Scanning LIDAR in Advanced Driver Assistance Systems and Beyond

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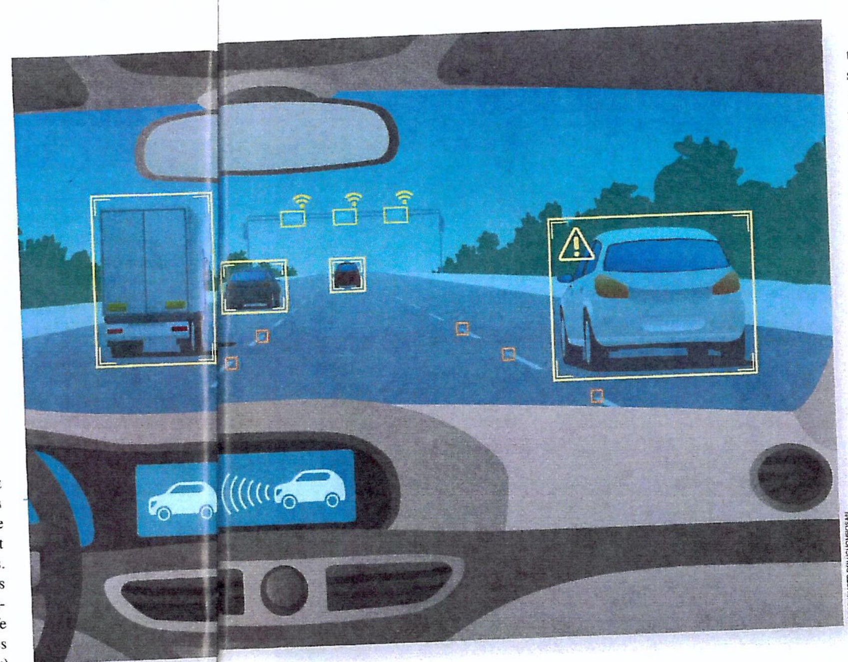
Scanning LIDAR in Advanced Driver Assistance Systems and Beyond

Building a road map for next-generation LIDAR technology.

By Rajeev Thakur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ADVANCED DRIVER ASSISTANCE SYSTEMS (ADASs) ARE accelerating the growth of infrared (IR) devices used in automotive applications. Some of these are well-known applications, such as ambient light sensing, steering wheel sensors, and rain sensors. However, many new technologies for ADASs, such as LIDAR, driver monitoring, adaptive beam, and matrix lighting, are still in the early evolution phase of the product life cycle. Figure 1 provides a snapshot of some of the IR devices from OSRAM Opto Semiconductors (Regensburg, Germany) and the applications for which they can be used.

Today, ADASs do not have a universally accepted definition; however, at a high level, one could state that the system senses the environment both around and inside the vehicle, tries to determine what the driver and vehicle together are doing, and then assists them in the execution of their intent. Even though an ADAS is primarily understood to be a safety-related technology, one could argue that ADAS functions could also include technologies like cruise control, automatic dimming of lights, gesture and voice recognition systems to interface with entertainment, and driving maps. As more consumer-oriented functions are built into vehicles, those outside the automotive industry may ask why it takes so much time to develop some of these technologies, especially compared to what they see, for example, in the consumer smartphone market and in Silicon Valley. Figure 2 demonstrates the contrast between the cultures of Detroit and Silicon Valley.

As we see more pressure from competitive forces, we also see an attempt at merging the cultures of Detroit and Silicon Valley. Currently, the stream of innovative ideas to expand the portfolio of ADASs all the way to the fully autonomous vehicle must be filtered through the rigor of traditional automotive development cycles, which have their own pressures and time lines. To keep up with the pace of change and consumer demand, the automotive industry will have to speed up development cycles to match the pace of the consumer market.

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An automobile, at its core, is a safety device that must operate reliably for ten to 15 years. According to a recent Society of Automotive Engineers (SAE) paper on active safety by Jake Fisher, director of automotive testing at *Consumer Reports*, safety is the top buying consideration for consumers, followed by cost and reliability of the vehicle. The paper also states that consumers are willing to pay 10–30% more for backup cameras, blind-spot monitoring, FCW/automatic brakes, rear cross-traffic alert, and lane departure warning systems. A paper written by David Zuby of the Insurance Institute for Highway Safety (IIHS) cites a 28–38% reduction in insurance claims for vehicles with automatic emergency braking compared to those without, aligning well with the growing consumer interest in ADAS applications.

When it comes to safety-related applications, consumers demand assurance from a regulatory body that the systems meet minimum standards for safe use. The automotive industry, National Highway Traffic Safety Administration (NHTSA), SAE, IIHS, and other such entities are working together to develop requirements, testing methods, and acceptance criteria, while at the same time working to do so without thwarting innovation or boxing out competing technologies that may offer a better solution. To fulfill and complete this task, the process can typically take four to six years. Figure 3 conveys the complexities in the process of bringing a safety feature through the regulatory system before it becomes available to the consumer.

When NHTSA sees an existing technology that would significantly benefit the safety of vehicles or reduce economic costs of transportation, by mandate, it issues a Notice of Potential Rule Making (NPRM); solicits comments from the public, OEMs, and suppliers; and makes a ruling on either moving forward with an NCAP or FMVSS change to introduce the technology. The NPRM is a key trigger to the industry that the chances of a technology going mainstream are now high, spurring innovation and development projects to either guide the regulation or be prepared to introduce it if a change is set forth. The more proactive an OEM or supplier is in envisioning either the usefulness of a technology or the probability of it being mandated in the near future, the better it is positioned to capture a lead position in the market—bringing us to LIDAR and ADASs, the focus of this article. Using the example of LIDAR technology will help illustrate the challenges in bringing a new technology to market and in it becoming one of the pillars for external sensing needed in the fully autonomous vehicle. For the purpose of this article, we will focus on only the ADAS active safety applications of automatic emergency braking, forward collision warning, blind-spot detection, and rear cross-traffic alert. Forward camera, radar, and LIDAR are generally accepted as the key sensing technologies for these ADAS applications. Stereo cameras and ultrasonic sensors are also used but expected to gradually give way to LIDAR. Table 1 compares radar, camera, and LIDAR technologies.

The additional value that LIDAR brings to the camera and radar combination is angular resolution of the object detected, especially scanning LIDAR, which can have a less than 0.5° angular resolution in the horizontal field of view (HFOV). Flash LIDAR (see Figures 4 and 5), primarily aimed at collision avoidance and detection of large objects such as cars, pedestrians, and cyclists, has been on the market for over four years and is comparatively low cost. However, flash LIDAR is not capable of reliably

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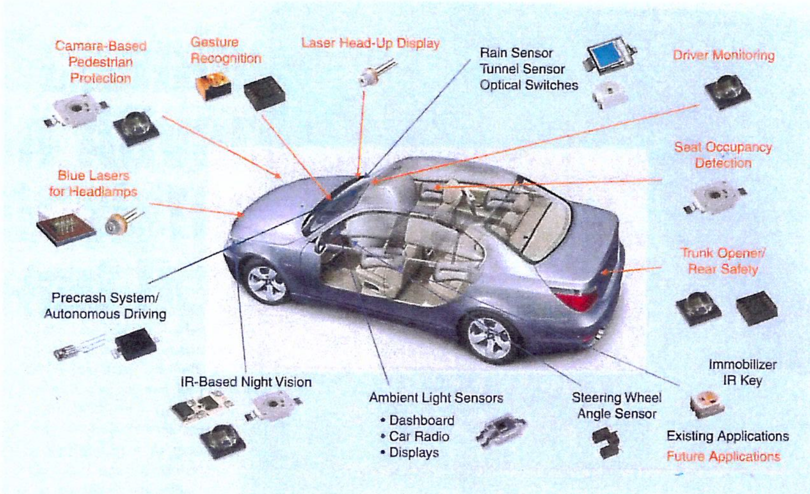


FIGURE 1. IR sensing devices with automotive use cases. (Courtesy of OSRAM Opto Semiconductors.)

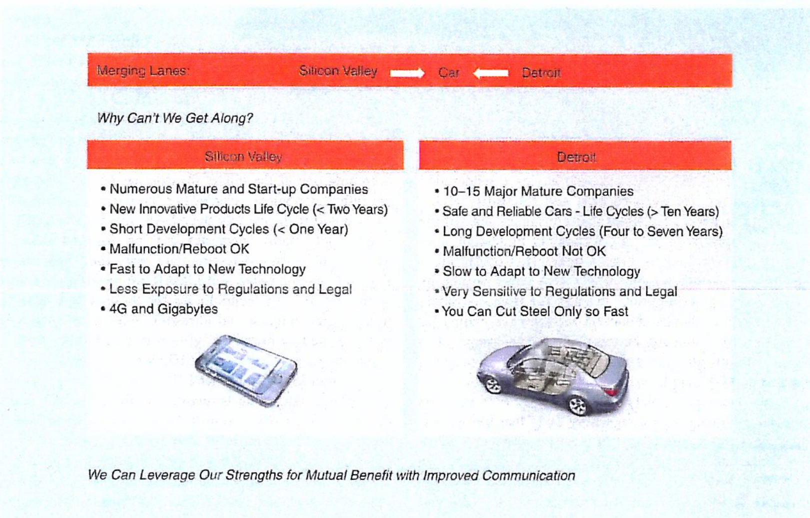


FIGURE 2. The contrasting industrial cultures of Detroit (automotive) and Silicon Valley. (Courtesy of OSRAM Opto Semiconductors.)

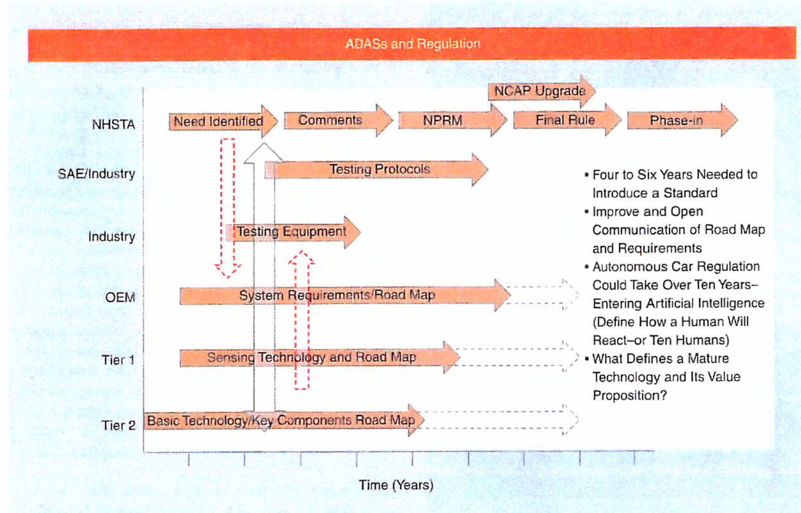


FIGURE 3. The automotive regulatory process with a time line. (Courtesy of OSRAM Opto Semiconductors.)

Table 1. A comparison of radar, camera, and LIDAR technologies.

All three have limitations—optimum fusion determined by regulation/consumer expectations.

Sensor	Typical Range	Azimuth FOV	2015 Price Range	Typical Applications	Comments
24-GHz RADAR	60 m[1]	56°[1]	US$80–100	Blind-spot detection Forward collision warning	USA bandwith 100–250 MHz[2]; robust for rain/snow; concerns for people detection/angular resolution
77-GHz RADAR	200 m[1]	18°[1]	US$150–175	Adaptive cruise control Forward collision warning	USA bandwith 600 MHz[2]; robust for rain/snow; concerns for people detection/angular resolution
Front Mono Camera	50 m[1]	36°[1]	US$80–100	Lane departure warning Forward collision warning Traffic sign recognition	Versatile sensor (applications); limited depth perception, affected by rain/fog; needs illuminations (visible/IR)
LIDAR (Flash)	50 m	56°	US$60–100 US$60–100	Blind-spot detection Forward collision warning	Concerns for rain/snow; good reflection off people with angular resolution; range and S/N limited by eye safety
LIDAR (Scanning)	120 m	360°[1]	US$100–500	Mapping environment BSD/FCW/LDW/ACC	Concerns for rain/snow; typically higher price for angular resolution; range and S/N limited by eye safety

• False positives – Nuisance to consumer – Turns feature off (if possible)
• False negatives – did not meet spec/expectations
=> Optimum combination of sensors will be a learning process
1: J. Harding et al., "Vehicle to vehicle communications: Readiness of V2V technology for application," National Highway Traffic Safety Administration, Washington, D.C., Rep. DOT HS 812014, 2014, Table V-7.
2: D. Kissenger, *Millimeter Wave Receiver Concepts for 77 GHz Automotive Radar in Silicon Germanium Technology*. New York: Springer, 2012.

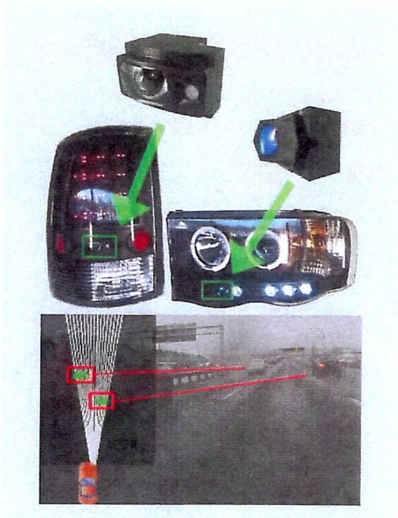


FIGURE 4. Flash LIDAR in headlamp and taillamp. (Courtesy of LeddarTech, Québec, Canada.)

detecting potential safety hazards such as a large piece of tire on the road or a pothole. A flash LIDAR sends out a burst of IR light through a laser to a fixed field of view. The reflected light from objects in the path is received typically in an array of p-i-n photodiodes. This signal is then analyzed to compute the distance and angular location of the object. To achieve better resolution, more photodiodes can be added. For better range, more power is used in combination with a reduced pulsewidth to ensure the duty cycle is eye safe.

FIGURE 5. Flash LIDAR (small enough to fit in a headlamp). (Courtesy of Phantom Intelligence, Québec, Canada.)

The need for scanning LIDAR comes primarily from the quest for the autonomous vehicle. It is widely accepted in the industry that a local instantaneous 3-D map of the environment around the car is needed to navigate it safely. This perception grew out of the Defense Advanced Research Projects Agency challenges where scanning LIDAR was widely used and proved its worth. In support of scanning LIDAR, at the 2016 Consumer Electronics Show (CES), Ford Motor Company announced plans to use Velodyne (Morgan Hill, California) LIDAR for its first autonomous vehicle. Range and resolution are the two key system requirements for scanning LIDAR systems. The range must be back calculated from the maximum speed at which the autonomous vehicle is expected to drive. Angular resolution and the smallest size of an object you want to be able to detect and classify are based on how small of an object can cause the car to have a collision or veer away from its course after collision and then cause harm. It would be difficult to compile a list of objects that are small enough to be undetectable by the sensor but big enough to affect the course of the vehicle. New tire technology that can withstand nails and suspension systems that adapt to potholes make this complex problem easier. The Velodyne HDL-64E datasheet calls out 0.08° of resolution for azimuth (horizontal); at 133 m distance, this equates to an object approximately 7-in wide. Anything smaller than 7 in would not be detected, and as the car gets closer to the object, it appears larger, assuming 100% reflectivity, good weather conditions, and a flat, straight road.

To add further complexity to this issue, software is playing an increasingly larger role in using the raw data from sensors and classifying them as objects for tracking. Data fusion, where raw data from the camera, radar, and other sensors are used to identify and track objects with higher confidence, is evolving in step with sensor hardware capabilities. Figure 6 summarizes the confusion in the industry regarding system specification requirements for scanning LIDAR. With the expected release in 2016 of NHTSA's road map for autonomous vehicles, the industry will take the first step toward standardization of system requirements for various sensors used in external sensing of environment, including scanning LIDAR.

SCANNING LIDAR SYSTEM CONFIGURATIONS

A high-level review of the scanning LIDAR configurations on the market includes the following listed below.

- *Mechanical/spinning LIDAR*: Typically these systems have IR-coherent light emitted from a laser, which is then collimated and circularized into a round beam with optics. Each beam is matched with a receiver, typically an avalanche photodiode (APD). Multiple emitter–detector pairs are mounted on a column that is spun by a motor typically between 10 and 20 Hz. The duty cycles are low to ensure eye safety. The vertical field of view resolution is determined by the number of emitter–detector pairs stacked vertically, while the HFOV resolution is determined by the duty cycle and the motor rotation speed. These systems are believed to have the cleanest signal and noise ratio to date and generally provide 360° HFOV. The challenges are size and cost. There is also some lingering doubt about the need for self-calibration as the motor bearings wear.
- *Microelectromechanical system (MEMS) mirror*: A MEMS mirror is used to scan the FOV with the laser beam, after it has been collimated and circularized to a round shape. The detector side is typically an APD array. MEMS is a proven technology in commercial use. The LIDAR application of MEMS is under development by a number of companies. The attractiveness of this concept is the small form factor and potential ability to reach lower cost with use of proven technology. This will need to be tested by the market when it becomes available. A concept for such a LIDAR is shown in Figure 7.
- *Optical phased array (OPA)*: Similar to the MEMS scanning concept, an OPA is used instead of a MEMS mirror to scan the FOV. OPA is a comparatively new technology in relation to MEMS. Quanergy (Sunnyvale, California) showed a form factor for an OPA LIDAR at the 2016 CES [1].

What Is the Specification? (LIDAR Example)

- System Requirements Drive Component Requirements
- System Requirements Not Well Defined in Initial Stage
  - Application: Map Environment/Avoid Collisior
  - **Range: 100–400 m**
  - Range Accuracy: 2–10 cm
  - FOV Horizontal: 24–360°
  - FOV Vertical: 6–20°
  - **Angular Resolution: 0.3–30°**
  - Operating Conditions: –40–125°C
  - Packaging/Mounting: Small/Should Not be Noticeable/ Should be Robust for Usage and Service
  - SOP: One to Five Years
  - Test Specifications/Regulation: Not Available Yet
  - Price: US$
- **Takeaways**
  - Manufacturers Developing Modular Designs—Meet High/Low End of Spec
  - Road Map from NHTSA/OEM/Tier 1s Can Speed Up Innovation Efforts

FIGURE 6. The system specification requirements for scanning LIDAR can be confusing.

The next few years will be competitive for these different technologies as they carve out their niche in the scanning LIDAR market. A number of nonautomotive markets also have high interest in LIDAR technology, such as drones, mining, and military.

LASER/EMITTER CONSIDERATIONS

Ideally one would like to realize a high signal-to-noise ratio by blasting out as much laser power as possible at the object to be detected; however, this would not be safe for the human eye. Lasers with wavelengths between 400 and 1,400 nm can reach the retina and create permanent damage if the exposure time and power density are above acceptable eye safe limits. Lasers above 1,400 nm are typically more expensive, though safer for the eye at higher power limits. The wavelength of choice is currently 905 nm, as these lasers are comparatively economical and are able to achieve the desired range with a low duty cycle. They are also available in various packages and power levels from multiple suppliers. Pulsewidth is another key performance criterion for the

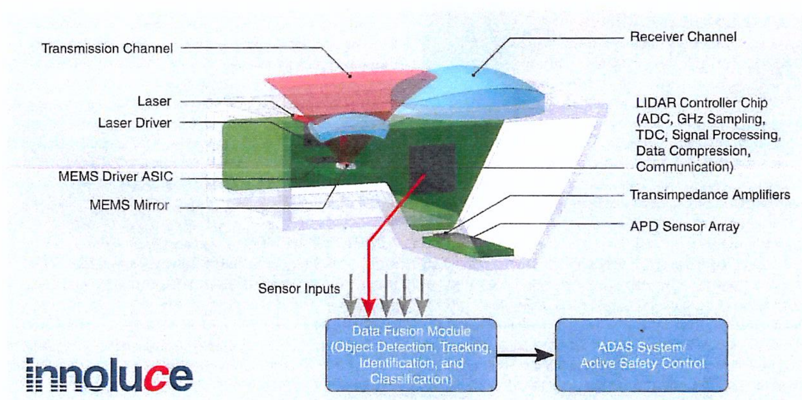
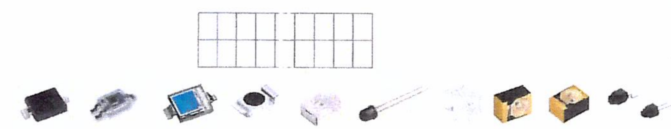


FIGURE 7. An artist's impression of a LIDAR sensor. (Courtesy of Innoluce, Nijmegen, The Netherlands.)

- **Sensitivity**: High (50 A/W) → APD; Low (0.5 A/W) → p-i-n Photodiode
- **Wavelength**: 905/1,550 nm → Compatible with Laser Peak Wavelength
- **Cost**: APD Typically 20X More Than Photodiode
- **Package**: Single/Array → Depends on System Design

• Photodiode	• Fast Switching Time (10 ns); Linear Response; Small Temperature Coefficient; Preferred in Flash LIDAR
• Phototransistor	• High Photocurrent; Small Package; Cheaper; Higher Temperature Coefficient
• Avalance Photodiode	• High SNR/Voltage Supply/Temperature Sensitivity/Price; Preferred in Scanning LIDAR
• Single Photon Multiplier	• Higher Gain Than APD at Lower Operating Voltage; Dynamic Range/Recovery Time Poor–Improving

Near Future: Considering Photodiode Arrays NxM for Collision Avoidance LIDAR



A/W–Amperes/Watt; APD–Avalanche Photodiode; SNR–Signal to Noise Ratio; LIDAR–Light Detection and Ranging

FIGURE 8. Photodetectors—requirements and road map. (Courtesy of OSRAM Opto Semiconductors.)

laser. A smaller pulsewidth allows a higher peak power to be used while still being safe for the eye because the average power and exposure time are low. OSRAM's road map includes a surface-mounted laser package with >100-W peak power and <5-ns pulsewidth.

RECEIVER CONSIDERATIONS

The peak wavelength photosensitivity of the receiver and emitter wavelength should match, typically 905 nm. The pulsed IR laser light from the emitter hits an object in its FOV and, based on surface conditions and optics, a part of this IR light is received back into the LIDAR through a receiving lens into an array of p-i-n photodiodes or other receiver elements. Since the emitter and receiver windows are clocked and synced, it is possible to calculate to which cylindrical section the return signal belongs.

The more photodiode pixels there are, the more resolution you achieve on the angular position of the object in the FOV of the receiving lens. When the returning amount of reflected light is very low, you want high sensitivity to ensure you get a signal. APDs are used in scanning LIDAR units (sensitivity 100× greater than p-i-n photodiode; typically at 20× higher price for similar receiving area). You also want low sensitivity to temperatures. Single photon multipliers are also an option but seem to suffer from low dynamic range and slow recovery time issues. Finally, the package of the array ideally should be small and suit mass-manufacturing techniques (see Figure 8).

The technology for self-driving cars is already available. The challenge now is standardizing the functions and testing requirements in usage conditions. The usage conditions will expand from ADASs to city driving conditions and maybe off highway at some point in the future. In early stages, one could imagine, for example, automated car lanes to piggyback on carpool lanes. Consumers have shown that they are willing to pay for active safety, but the jury is still out on the question of whether a consumer would purchase a car without a steering wheel. The sensors to assist ADASs, including LIDAR, will evolve rapidly to serve the autonomous driving market. NHTSA's plan to publish a road map this year for the autonomous car will provide a landmark document for the industry and will help to define the picture of what is to come.

ABOUT THE AUTHOR

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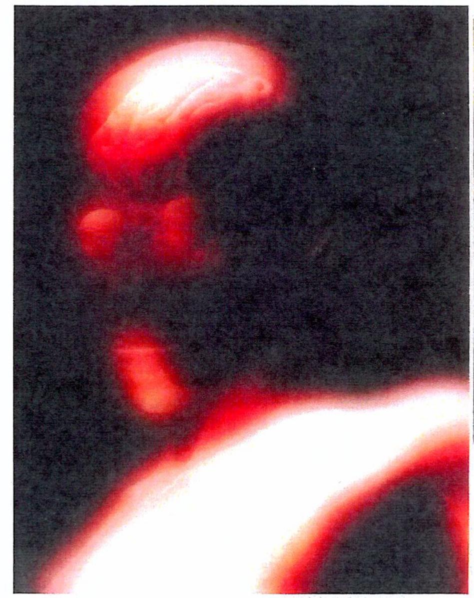
How Should the State of the Brain Be Described?

By Narisa N.Y. Chu

A call to standardize descriptions of brain states for data collection and research.



The IEEE Brain Initiative and the Consumer Technology Association (CTA, formerly the Consumer Electronics Association) promote brain research, development, and commercialization. CTA's recent standardization of electroencephalogram (EEG) signal data interoperability facilitates brain technology developments in the Internet environment for consumer-friendly applications. Emerging brain-computer interface (BCI) consumer products have accelerated new tool development to be blended seamlessly in rehabilitation, education, and entertainment. It has been observed that, while some of these developments flourish via collaboration, others tend to proliferate. To continue the recent commercialization advancement in BCI headsets, it behooves the industry to standardize EEG brain signal collection to form an open databank to allow data exchange via the Internet. Specific issues are raised with respect to the fundamental harmonization of brain states and its linkage to EEG signals for big data analytics and Internet of Things connectivity. Replacing proprietary formats with standard EEG data is the purpose of this article, and the progress and challenges of the ongoing standardization effort within the CTA are discussed.

BACKGROUND

CTA's Standards Committee R6 SC4 WG3 on Health Care began its specifications for EEG data interoperability on 16 September 2015. Nima Bigdely-Shamlo, the committee chair, and Christian Kothe of Qusp brought in XDF open-source software interface specifications as the starting documentation for #2060 in a series of standards as follows:

- #2057, Local Transmission—Lab Streaming Layer (LSL)
- #2058, Event Description—Hierarchical Event Descriptor (HED)
- #2059, User Brain State Description
- #2060, File Storage—Extended Data Format (XDF)
- #2061, Group-Level Metadata Encapsulation—EEG Study Schema (ESS).

The structure and the scope of EEG data exchange network flow are shown in Figure 1. Recommended standards, designated in red in the figure, are mostly available from open source. These standards facilitate the data flow architecture not only for BCI local access and processing, but throughout the Internet with big data analytics prospects for global processing. A presentation made by Bigdely-Shamlo, on 5 November 2015, reported that initial brain research led by the Army Research Laboratory had accumulated 855 GB of data from 756 recording sessions (16 studies) using

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