

F R O S T & S U L L I V A N

FROST & SULLIVAN BEST PRACTICES AWARD

LIGHT DETECTION AND RANGING - NORTH AMERICA

Price/Performance Value Leadership 2019



FROST & SULLIVAN

2019

BEST
PRACTICES
AWARD

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Background and Company Performance

Industry Challenges

With autonomous driving poised to revolutionize the automotive industry, vehicle manufacturers, shared mobility companies, and Tier I suppliers have begun making strategic investments in lidar technologies. Lidar can detect objects at greater distances with higher accuracy and better fidelity than possible with other technologies, such as radar, and does so using a high-resolution 3-D characterization of objects in a scene. Lidar hardware in self-driving cars works by giving advanced driver assistance systems (ADAS) the ability to accurately decipher surroundings through a 3-D representation of a point cloud formed by collated laser light reflections.

A lidar-equipped ADAS precisely determines how far objects are from the vehicle, ensuring quick and controlled driving decisions that prevent collisions. Unlike cameras, lidar collects and delivers data at the highest resolution in any type of weather, day or night.

Lidar systems have historically been expensive, typically costing approximately US \$75,000 per unit (or more). Vendors are under tremendous pressure to keep prices competitive, but most lidars' complex design—including non-silicon digital components, fiber lasers, transducers, optical analyzers, and microprocessors—makes it more expensive than radar, ultrasonic sensors, and cameras. Traditional mechanical and solid-state lidar offerings feature thousands of discrete components, and higher range or resolution comes at the expense of power consumption, form factor, and/or cost.

Automakers are on the lookout for a cost-effective, mass market-ready, high-performance lidar that has a high angular resolution and frame rate, long detection range, and a small form factor. A solution that meets these needs will move them closer to their end goal of level 4 and 5 autonomous driving.

Price/Performance Attributes and Customer Impact

Bridging market gaps with mass, form factor, and power improvements

San Francisco-based technology start-up Ouster commercially launched its OS-1-64 lidar sensor in December 2017 as a budget-friendly option for mass market production. Its dramatically simplified architecture and 7th-generation custom silicon design provide unmatched resolution and performance in a smaller size and lighter weight.

Ouster's next-generation lidar offers the momentum that autonomous driving technology needs, and Frost & Sullivan recognizes Ouster's OS-1-64 as a display of true best-in-class performance and innovation. This is evident by the sensor's numerous abilities, such as the measurement of 1.3 million points per second using less than 17 watts of power—something that was previously difficult for high-performance lidar. Additionally, it has the range to detect objects up to 120 meters away.

Comparatively, the OS-1-64 sensor is as much as 30 times smaller than competitors' solutions and can easily fit into a headlight cluster, windshield-mounted system, or side-view mirror. It is 73 mm tall and 85 mm in diameter and weighs only 380 grams, which is roughly the size of a baseball and about twice as heavy as one. OS-1-64's low beam divergence (more than 2.5 times smaller spot sizes/better spatial resolution) and wide field of view at 33.2 degrees vertical allows for a deeper, more detailed, and clearer view of surroundings than scanners, cameras, or radars.

Ouster's sensors are unique among high-resolution lidar sensors for another reason—they operate at the near-infrared 850nm wavelength. The company's patented light filtering technology allows it to use the 2x signal found at 850nm while avoiding the penalty of the 5x noise typically seen there. The 850nm wavelength has been shown to have lower atmospheric water vapor absorption and more consistent operation compared to other available lidar operating wavelengths.

This translates to an operating wavelength that is not absorbed by humid air or fog, heightening the sensitivity of its low-cost silicon complementary metal-oxide semiconductor (CMOS) technology while improving resolution and reliability. The constant laser power also delivers a more consistent image because it is largely unaffected by solar interference and works nearly as well in bright sunlight as it does at night.

The OS-1-64 produces structured lidar data in which horizontal and vertical angular spacing are perpetual, yielding fixed-size 2048x64-pixel depth map and ambient light images on every single frame. Frost & Sullivan found that the OS-1-64's ambient light rejection capabilities excel in the market, effectively viewing obstacles using a lower ambient flux than needed by the wavelengths used by competitors.

OS-1-64 brings an aggressively priced lidar sensor to a more diverse customer set

Ouster has gained the market's attention with an aggressively priced lidar platform. Frost & Sullivan found that many of Ouster's peers remain stuck in the research and development phase because they struggle to identify a cost-effective architecture and components that are suitable for mass production.

Ouster uses vertical-cavity surface-emitting laser (VCSEL) and single photon avalanche diode (SPAD) technologies that are found in consumer devices, including iPhones, to improve sensing resolution. Its custom VCSEL modules integrate all lasers onto a single semiconductor die, and increase brightness by orders of magnitude while reducing light pulses to a few nanoseconds. Ouster has made significant progress eliminating the high-cost materials used in traditional lidars through its patented new multi-beam flash lidar technology, which uses two custom semiconductor chips (one monolithic laser array and one monolithic receiver ASIC) with no moving parts. Ouster integrated this technology into both its OS-1 and OS-2 product lines. The simpler architecture of this patented technology has enabled it to replace nearly all of the high-cost components in a lidar

system, allowing it to introduce an aggressively priced lidar into the market. While competitive offerings include about 12 components at the sensor level and more than 100 components at the system level for every channel, the OS-1-64 unifies all 64 channels and processes all digital signals on one chip. The OS-1-64 detector can store more than 1 trillion photons per second in its on-chip memory, and ultimately generate the millions of 3-D points per second that are needed for autonomous driving.

This simple design allows sensors to be assembled much faster, and Ouster can build a sensor at its final assembly facility in San Francisco's Mission District in about an hour—competitors need more than 40 hours to complete a single sensor. Ouster is already producing 400 to 500 OS-1-64 sensors per month and will have the capacity for several thousand sensors per month by the end of 2019.

It is expected that the OS-1-64 will help ADAS manufacturers achieve economies of scale at \$12,000 per unit. With an even more aggressive pricing strategy for high-volume orders, Ouster could achieve a price more than 80% lower than its competition.

Ouster has won the confidence of top-tier global suppliers and venture capital firms

Ouster has raised \$90 million from investors, including \$27 million in a Series A funding round in late 2017. Despite only being established in 2015, Ouster has been successful in winning the confidence of the top 10 automotive original equipment manufacturers (OEMs) and Tier I global suppliers, in addition to top-tier investors (including Cox Enterprises, Amity Ventures, Fontinalis Partners, Tao Capital Partners, Carthona Capital, and Constellation Technology Ventures). The goals of these investors align with the company's mission of disrupting the lidar market by designing cutting-edge, low-cost lidar suited for mass production.

Ouster's success has moved beyond automotive OEMs, and it has established new clients in the robotics industry for a wide range of applications, in addition to clients in the factory automation, mining, agriculture, drone, security, defense, and surveying industries. In all, the company has established over 450 customers across 15 different vertical industries. For factory automation, some key applications are in the area of package delivery, warehouse automation, mapping, and collision avoidance. In mining, key applications include safe navigation, mapping, and cold-weather performance, while in fixed-installation building security, Ouster's lidar can provide accurate visual data for intrusion detection that works as well during the day as it does at night.

Ouster's technology combines the best capabilities of cameras and lidar onto a single solution

Ouster has introduced an ambient light-sensing solution that combines the best capabilities of cameras and lidar. Ouster aggressively leverages this proprietary technology to offer

extremely high-resolution 3-D characterization of objects and depth images without significant backend processing and without the need of a separate camera.

Ouster's superior technology is reflected by its offer of a linear photo response. Frost & Sullivan notes that through extensive technological innovation, the company outperforms competitors with its superior low light sensitivity and ability to collect and deliver data at the highest resolution in a wide variety of weather conditions and environments. Ouster captures signal and ambient data at each pixel to deliver a 3-D frame with a very natural image and 360-degree panoramic frame, which most competitors lack.

Ouster's lidar offers superior image quality

Ouster's OS-1-64 solution captures and correlates laser light, ambient light, and depth. These layers are perfectly aligned and correlated in space and time with zero mismatch because they are captured by the same sensor, not two different sensors. According to the company, it is able to feed these layers and images with deep-learning algorithms. Customers are able to distinguish surrounding vehicles from contextual objects with in-depth information about every pixel in an image. The data layers have 16 bits per pixel and a greater linear response than competing products, creating unmatched object clarity and classification at about half the cost.

Ouster has demonstrated the use of deep learning algorithms made for cameras on lidar data for the first time. Frost & Sullivan applauds the company for successfully delivering a sensor with this unique capability.

Ouster showcases its commitment to delivering its customers best-in-class and superior image quality offering highest resolution depth images and ambient images in real time without motion distortion. Frost & Sullivan's research shows that Ouster delivers unmatched imaging solutions related to object capturing, object identification, and mapping generating a rectilinear image that looks like the image gathered from a camera.

Moreover, Ouster provides a better spatial resolution. OS-1-64 delivers one of the highest resolutions available today. The spot size at 100 meters is anywhere from 3 to 6 times smaller than existing offerings. Compared to other lidar sensors available, with high field failure rates that increase with high resolution, Ouster presents one of the lowest failure rates in the industry. Ouster offers increased resolution without any trade-off and provides performance without compromise.

Conclusion

The automotive industry is swiftly moving towards an autonomous future, but for the autonomous driving market to really take hold, the necessary sensor technology needs to greatly improve. Current solutions are prohibitively expensive, fail frequently in the field, lack resolution, are bulky, and have environmental limitations. Driven by its passion to disrupt the autonomous driving market, Ouster has developed a solution to make up where traditional sensing technologies like cameras and radar have fallen short. As self-driving technology hits the road, Ouster is finding greater acceptance in robotaxis that will begin to commercialize their services in the next few years. Some of Ouster's customers have found that their technology's failure rate is the lowest they have seen in the industry so far, touting nearly 90 percent lower than others available in the market today. While this is an important requirement in robotaxis, it is also a key feature that will put the company at an advantage when catering to the exacting needs in mining and agriculture applications.

Ouster's scalable OS-1-64 solution has enhanced the size, capabilities, and power requirements of lidar, and done so at a price point that overcomes the cost constraints hampering the market. With its proven ability to mass manufacture its solution, Ouster is expected to reduce the pricing pressure OEMs and Tier I suppliers experience as they strive to achieve economies of scale.

For its strong overall performance, Ouster has earned Frost & Sullivan's 2018 Price Performance Value Leadership Award.

Significance of Price/Performance Value Leadership

Ultimately, growth in any organization depends upon customers purchasing from your company, and then making the decision to return time and again. A key component of customer retention is the delivery of a high-quality product at a reasonable price. To achieve these dual goals (customer engagement and price/performance), an organization must strive to be best-in-class in three key areas: understanding demand, nurturing the brand, and differentiating from the competition.



Understanding Price/Performance Value Leadership

Best-in-class organizations are particularly successful in two critical areas: first, helping customers to appreciate and enjoy the product at every price point; and second, ensuring that customers perceive a demonstrable difference in performance features at every escalating price point. Ultimately, this balance allows companies to profitably deliver a variety of product options to customers, differentiate the product suite, and compete at every level of the market.

Key Benchmarking Criteria

For the Price/Performance Value Leadership Award, Frost & Sullivan analysts independently evaluated two key factors—Price/Performance Attributes and Customer Impact—according to the criteria identified below.

Price/Performance Attributes

- Criterion 1: Functionality
- Criterion 2: Ease of Use
- Criterion 3: Product/Service Quality
- Criterion 4: Performance Reliability
- Criterion 5: Prioritization of Features

Customer Impact

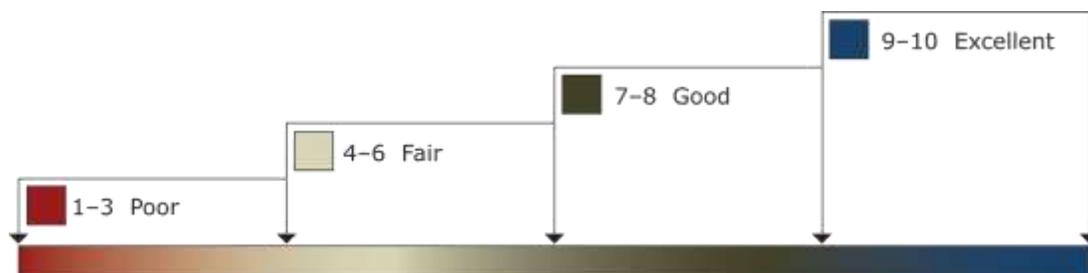
- Criterion 1: Perceived Value
- Criterion 2: Customer Purchase Experience
- Criterion 3: Customer Ownership Experience
- Criterion 4: Customer Service Experience
- Criterion 5: Brand Equity

Best Practices Award Analysis for Ouster

Decision Support Scorecard

To support its evaluation of best practices across multiple business performance categories, Frost & Sullivan employs a customized Decision Support Scorecard. This tool allows our research and consulting teams to objectively analyze performance, according to the key benchmarking criteria listed in the previous section, and to assign ratings on that basis. The tool follows a 10-point scale that allows for nuances in performance evaluation. Ratings guidelines are illustrated below.

RATINGS GUIDELINES



The Decision Support Scorecard is organized by Growth Performance and Customer Impact (i.e., These are the overarching categories for all 10 benchmarking criteria; the definitions for each criterion are provided beneath the scorecard). The research team confirms the veracity of this weighted scorecard through sensitivity analysis, which confirms that small changes to the ratings for a specific criterion do not lead to a significant change in the overall relative rankings of the companies.

The results of this analysis are shown below. To remain unbiased and to protect the interests of all organizations reviewed, we have chosen to refer to the other key participants as Competitor 2 and Competitor 3.

<i>Measurement of 1-10 (1 = poor; 10 = excellent)</i>			
Price/Performance Value Leadership	Price/Performance Attributes	Customer Impact	Average Rating
Ouster	8.8	9.0	8.9
Competitor 2	8.5	8.5	8.5
Competitor 3	8.0	7.8	7.9

Price/Performance Attributes

Criterion 1: Functionality

Requirement: The product offers enhanced functionality to serve the broadest range of applications

Criterion 2: Ease of Use

Requirement: Customers typically feel that the products are easy to use to generate optimal performance

Criterion 3: Product/Service Quality

Requirement: Products or services offer the best quality for the price, compared to similar offerings in the market

Criterion 4: Performance Reliability

Requirement: The product consistently meets or exceeds customer expectations for performance over its life cycle

Criterion 5: Prioritization of Features

Requirement: The features that customers most value and expect are most commonly available and most aggressively priced

Customer Impact

Criterion 1: Perceived Value

Requirement: Customers typically feel that they received more from the product or solution than they paid for it

Criterion 2: Customer Purchase Experience

Requirement: Customers feel like they are buying the most optimal solution that addresses both their unique needs and their unique constraints

Criterion 3: Customer Ownership Experience

Requirement: Customers are proud to own the company's product or service, and have a positive experience throughout the life of the product or service

Criterion 4: Customer Service Experience

Requirement: Customer service is accessible, fast, stress-free, and of high quality

Criterion 5: Brand Equity

Requirement: Customers have a positive view of the brand and exhibit high brand loyalty

Decision Support Matrix

Once all companies have been evaluated according to the Decision Support Scorecard, analysts can then position the candidates on the matrix shown below, enabling them to visualize which companies are truly breakthrough and which ones are not yet operating at best-in-class levels.



Best Practices Recognition: 10 Steps to Researching, Identifying, and Recognizing Best Practices

Frost & Sullivan analysts follow a 10-step process to evaluate Award candidates and assess their fit with select best practices criteria. The reputation and integrity of the Awards are based on close adherence to this process.

STEP	OBJECTIVE	KEY ACTIVITIES	OUTPUT
1 Monitor, target, and screen	Identify Award recipient candidates from around the globe	<ul style="list-style-type: none"> • Conduct in-depth industry research • Identify emerging sectors • Scan multiple geographies 	Pipeline of candidates who potentially meet all best-practices criteria
2 Perform 360-degree research	Perform comprehensive, 360-degree research on all candidates in the pipeline	<ul style="list-style-type: none"> • Interview thought leaders and industry practitioners • Assess candidates' fit with best-practices criteria • Rank all candidates 	Matrix positioning all candidates' performance relative to one another
3 Invite thought leadership in best practices	Perform in-depth examination of all candidates	<ul style="list-style-type: none"> • Confirm best-practices criteria • Examine eligibility of all candidates • Identify any information gaps 	Detailed profiles of all ranked candidates
4 Initiate research director review	Conduct an unbiased evaluation of all candidate profiles	<ul style="list-style-type: none"> • Brainstorm ranking options • Invite multiple perspectives on candidates' performance • Update candidate profiles 	Final prioritization of all eligible candidates and companion best-practices positioning paper
5 Assemble panel of industry experts	Present findings to an expert panel of industry thought leaders	<ul style="list-style-type: none"> • Share findings • Strengthen cases for candidate eligibility • Prioritize candidates 	Refined list of prioritized Award candidates
6 Conduct global industry review	Build consensus on Award candidates' eligibility	<ul style="list-style-type: none"> • Hold global team meeting to review all candidates • Pressure-test fit with criteria • Confirm inclusion of all eligible candidates 	Final list of eligible Award candidates, representing success stories worldwide
7 Perform quality check	Develop official Award consideration materials	<ul style="list-style-type: none"> • Perform final performance benchmarking activities • Write nominations • Perform quality review 	High-quality, accurate, and creative presentation of nominees' successes
8 Reconnect with panel of industry experts	Finalize the selection of the best-practices Award recipient	<ul style="list-style-type: none"> • Review analysis with panel • Build consensus • Select recipient 	Decision on which company performs best against all best-practices criteria
9 Communicate recognition	Inform Award recipient of Award recognition	<ul style="list-style-type: none"> • Present Award to the CEO • Inspire the organization for continued success • Celebrate the recipient's performance 	Announcement of Award and plan for how recipient can use the Award to enhance the brand
10 Take strategic action	Upon licensing, company is able to share Award news with stakeholders and customers	<ul style="list-style-type: none"> • Coordinate media outreach • Design a marketing plan • Assess Award's role in future strategic planning 	Widespread awareness of recipient's Award status among investors, media personnel, and employees

The Intersection between 360-Degree Research and Best Practices Awards

Research Methodology

Frost & Sullivan's 360-degree research methodology represents the analytical rigor of our research process. It offers a 360-degree-view of industry challenges, trends, and issues by integrating all 7 of Frost & Sullivan's research methodologies. Too often companies make important growth decisions based on a narrow understanding of their environment, leading to errors of both omission and commission. Successful growth strategies are founded on a thorough understanding of market, technical, economic, financial, customer, best practices, and demographic analyses. The integration of these research disciplines into the 360-degree research methodology provides an evaluation platform for benchmarking industry participants and for identifying those performing at best-in-class levels.

360-DEGREE RESEARCH: SEEING ORDER IN THE CHAOS



About Frost & Sullivan

Frost & Sullivan, the Growth Partnership Company, enables clients to accelerate growth and achieve best-in-class positions in growth, innovation and leadership. The company's Growth Partnership Service provides the CEO and the CEO's Growth Team with disciplined research and best practices models to drive the generation, evaluation and implementation of powerful growth strategies. Frost & Sullivan leverages more than 50 years of experience in partnering with Global 1000 companies, emerging businesses, and the investment community from 45 offices on six continents. To join our Growth Partnership, please visit <http://www.frost.com>.