash lidars as part of their roadmap design because of the potential low cost and small form factor, which promotes better car designs. Automakers should understand that solid-state 3D flash lidars will not replace radar or cameras, but rather they complement each other with their advantages for better safety.

Service providers should identify business opportunities with solid-state 3D flash lidars vendors. For example, offering cloud-based processing and traffic data mining with 3D mapping point cloud data from solid-state lidars.

Business Impact: Solid-state 3D flash lidar enables vehicles' upgrade to a higher level of driving automation at affordable prices. In addition, the low cost and lightweight, solid-state 3D flash lidar has the potential to be widely adopted in manufacturing automation, logistics delivery and drones.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Advanced Scientific Concepts (ASC); Continental; LeddarTech; Oryx Vision; Ouster; Quanergy Systems

Recommended Reading: "Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

"Top 10 Strategic Technology Trends for 2020: Autonomous Things"

Distributed Fiber Optic Sensing

Analysis By: Nick Jones

Definition: Distributed fiber optic sensing (DFOS) measures the scattering of light in an optical fiber caused by temperature, strain or acoustic vibration, making the fiber itself a linear sensor. Changes in the sensed values generate different optical scattering patterns in the fiber, enabling continuous measurement of the sensed values at any point on a fiber, which can be several tens of kilometers long.

Position and Adoption Speed Justification: DFOS is well-adapted for creating long linear sensors, but is a relatively expensive and specialized technology that is predominantly used for monitoring physically large and expensive assets. Technology selection and installation are complex, requiring specialist contractors, and there are no significant standards. However, despite its cost and rather specialized nature, DFOS is able to perform sensing tasks that wouldn't be economically or technically possible with any other technology, so we expect its use to grow through 2030.

User Advice: Organizations should consider DFOS when they require temperature, strain or acoustic/vibration sensing over long distances on large linear assets, such as roads, power lines, pipelines, tunnels, railways or large structures, such as bridges. DFOS is also attractive, because it doesn't involve any electronics in the sensed region, As a result, it doesn't require power or connectivity to the sensed objects, so it is intrinsically safe. Because DFOS uses optical techniques, it isn't affected by electrical interference. Because the sensing element is a fiber optic, DFOS sensors are able to operate at high temperatures and can be made resistant to chemical corrosion. DFOS will be superior to alternatives, such as sensor networks, in situations where it provides lower installation and operation costs, compared with managing large numbers of distributed sensors.

Business Impact: DFOS is well-suited to applications in a wide range of engineering situations in which it's necessary to monitor physically large, and often linear, assets. It is also useful when deploying large numbers of individual sensors would be too costly or impractical, because of the nature of the asset or a lack of power or backhaul connectivity. Examples include:

- Perimeter security monitoring for intrusion detection
- Roadway monitoring of vibration and stress; traffic speed estimation from vibration monitoring
- Tunnels or mines (for example, to detect fire or ground movement)
- Oil wells, oil and gas pipelines
- Power cable monitoring
- Large-scale civil engineering structures, such as bridges, dams or other concrete constructions

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Sample Vendors: FemtoFiber Tec; OptaSense; Sensonic; Silixa

Recommended Reading: N/A

3D Sensing Cameras

Analysis By: Amy Teng; Rajeev Rajput

Definition: 3D sensing cameras capture depth information of objects and surroundings. There are various solutions including stereo vision with two cameras, structured-light solution, and time-of-flight (TOF).

Position and Adoption Speed Justification: 3D sensing cameras enable various use cases including gesture recognition as human-machine-interface, factory automation, automotive ADAS for safety, among others. Smartphones are the largest application segment as Apple brought this technology into smartphones for augmented reality (AR) activities and authentication. Chinese

OEMs and Samsung tend to place 3D sensing cameras on the back side of smartphones for picture quality enhancement and a wide variety of AR applications.

3D sensing cameras combined with increased resolutions of vision cameras and improved imaging processing power of smartphones, have enabled accurate object detection and spatial measurements. It enables innovations like virtual fitting that helps mobile consumers make decisions, 3D object measurements that can create a 3D model through physically scanning the object and then materializing it by 3D printing.

The fierce competition of the smartphone market has made smartphone OEMs introduce 3D sensing cameras as differentiations, the vertical integration of camera module supply chain have made cost of 3D sensing cameras more affordable for vendor adoption, as a result the market saw increased penetration during the past year.

Microsoft started shipping Azure Kinect DK in March 2020, Intel expanded RealSense depth camera family by adding LiDAR Camera L515 in April 2020. With these vendor products, we expect to see more AR/MR and autonomous applications in the commercial market.

Some home appliances, like robot vacuums, have adopted 3D sensing cameras for obstacle detection and avoidance. The adoption of 3D sensing cameras in cars is complex concerning critical requirements for safety and reliability, regulations and evolution of autonomous vehicles. Currently the one-vision camera solution with a mm wave radar is the major technology used in 3D sensing in cars. LiDAR will be used with vision cameras to provide deeper perceptions of surroundings for L3 and L4 autonomous driving capabilities throughout the next five years.

User Advice: The idea of 3D sensing camera enabled interactive experiences started from game consoles like Nintendo Wii and Xbox One Kinect, but its value in mobile devices is still at early development.

Electronics OEMs should build a multiphase feature roadmap by specifying incremental 3D features and corresponding 3D sensing solutions across their product lines. Focus at building 3D sensing algorithms and sensor fusion platform through reuse experiences to develop synergy.

Service providers should identify possible uses with 3D sensing camera and develop software applications and cloud services for targeted audience. A good software should be designed based on the specific use case, rather than a generic one.

Businesses, in general, should strive to use an optimized 3D sensing camera solution to digitize the physical objects and/or steps to optimize work process, improve workforce collaboration and improve customer experience.

Business Impact: Many AR applications can be achieved without 3D sensing cameras, but some applications that require accurate depth and edge information will find 3D sensing cameras are very useful and time-saving. Facial recognition for authentication is the typical example, others are like virtual fitting for e-commerce, 3D model reconstruction for product reviews, floor plan for renovations.

Business can leverage 3D sensing cameras' object recognition ability to achieve autonomous operations to improve productivity. For example, using 3D sensing cameras and machine learning (ML) to train an algorithm to recognize defective parts .

Continuous 3D sensing in motion can build simultaneous localization and mapping (SLAM), combined with microphone array to collect surrounding sound will and/or other sensing technologies (like gas sensor) can collect more detailed environmental data, and reconstruct a high-fidelity model for other advanced applications like re-examinations or simulations. For example, using drones carrying 3D sensing cameras to scan the walls of tunnels.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: ams; Apple; Google; Infineon Technologies; Intel; Microsoft; Sony

Recommended Reading: "Emerging Technology Analysis: 3D Cameras in Smartphones Enable Differentiation via Authentication and Augmented Reality"

In-Display Optical Fingerprint

Analysis By: Roger Sheng

Definition: Optical in-display fingerprint is integrating the fingerprint function into displays with optical sensor solutions. The optical receiver module which is attached on the bottom of the display panel detects the lights traveling from the surface of displays to recognize the fingerprints for user authentication. It can be a unique CMOS image sensor or a typical compact camera module.

Position and Adoption Speed Justification: Optical in-display fingerprint is seen as an essential user authentication solution when Android smartphones adopt full-screen display trend which can provide larger view area. Compared to Apple, Android smartphone OEMs tend to have both fingerprint and face recognition functions in their premium products and keep fingerprint function in the mainstream market. With highly integrated fingerprint sensors and displays, a finger can simply be placed on the surface of displays for authentication which is the replacement of traditional capacity fingerprint sensors in the full-screen display models.

In 2019, optical in-display fingerprint market had very strong growth due to the population of full-screen display in the premium Android smartphones. Goodix Technology leads the market by its innovative products and strong relationship with Chinese local smartphone OEMs. The growth of optical in-display fingerprint also needs to thank the growing AMOLED adoption. The simplified structure of AMOLED displays enables easy implementation for this solution. The cost competitiveness of optical in-display fingerprint solution is quickly improved after the rising volume and intensive competition among Chinese chip vendors. The chip vendors are developing new generation optical fingerprint which will have larger sensor area and faster response time. Besides AMOLED solution, some Chinese companies are developing LCD-based optical in-display fingerprint solutions for lower cost. We estimate it will be adopted in the entry-level smartphones when the LCD-based solution is ready. Thus, optical in-display fingerprint technology position is moved forward aggressively in this Hype Cycle update.

User Advice: There are various emerging authentication technologies for smartphones, such as ultrasonic and 3D face recognition. Optical in-display fingerprint will not compete with face recognition directly but they are complementary because multiple authentication methods for a smartphone are reasonable to handle unexpected situations. In the COVID-19 pandemic period, people have to wear masks which shows the convenience of fingerprint solutions. Ultrasonic in-display fingerprint is a major competitor of the optical in-display fingerprint. Compared to ultrasonic in-display fingerprint, optical in-display fingerprint has advantage in cost, but smaller detection area and less security due to the lack of 3D bio-check. Smartphone OEMs should design more authentication schemes by software to enhance the security when they use optical in-display fingerprint in their products.

Besides smartphones, optical in-display technology will be significant in portable personal electronics such as smartwatches where AMOLED adoption rates are the highest among display electronics. Consumer device OEMs focusing on portable personal electronics should monitor the improvement of this technology and design it in the new full screen products.

Business Impact: Optical in-display fingerprint is growing quickly, smartphones and wearables will be the major markets because these electronics need a quick and convenient authentication solution to improve user experience with personal data protection.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: Goodix Technology; Samsung Display Solutions; Synaptics

Recommended Reading: "Market Trends: New Biometric Authentication Methods in Smartphones Will Redefine User Experience"

ToF MEMS-Based Ultrasonic Sensor

Analysis By: Anushree Verma; Bill Ray

Definition: ToF MEMS-based ultrasonic sensors use emitted sound to calculate distance from the time of (reflected) flight. Conventional ultrasonic sensors are very common in automobiles and industrial applications, but are too bulky and power hungry for mobile use. ToF MEMS-based ultrasonic sensors are smaller and consume less power but still have the advantages of ultrasonic sensors.

Position and Adoption Speed Justification: Most existing systems for accurate range sensing are optical-based. However, there are many limitations for high-energy optical sensors, such as the influence of ambient light and the possibility to damage human eye. On the other hand, the low-energy optical sensors cannot provide precise ranging accuracy.

Although ultrasound is not a new technology, MEMS-based ultrasonic sensors need advanced micro-electromechanical systems (MEMS) manufacturing technology as well as high-performance signal conditioning to resolve sufficient accuracy across a specified range; this requires an accompanying ASIC. Such an ASIC can use repeated scanning to create ultrasonic radar — building up a three-dimensional model of the surrounding area for robot guidance or inside-out headset tracking (providing six degrees of freedom to VR products). Other applications include gesture recognition and proximity sensing in mobile devices.

Despite the advantages of the technology, ultrasonic ToF has to compete with systems using visual, IR wavebands and high-frequency radar. TDK has been actively developing the product range acquired from Chirp Microsystems and extended the sensing range as well, and therefore, the profile has progressed a little along the Hype Cycle, but challenges remain the same.

User Advice: Product management leaders at mobile device, automotive and industrial OEMs must evaluate and adopt this technology where optical sensors are not suitable, such as wearables and medical.

The product management leaders at mobile device OEMs, who plan to use these sensors to replace optical, have to verify its performance in more commercial products.

Product managers can utilize it for smart spaces such as room-scale sensing, enabling ultralow power and always-on sensing for human presence detection and so forth.

Business Impact: ToF MEMS-based ultrasonic sensors can be used in automotive and industrial for detecting the range, including small drones, robots and HMDs. With the extended sensing range, this can be utilized for smart spaces applications as well. There can be use cases for mobile devices. Unlike optical ToF sensors, the ToF MEMS-based ultrasonic sensors are able to work in direct sunlight, which will helps it to expand its target applications.

In addition, the ToF MEMS-based ultrasonic sensor can be used in some applications that cannot be penetrated by light, such as wearables and medical.

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Sample Vendors: TDK; TDK (Chirp Microsystems)

Biochips

Analysis By: Michael Shanler

Definition: Biochips are miniaturized laboratory testing platforms applied within semiconductor and biological sciences. They are commonly used in drug R&D and point-of-care testing (POCT) in clinical diagnostics. The typical format involves an array of molecular sensors composed of biochemical materials printed onto the chip's surface, in combination with microfluidic channels. This technology is commonly referred to as a "lab on a chip."

Position and Adoption Speed Justification: While many biochip manufacturers have offered commercially available products since the early 1990's (DNA microarray, gene-expression profiling arrays, nanosensors, tissue microarrays and protein biochips), most of the usage was for nonclinical settings. Furthermore, many biochips are not available at scale or at price points that work for their customers. Over the past decade, however, biochip instruments have dropped in price, making the technology much more affordable for POCT. Diagnostics equipment manufacturers have accelerated biochip testing formats, content and applications. Nonhealthcare employers are beginning to inquire with Gartner about biochip usage and on-site rapid testing capabilities at corporate facilities for tracking disease, toxic chemicals, pollution, antigens and banned/illicit substances.

Biochip manufacturers have improved scalability and expanded the available materials for sensors, and the detection technologies have grown in sophistication. As a result, vendors are making significant performance improvements in biochip platforms, and POCT is now enabled for a variety of applications, like enzyme-linked immunosorbent assays (ELISAs) and antibody detection using closed-loop automated systems in healthcare environments.

A significant rise in the adoption of personalized medicine, genomics research and clinical biomarker studies, as well as vendors' focus on technological advancements, are the key factors that will further encourage the development of the global biochips market.

The COVID-19 pandemic should increase demand for more POCT and drive further biochip technology adoption, as testing dynamics for both government-supported or nationalized healthcare and for-profit healthcare models mature. While biochips are now established for diagnostics and miniaturized R&D assays, relying on them and the informatics associated with healthcare and disease tracking is becoming more challenging. False positives and negatives on biochips and nonstandard test methodologies, training on sample collection, and chip quality issues contribute to negative user sentiments. For these reasons, the technology is heading into the Trough of Disillusionment.

User Advice: CIOs responsible for data integration of biochips will need to focus on the chip reader/detector instrument communications protocols. CIOs that operate in the healthcare life science space, such as POCT, must ensure that security, legal, validation and regulatory compliance requirements — such as Health Insurance Portability and Accountability Act, 510(k), GxP and data integrity — can be maintained.

CIOs and stakeholders of organizations that manufacture or develop biochip sensors, diagnostics and service-related products should explore how biochips can further enable rapid diagnostics for diseases and environmental change tracking. Developing economies hold immense growth opportunities as the cost points, instrument portability, "closed loop" processing and stand-alone designs improve.

Business Impact: Biochips are becoming essential tools for performing rapid diagnostics, especially for serological assays or assays with expensive reagents that evaluate source or donor blood and tissue samples.

Private organizations, along with the governments of many countries, have increasingly realized several benefits of biotechnology — such as low cost, rapid testing and ease of deployment in emergency situations.

Products based on DNA microarrays, protein chips, lab-on-a-chip, and organ-on-a-chip technologies will generally cut both time and costs in their respective applications.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: Abbott; Agilent; Cellix Bio; Danaher; GE Healthcare; Illumina; PerkinElmer; QIAGEN; Roche; Thermo Fisher Scientific

Recommended Reading: "Maverick* Research: DNA Data Governance and the Future of Privacy"

"Survey Analysis: Technology Innovations That Deliver the Greatest Value"

"Gartner's Top Strategic Predictions for 2020 and Beyond: Technology Changes the Human Condition"

Solid-State MEMS Scanning Lidar

Analysis By: Masatsune Yamaji

Definition: A solid-state micro-electromechanical system (MEMS)-based scanning lidar replaces moving parts with silicon-based hardware and integrates an application-specific integrated circuit (ASIC) to reduce the size of the entire module. The lidar creates a 3D map of its surroundings by emitting millions of laser dots per second and measuring the time it takes for the laser to bounce back.

Position and Adoption Speed Justification: Solid-state MEMS-based scanning lidar is designed to replace mechanical spinning lidar. With little or even no moving parts, solid-state MEMS-based scanning lidar is cheaper and more reliable. The size is also smaller through the use of fully integrated chips. Although the field of view is limited, the cost benefit of MEMS allows one vehicle to use multiple solid-state MEMS-based scanning lidars. In the long run, almost all electronic semiconductor components, including the laser beam, control circuitry, MEMS mirror, detectors and computing application-specific integrated circuit (ASIC), will run on a single chip. This will lead to even lower cost when it achieves mass production. The major application is in automotive.

Solid-state MEMS-based scanning lidar is moved ahead a few steps in the Hype Cycle position this year. Various technologies for lidars are competing each other today, but we believe that it will climb to the enlightenment stage soon. This is because an increasing number of vendors have released new versions of solid-state MEMS-based lidars with better performance and lower cost over the past year.

User Advice: For lidars deployed for automotive use cases, there are various lidar solutions that are competing with each other, and autonomous vehicle makers must work with solution providers to evaluate the quality and cost. In addition, building information modeling (BIM) software vendors must develop new algorithms to analyze the point cloud collected by solid-state lidar.

Autonomous things developers, such as service robot OEMs, should start the evaluation of solid-state MEMS scanning lidar for future product planning.

Business Impact: Solid-state MEMS-based scanning lidar can be used as simultaneous localization and mapping (SLAM) technology to create 3D modeling. It can be applied in industrial automation, security and surveillance, logistics, automotive, 3D mapping, and drone flight management.

Unlike current mechanical lidar placed on the roof of automotive, the solid-state lidar is very small and embedded in the surface of the automotive technology, which means that vehicle designs are not negatively impacted by the incorporation of these sensors.

The other major application area for solid-state lidar is drones. Mechanical lidar was used for BIM to create 3D point for high-resolution modeling. However, since the payload of drone is limited, it's hard to use mechanical lidar in drone. With solid-state lidar, drone can be very useful in inspection to provide real-time construction quality control. Also, it can be used for obstacle avoidance for intelligent flight operations.

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Sample Vendors: Blickfeld; Innoviz; LeddarTech; Luminar Technologies; MicroVision; RoboSense

Recommended Reading: "Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide"

"Top 10 Strategic Technology Trends for 2020: Autonomous Things"

Radar Sensing

Analysis By: Nick Jones

Definition: Radar sensing refers to the use of radar systems, using frequencies of a few GHz to more than 100 GHz to sense proximity, measure distance and recognize gestures. Simple systems use a single transceiver to measure distance. More-sophisticated solutions integrate multiple transceivers onto a single chip to create a 3D radar image of the environment.

Position and Adoption Speed Justification: The term “radar sensors” covers a number of technologies of varying maturity, including:

- Simple distance-measuring units that have been used for several years for such purposes as people counting and automotive parking sensors.
- Sophisticated radar-on-a-chip systems used to deliver a cloud of 3D point measurements for short-range sensing of a few meters — for example, for collision avoidance, and to count the number of occupants in a room or a car. In limited early commercial deployment.
- Tiny, high-frequency radar-on-a-chip sensors for gesture recognition intended for user interfaces (UIs) on wearable devices, such as smartwatches. They have been demonstrated, but are not yet in mainstream commercial use.
- Systems that sense objects or people by analyzing RF emitted for purposes, such as networking. For example, Wi-Fi access points can identify nearby people and detect whether they’ve fallen over. In limited, early, commercial deployment.

User Advice: Organizations using optical distance-measuring systems, such as light detection and ranging (LIDAR), 3D cameras or stereoscopic cameras, should investigate radar sensors. Potential advantages include:

- Anonymity — for example, for sensing room occupancy or retail people counting; although radar can provide a person’s approximate size and location, it senses a relatively low-resolution point cloud that doesn’t provide personally identifiable information (PII), such as an optical image of the face.
- High-precision distance measurement. Some radar sensors can sense distance very precisely — for example, to within a millimeter or better. This enables some radars to remotely determine information, such as human respiration rate and even sometimes heart rate for emotion sensing. The ability of radar to sense small distances will also enable microgesture sensing — such as movement of a single finger
- Radar is not vulnerable to optical interference, such as fog, smoke or poor weather — for example, for automotive collision sensing. Radar sensors also don’t need illumination to operate, unlike optical gesture recognition systems
- Radar systems operating at low frequencies, such as a few GHz, can “see” through obstructions such as walls and, in some cases, sense inside the human body
- Low power consumption — for example, for use in battery-powered devices, such as wearables
- Lower cost than technologies, such as LIDAR
- Reduced maintenance, no need to clean optical lenses.

Business Impact: Radar sensors will be attractive in a wide range of industries that need reasonably precise short to medium range sensing of objects and people. Examples include:

- Retail (for example, for footfall analytics or people counting)

- Monitoring and counting objects (such as on production lines)
- Gesture and microgesture recognition on wearable and portable devices
- Fall detection systems for vulnerable individuals
- Drone and automobile navigation and collision prevention
- Subcutaneous sensing for healthcare
- Movement/displacement sensing (for example, of shifting embankments)
- 3D measurement (for instance, to identify the free space in a shipping container)
- Emotion sensing based on respiration or heart rate

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Sample Vendors: acconeer; Google; imec; Texas Instruments; Vayar

Recommended Reading: "Top 10 User Experience Technologies That Will Drive Innovation"

"Unlock the Innovation Potential of Future Location-Sensing Technologies"

Climbing the Slope

Sensor Fusion

Analysis By: Amy Teng

Definition: Sensor fusion is a process that aggregates and "fuses" many disparate sensor inputs to increase sensor data accuracy and/or sensing coverage for the system to develop insights and decisions. A sensor fusion solution usually includes a set of sensors, a hardware sensor hub, a fusion engine and a software sensor fusion stack.

Position and Adoption Speed Justification: Sensor fusion for automotive and industrial systems has been prevalent for decades. Sensor fusion also exists in smartphones and tablets where the sensor data has been interpreted by OS allowing app developers access through APIs.

During the past few years, sensor fusion has evolved to include lidar, radar and visual sensing for autonomous cars, simultaneous localization and mapping (SLAM) for drones and robots, and six degrees of freedom (6DoF) visual and 3D audio immersion for head-mounted displays (HMDs).

Technology evolution of autonomous things and Internet of Things (IoT) will keep on pushing the number and the diversity of sensor and sensing technology to a higher level, driving continuous enhancement of sensor fusion technology. Sensor fusion algorithms' development has been benefited by the growing leverages of artificial intelligence (AI)/machine learning (ML) technology.

When this combined with improved sensor accuracy and advanced computational power of sensor engine, sensor fusion can analyze faster and better than before. Therefore, we moved its position a bit forward

User Advice: Sensor fusion software stacks can be derived from three resources: open source, sensor companies and software companies who focus on serving customers who have sensor fusion requirement. Sensor fusion software can be ported to a variety of different hardware platforms, ranging from application processors, general purpose microprocessors and microcontrollers, programmable logic, integrated combo sensors, and purpose-built devices like Microsoft's customized holographic processing unit (HPU) for HoloLens. Consider discrete, low-power sensor hub solution to offload the process of main processor when designing for power constraint and long battery life applications.

Build a central platform to manage sensor fusion algorithms across different products and applications to gain reuse efficiency. For example, a smartwatch and wristband can share same algorithm for detecting a wearer's gesture and posture, the two devices can also share the same voice actuated algorithm with smart speakers.

Leverage AI/ML to accelerate the pattern recognition of sensor signals and shorten sensor fusion development time.

Sensor fusion can also offer reduced size and weight, which is particularly important in drone applications.

Business Impact: Sensor fusion technology is a key element of enabling real-time contextual analysis because it comprehends the status of a system. Additionally, leverages AI/ML and clever manipulation of different types of input sensors to train model will explore new algorithms, resulting in new insights or new applications unseen before. For example, fusion of sound waves and surface vibration of sound source can create a new type of noise-cancellation device.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Sample Vendors: CEVA (Hillcrest Labs); CyweeMotion; Kionix; Knowles; NXP; Qualcomm; QuickLogic; Renesas; STMicroelectronics; TDK (InvenSense)

Recommended Reading: "Cool Vendors in Novel Sensors"

"Market Trends: Supplying Intelligent Sensors for the IoT Takes Cooperation, Integration and Software"

Ultrasonic Fingerprint Sensors

Analysis By: Amy Teng

Definition: Ultrasonic fingerprint sensors make use of the principles of medical ultrasonography. The sensor radiates high frequency sound waves and collects the reflected waves to create visual images for identifying biometric syndrome of fingerprint.

Position and Adoption Speed Justification: Ultrasonic fingerprint sensors are competing with many other similar purposes but different biometric detection technologies. The advantage of ultrasonic fingerprint sensors is obvious, but cost is the decisive factor because its major market — smartphones — is highly competitive and price-sensitive.

Currently placing an ultrasonic fingerprint sensor under the display module without blocking the display viewing area is the main design trend, wherein Qualcomm is the major technology provider. Optical fingerprint sensor technology that is integrated in the display is the main rival technology led by Chinese semiconductor vendors like Goodix Technology and Egis.

Samsung's S10, Note 10 and latest S20 series of smartphone have adopted the technology, alongside Qualcomm's new fingerprint sensor, 3D Sonic Max, and the partnership with display panel maker BOE Technology Group. Qualcomm has further enhanced the capabilities of its ultrasonic fingerprint sensor technology by offering larger active area, faster processing power per area, and support from its Snapdragon processors. The partnership with BOE will drive vertical integration and cost reductions. As a result, we move its HC position a bit forward.

User Advice: An ultrasonic fingerprint sensor offers more design flexibility in contrast to Apple's Touch ID technology:

- It can penetrate the surface layer of electronics devices to reach the fingertip and sense the fingerprint.
- It is immune to noises caused by dirt, lotion and water.
- Its sensing area can be curved and broadened.

Ultrasonic fingerprint sensors can create an "invisible biometric sensing" aesthesia for mobile devices. The sensor can be placed beneath an OLED display or metal casing, and sensing areas can be larger so secured gestures or other innovative features (like dual fingerprint sensing to improve security).

Biometric sensing technology used as identity authentication provides a straightforward, native and secure feeling to users physically. It will continue to evolve and coexists with the increased adoption of two-factor authentication (2FA).

Technology product managers should view the biometric-sensor-based technology as part of the fundamental security elements in the product roadmaps, keep on recruiting vendor expertise and cumulating experiences to build a security strategy across different product lines.

Biometric sensing and identity authentication technology is more than locking and unlocking a device in faster speed and an easier way; product manager should collaborate with fingerprint technology suppliers to expand this secured, convenient experience to engage ecosystems (like mobile payment and access control) to add value to products.

Business Impact: Fingerprint sensing technology has been evolving for more than 10 years since iPhone 5S introduced Touch ID in 2003. The capacitive fingerprint sensor has been widely adopted due to its cost advantages. Emerging technologies like facial-recognition-based authentication technology (starting from Apple introduced Face ID in 2017) have gradually cannibalized its market share.

Additionally, ultrasonic fingerprint sensors compete against optical fingerprint sensors that provide similar use experiences at much lower cost. Investment for this market must carefully review technology suppliers' ability of vertical and system integrations because they are facing a highly competitive smartphone market where only vendors who scale in short-time can make profits.

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: Qualcomm

Recommended Reading: "Growing Adoption of Fingerprint Technology in China Brings New Opportunities for Biometric Sensor Suppliers"

"Market Trends: New Biometric Authentication Methods in Smartphones Will Redefine User Experience"

Printed Electronics

Analysis By: Ivar Berntz

Definition: Printed electronics refers to the production of electronic components through printing technologies. "Electronic components" are typically integrated circuit boards, diodes, sensors or other devices that are incorporated into electronic devices, such as capacitive-touch sensors, organic light-emitting diodes (OLEDs) and displays, printed circuit boards and semiconductor devices. "Printing technologies" are analog imaging technologies, including offset, gravure and screen printing, and digital technologies, such as inkjet or aerosol jet imaging.

Position and Adoption Speed Justification: Printed electronics (PE) technology creates bright, flexible and stretchable devices that can be deployed in ways rigid devices cannot. Electronics and parts manufacturers get the advantages from the underlying benefits of 3D printed electronics. These benefits include additive design, printability on nonflat surfaces, mass customization, reduced material wastage, simplified assembly, smaller product size, absence of harmful chemicals, and, when embedded, protection from external damage. The market for printed electronics is set to thrive and grow over the next few years. Current progress made has led to a positive movement on the Hype Cycle. The main factors that are still restraining growth are creativity, large know-how base of competitive technologies, and finding an optimum combination of cost and performance. Exponential growth can be expected once these hurdles are cleared and other innovations, like energy harvesting and location sensing, allow for further new usage areas and applications.

User Advice: There are videos on online platforms showing how one can modify an existing consumer inkjet printer to make your own printed electronics, for example, circuit boards and even solar cells. This shows how pervasive this innovation has already become. Being able to print parts with embedded circuitry and wiring in them reduces assembly complexities and allows for upgrades and bug fixing using relatively inexpensive components. This innovation is important in that it allows for complex, yet also easily disposable, parts that can be used for in situ monitoring or testing at an increasingly lower price point. Given also the wide range of materials that can be used, there are various military applications with stringent survivability and resilience requirements of the electrical, thermal and mechanical properties of 3D printed electronics (see "The Strength of 3D Printed Electronics" webinar). On the civilian side, such as in real estate and transportation, they are already building envelopes, roof panels and windows layered with organic photovoltaic (OPV) cells, with the double duty of producing energy while also providing heat reducing shade.

Users considering using printed electronics should focus on:

- New markets, such as rise in applications in IoT and asset monitoring, medical and fashion wearables, organic photovoltaic cells, smart packaging and RFID. Increasing market size will help accelerate proliferation and cost reduction.
- Another rising application is printed electronics for sensor arrays. Flexible sensors are becoming increasingly attractive for benefits including the printing of multiple arrays, cost efficiency, thinner profiles, lighter weight and conformability.
- Trying to create value beyond cost reduction including thinness, light weight, robustness, stretchability, larger area, wider substrate compatibility and flexibility.
- Conducting trial-and-error testing, as many applications, their processes, substrates, materials and conductive inks are still new.

Business Impact: There are, at this moment, quite a few areas where this innovation could have a significant impact. Examples include:

- Health sensors, for example, cortisol, respiration or hydration wearable patches, including on-demand types, like strain.
- Electronics fabrication and repair at the point-of-need (PON), for example, the international space station (ISS).
- Built-in antennas, location sensing, power harvesting and storage capabilities in electronics devices, like jewelry, sunglasses.
- Single-use printed electronics in ammunition, as being tested by the U.S. Army.
- Lightweight, innovative, and flexible displays in consumer electronic devices, ranging from the diminutive to very big.
- 3D sensors, for example, light or touch sensitive, using a variety of materials, including polymers.
- Dimming elements in lighting panels, steering wheels and OLED displays, for instance, for the automotive industry.

- Printed conductive inks for electronic applications in transistors, sensors, antennas of RFID tags, body implants and wearable electronics.
- Promising new applications like smart windows, electronic paper, e-textiles and batteries.

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Adolescent

Sample Vendors: DuPont; Epson; Heidelberger Druckmaschinen; Nano Dimension; RISE Acreo; Sumitomo; ThinFilm; Toppan Printing; Xerox (PARC)

Recommended Reading: “Market Insight: Tech CEOs Must Exploit China Manufacturing Services for Competitive Advantage in IoT Hardware”

“Gartner Invest Analyst Insight: Impact of COVID-19 on the Semiconductor Industry in 2020”

“Unlock the Innovation Potential of Future Location-Sensing Technologies”

“Market Guide for Electronics Manufacturing Services”

Surface Acoustic Wave (SAW)-Based Sensors

Analysis By: Anushree Verma

Definition: Surface acoustic wave (SAW)-based sensors are MEMS sensors that exploit SAW. Based on their piezoelectric properties, certain materials like quartz create on their surface a mechanical displacement (surface acoustic wave) if an electrical field is applied. Sensing with acoustic waves is based on measuring the variations of the acoustic propagation velocity of the wave, or wave attenuation. These variations imply changes in wave properties, which can be translated into the corresponding change of the physical parameter measured.

Position and Adoption Speed Justification: SAW sensors have been around for a while in low-cost volume production. SAW sensors are rugged, small in size, inexpensive to produce, stable and have many applications across end-user industries.

The position advancement reflects new ways in which these sensors are finding application. Traditional use cases are well-established. However, there have been some advancements in SAW biosensors accounting for the advancement in this Hype Cycle, although not commercialized yet. SAW devices have to be coated with a sensing layer binding specifically to the analyte enabling reliable SAW biosensor signal responses.

User Advice: Users should focus on high-market growth areas, such as automotive for identification of moving object and parts or temperature sensing of coolant, outside air temperature or active in-vehicle sensing, wireless measurement of temperature and pressure in industrial applications, and wireless monitoring of subway net and railway vehicles. In addition, they should exploit its unique properties such as:

- High sensitivity along with extremely high robustness, low cost of production and small sizes of SAW-based accelerometers to compete in the market.
- Also, the fact that SAW-based accelerometers don't have any moving parts in their design could potentially make them extremely shock, vibration and temperature resistant.
- One uniqueness is that the sensor gets energy from radio frequency (RF) pulse to excite the surface acoustic wave (SAW) and transmit its response.

Business Impact: These will be key areas of impact:

- Being wireless and passive sensors, surface acoustic wave sensors are safer and more reliable/ suitable for power equipment.
- Communication and signal processing such as bandpass filters installed in TV systems, GPS receivers in L band, space communications, mobile telephony and digital optical communications.
- In biosensing or healthcare applications, it can enable direct and label-free detection of proteins in real time.

Benefit Rating: Low

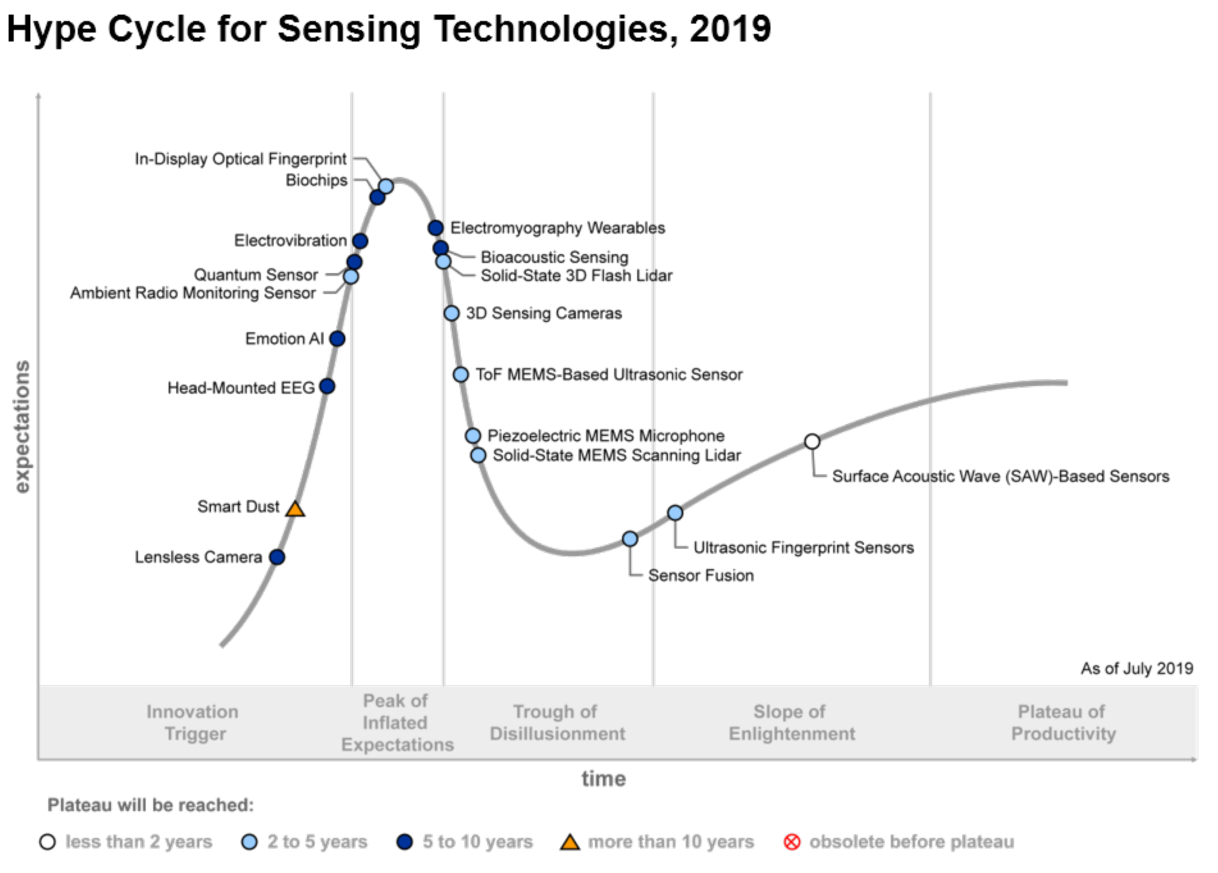
Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Sample Vendors: Epson; Microchip Technology; Tai-Saw Technology

Appendixes

Figure 3. Hype Cycle for Sensing Technologies, 2019



Source: Gartner
ID: 369959

Hype Cycle Phases, Benefit Ratings and Maturity Levels

Table 1. Hype Cycle Phases

Phase	Definition
Innovation Trigger	A breakthrough, public demonstration, product launch or other event generates significant press and industry interest.
Peak of Inflated Expectations	During this phase of overenthusiasm and unrealistic projections, a flurry of well-publicized activity by technology leaders results in some successes, but more failures, as the technology is pushed to its limits. The only enterprises making money are conference organizers and magazine publishers.
Trough of Disillusionment	Because the technology does not live up to its overinflated expectations, it rapidly becomes unfashionable. Media interest wanes, except for a few cautionary tales.
Slope of Enlightenment	Focused experimentation and solid hard work by an increasingly diverse range of organizations lead to a true understanding of the technology's applicability, risks and benefits. Commercial off-the-shelf methodologies and tools ease the development process.
Plateau of Productivity	The real-world benefits of the technology are demonstrated and accepted. Tools and methodologies are increasingly stable as they enter their second and third generations. Growing numbers of organizations feel comfortable with the reduced level of risk; the rapid growth phase of adoption begins. Approximately 20% of the technology's target audience has adopted or is adopting the technology as it enters this phase.
Years to Mainstream Adoption	The time required for the technology to reach the Plateau of Productivity.

Source: Gartner (July 2020)

Table 2. Benefit Ratings

Benefit Rating	Definition
Transformational	Enables new ways of doing business across industries that will result in major shifts in industry dynamics
High	Enables new ways of performing horizontal or vertical processes that will result in significantly increased revenue or cost savings for an enterprise
Moderate	Provides incremental improvements to established processes that will result in increased revenue or cost savings for an enterprise
Low	Slightly improves processes (for example, improved user experience) that will be difficult to translate into increased revenue or cost savings

Source: Gartner (July 2020)

Table 3. Maturity Levels

Maturity Level	Status	Products/Vendors
Embryonic	▪ In labs	▪ None
Emerging	▪ Commercialization by vendors ▪ Pilots and deployments by industry leaders	▪ First generation ▪ High price ▪ Much customization
Adolescent	▪ Maturing technology capabilities and process understanding ▪ Uptake beyond early adopters	▪ Second generation ▪ Less customization
Early mainstream	▪ Proven technology ▪ Vendors, technology and adoption rapidly evolving	▪ Third generation ▪ More out of box methodologies
Mature mainstream	▪ Robust technology ▪ Not much evolution in vendors or technology	▪ Several dominant vendors
Legacy	▪ Not appropriate for new developments ▪ Cost of migration constrains replacement	▪ Maintenance revenue focus
Obsolete	▪ Rarely used	▪ Used/resale market only

Source: Gartner (July 2020)

Gartner Recommended Reading

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Understanding Gartner's Hype Cycles

Unlock the Innovation Potential of Future Location-Sensing Technologies

Automotive OEMs Must Leverage Novel Sensing Technologies to Enhance the In-Cabin User Experience

Market Trends: Surveillance and ADAS Enabled by Machine Vision Create New Growth for Image Sensor Vendors

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