WHAT'S INSIDE?

H1 2019

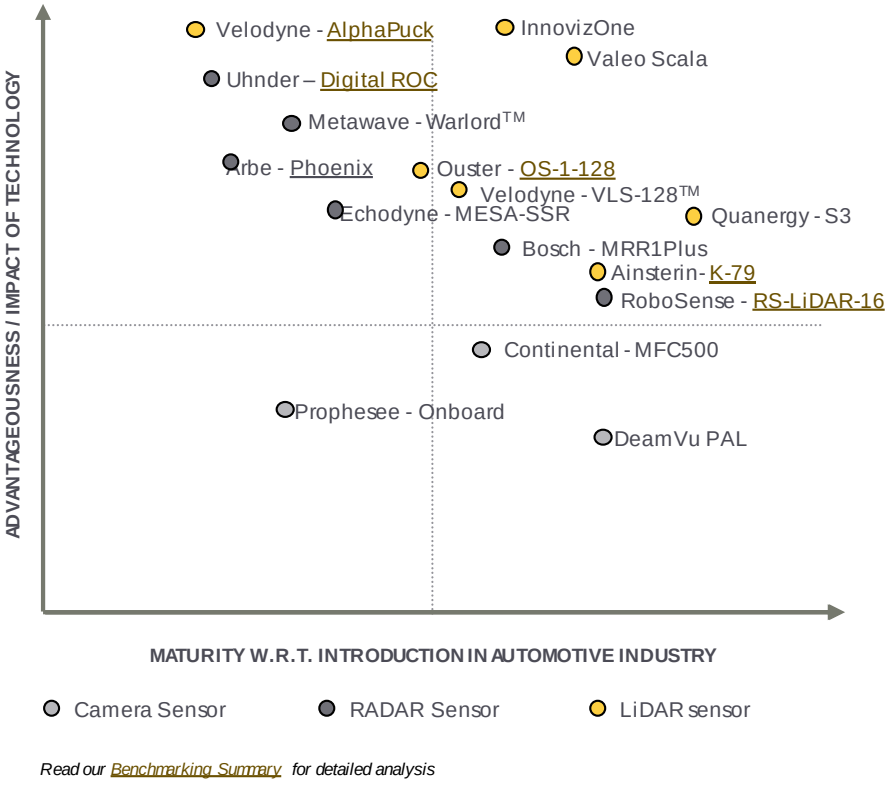
EXECUTIVE LENS

Summarized insights for Vision Systems w.r.t. trends in technology, market, and players

FutureBridge

State of the Trend

Vision sensor technology is being enhanced by companies working on higher detection range, enhanced reliability, smaller size and lower cost



Read our Benchmarking Summary for detailed analysis

- Many companies are enhancing range and effectiveness of their LiDARs using multiple techniques like surface mount flip chip, FMCW, etc. Read Technology Take-offs for details
- Tools like AI is being used by companies to enhance the input from vision sensors like Radar, LiDAR and camera
- Headlight manufacturer's are betting on partnership to fit vision sensors like LiDAR, Radar, etc. into headlamp assembly
- Some companies are using only cameras with some enhanced detection hardware and sophisticated software for autonomous vehicle, but effectiveness of same in harsh conditions are unknown

Key Developments in the past 6 months

Technology — TuSimple demonstrated production quality camera system for night driving capabilities

Technology — Uhnder introduces first digital automotive RADAR-on-chip

Adoption — RoboSense lidar to equip GACHA bus fleet for winter conditions

Funding — BrightWay Vision gets funding from Headlight Manufacturer KOITO and Magenta

Read Funding Summary for more

Emerging Trends

Collaborations in the industry for 'efficient, size and cost optimized LiDARs':

Single chip imaging radar systems from various players;

Partnerships to develop up to date high definition maps;

Players join hands to develop new LiDAR systems with better functionalities

- ams, Ibeo and ZF: Trio partners to develop solid state LiDAR >>
- Aurora acquires Blackmore to deliver safer, efficient and cost effective vision solutions >>
- Blickfeld and Koito partners to develop LiDARs fully integrated to headlights >>

Single chip imaging Radar solutions for autonomous cars

- Vayyar launches the First Single-Chip Imaging Radar to enable high-resolution 4D point cloud for automotive applications >>
- Uhnder readies to roll out single-chip, digital radar solution that could be used for imaging applications on autonomous cars >>
- Arbe robotics exhibits 4D imaging RADAR system >>

Partnerships and mergers to develop up to date localized High Definition maps

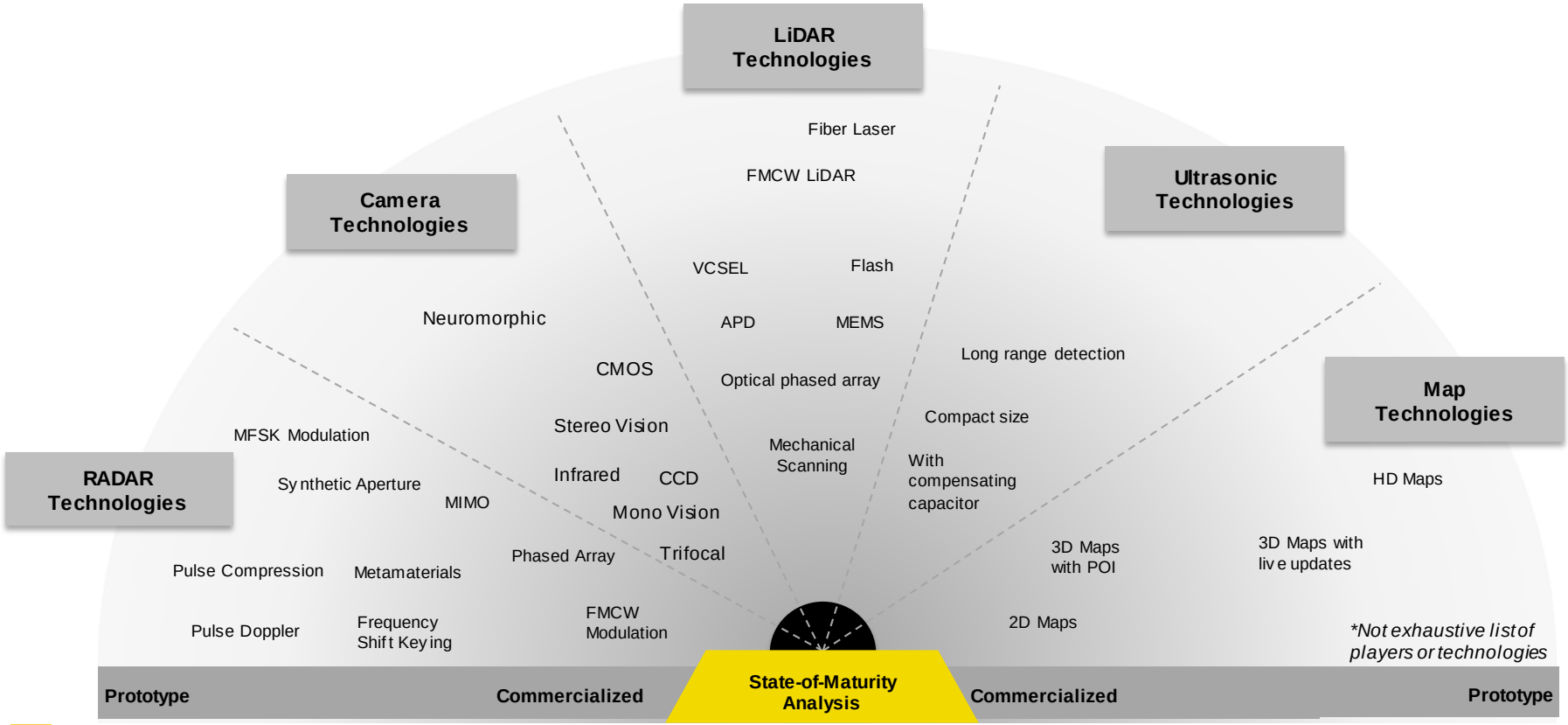
- Toyota and Carmera team up to build high definition maps >>
- TomTom Collaborates with DENSO to Develop End-To-End Autonomous Driving System >>
- HERE Technologies, the digital mapping company, has partnered with China's Navinfo to offer location services in China. >>

- More players are partnering to develop efficient and cost effective LiDAR solutions for autonomous systems
- Vehicle component manufactures and LiDAR players made partnership to integrate LiDAR to various automotive components such as headlights, bumpers, windshields etc.
- Developments were made towards the improvement of resolution and size optimization of automotive radars

For more details read our Pulse >>

Maturity Fan

Technologies enabling 3D vision (in Camera), Antenna miniaturization (in Radar) and solid state LiDARs moving faster towards commercialization



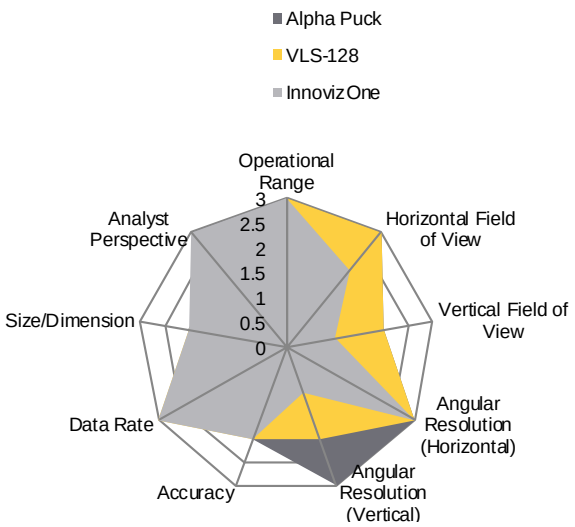
Benchmarking Summary

Alpha Puck from Velodyne leads in LiDAR, Warlord from Metawave in Radar and MFC500 from continental in cameras

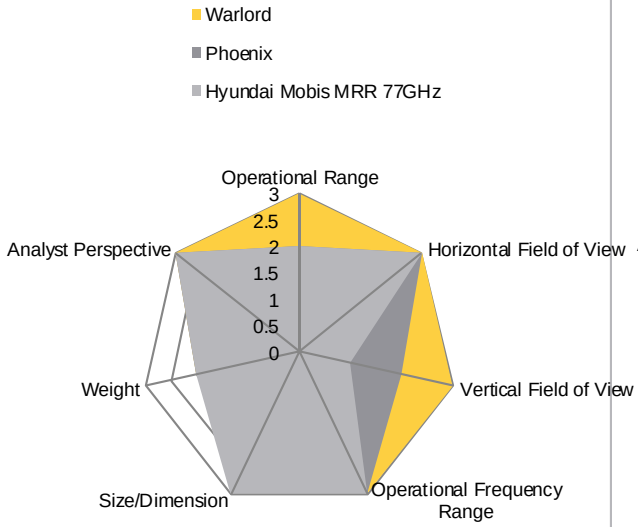
- Alpha Puck by Velodyne is the leading LiDAR followed by Velodyne VLS 128 and then by InnovizOne.
- In case of Radars Warlord is the leading one followed by Phoenix and Hyundai Mobis MRR 77.
- Among Cameras Continental MFC 500 is the best followed by Dream Vu and then by ZF Tri-cam.

Top three products of a long list are shown here based on cumulative performance against key parameters

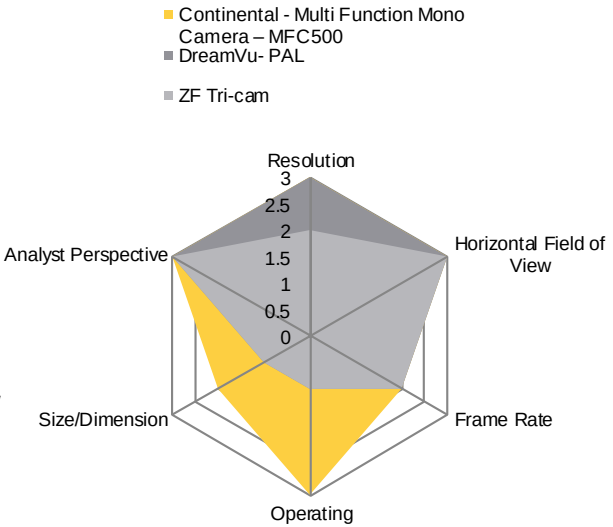
LiDAR



RADAR



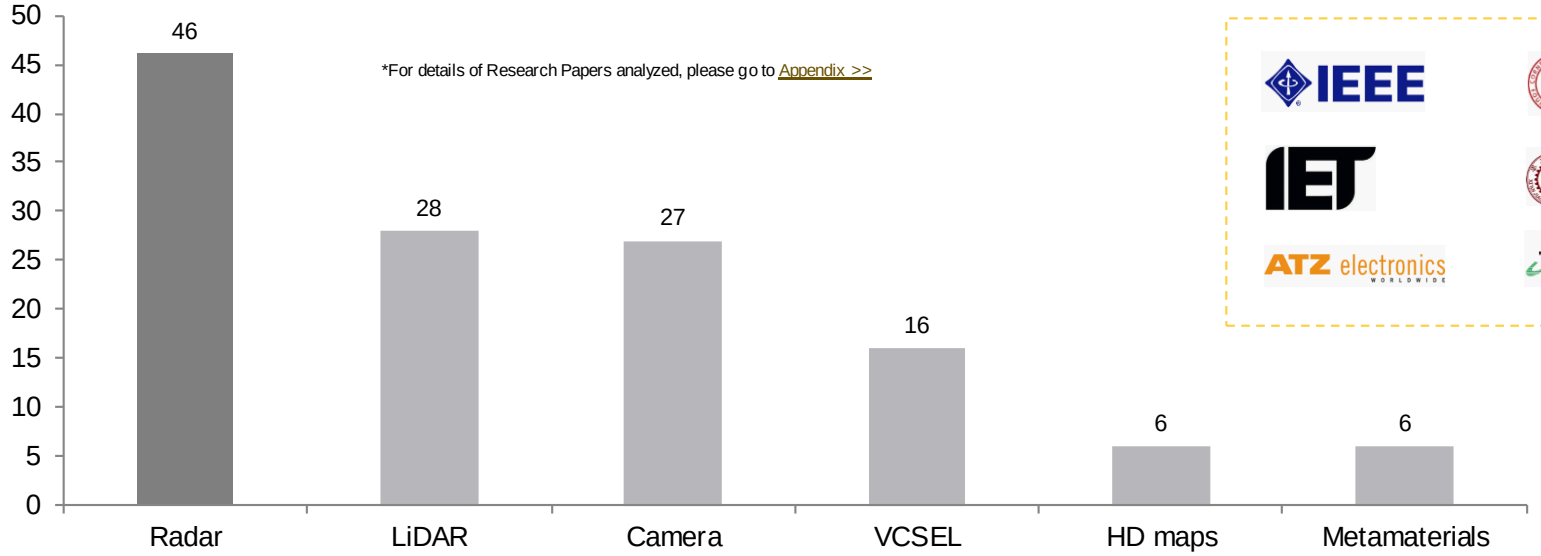
Camera



Read Benchmarking Chapter for more details

Research Activity Summary

Academic research is very active in vision system areas especially in addressing range, cost and detection challenges



*For details of Research Papers analyzed, please go to Appendix >>

IEEE | Cornell University | IET | 西安交通大學 XIAN JIAOTONG UNIVERSITY | ATZ electronics WORLDWIDE | TAIPEI TECH 國立臺北科技大學 National Taipei University of Technology

- Many researchers are exploring ways to increase detection capacity of vision sensors by changing frequencies, using AI based software, etc.
- Combining data from LiDAR, radar and camera whichever are available and putting in HD maps effectively can reduce error of sensing than using data in separation
- Research points out to effective transfer of data using V2X for enhanced detection range and reduce cost of sensor systems than trying to increasing vision sensor performance after certain limit

Challenges & Potential Solutions

Software based technological upgrades is solving many challenges of LiDAR and Radar systems

There are many challenges in case of LiDAR and Radar sensor faced by industry.

Researchers are coming up with innovative ideas to reduce cost, improve detection, faster and safer sensor data transfer, etc.

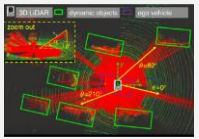
CHALLENGES

LiDAR Systems

Uncertainty estimation of LiDAR matching aided by dynamic vehicle detection and high definition map

Uncertainty of LiDAR matching(ULM) and aiding higher accuracy >>

- A novel Uncertainty of LiDAR matching(ULM) is proposed with help of dynamic vehicle detection and HD maps
- Better accuracy compared to conventional Hessian matrix-based approach
- Researchers propose to correlate ULM with detected DV and convergence feature of matching algorithm for calculating ULM



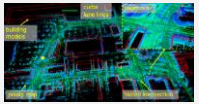
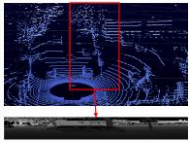
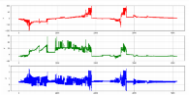


Image-based compression of LiDAR sensor data

LiDAR data compression makes faster and safer data transfer >>

- A method of compression of LiDAR data for high compression ratio, low computational requiring and least loss of data is explained in research paper
- It proposes conversion of LiDAR data into a 2D image array and using existing image compression method



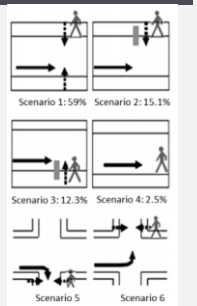


Radar Systems

Pedestrian recognition using micro Doppler effects of radar signals based on machine learning and multi-objective optimization

A pedestrian detection method using 79 GHz radar >>

- Proposed method aims early detection of pedestrians using micro Doppler characteristics of human body in near to crash situations (0–15 m)
- It says model involving a polynomial kernel for Support Vector Machine reported better result in terms of accuracy (99.5%)



High-Density clutter recognition and suppression for automotive Radar systems

Increasing radar detection capability using clutter recognition and suppression >>

- On the basis of distinctive beat frequency distribution in high-density clutter environment recognition parameter is defined
- Clutter is suppressed using correlation between up-chirp and down-chirp received signals

Challenges & Potential Solutions

Camera driven autonomous vehicle is being heavily researched and HD maps are getting sophisticated

Many researchers are developing a camera based approach in Autonomous Vehicle to reduce cost significantly and HD map optimization can help in AV localization

CHALLENGES

Camera Systems

Project AutoVision: localization and 3D scene perception for an autonomous vehicle with a multi-camera system

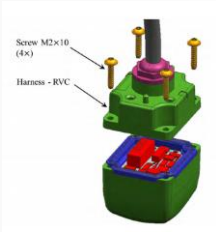
Navigating vehicle using multiple cameras >>

- Autonomous mobility has been showcased using localization and without GNSS
- Pilot project used 16 cameras and 4 LiDARs for 3D perception and navigation

Investigation on the Material Failure in a Small Scale Automotive Camera Module via Root Cause Analysis and Experimental Validation

Camera module material failure analysis >>

- Research paper investigated lens holder material failure using root cause analysis and experimental validation
- The lens holder structure has optimized after identifying structural problem and improved with 35% increase in strength

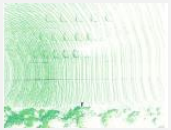


HD Maps

Exploiting sparse semantic HD Maps for self-driving vehicle localization

HD maps for autonomous vehicle localization >>

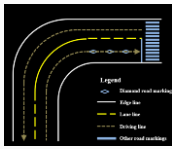
- Research paper demonstrates a localization system capable of localizing an autonomous vehicle against a map requiring roughly three orders of magnitude less storage than traditional methods
- System has been tested by authors for about 300 km for effectiveness of same



Generation of horizontally curved driving lines in HD Maps using Mobile Laser Scanning Point Clouds

HD Maps generation using mobile laser scanning >>

- Research paper proposes a semi-automated driving line generation method using point clouds acquired by a mobile laser scanning system
- The generated HD maps using the method explained in research paper can be used in AV for data localization

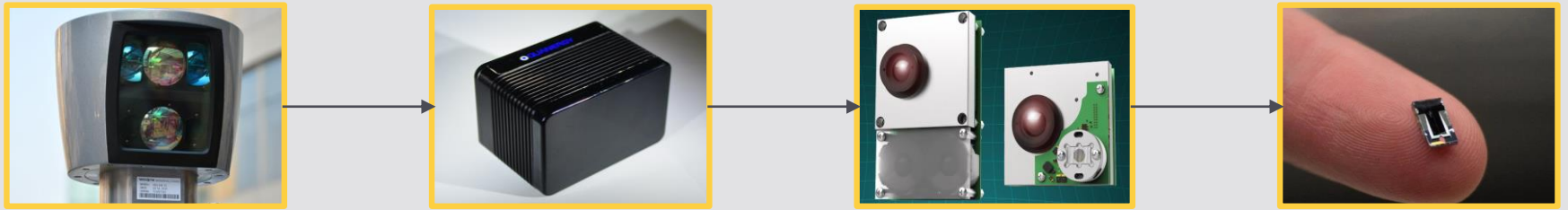


SoC – Innovations in Vision Sensors driven by need of Miniaturization in Automotive

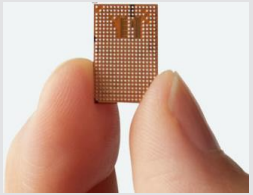
System on Chip technology is making LiDARs and Radars are getting miniaturized even at fractional size of existing ones

NEW

Miniaturization in LiDARs

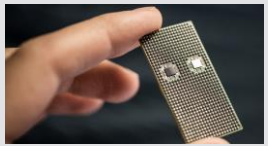


Miniaturization in Radars



UHNDER

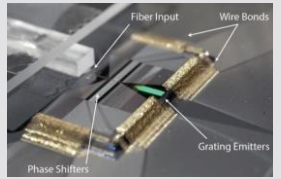
- Uhnder is the first to roll out a single-chip radar solution which is roughly 100X less expensive than LiDAR, based on a 28nm RF process with a fast DAC and ADC, fixed-function configurable pipelines, and a CPU subsystem



imec

- Imec is developing radar sensor SoC(systems-on-chip), integrating RF and mm-wave ICs, fast and low-power ADCs, high-speed dedicated digital processing
- It employs Phase Modulated Continuous Wave (PMWC) for CMOS implementation as it resistant to interference

VOYANT PHOTONICS



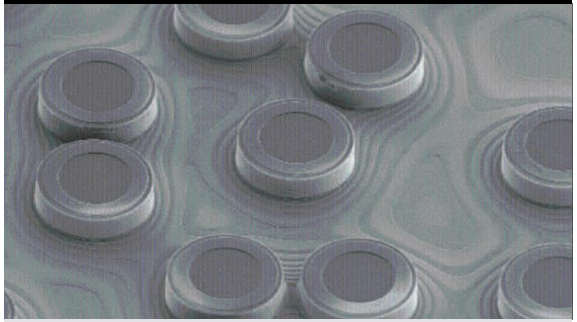
- Voyant Photonics claims to reducing cost of LiDAR by more than 10 times
- The company in July 2019 raised $4.3M from Contour Venture Partners, LDV Capital, and DARPA

Technology Take-offs

Following technologies emerged from stealth mode, main stream adoption and commercialization of these technologies emerges initiated in the industry

NEW

VCSEL



- ams, Ibeo & ZF partner for solid-state LiDAR >>
- TriLumina launches Surface-Mount VCSEL for 3D sensing >>
- Finisar demonstrate VCSEL arrays for 3D sensing >>

Metamaterials

- Lumotive unveils LiDAR with LCM beam-steering technology
- Metawave Demonstrates mm Wave Analog Phase Controller
- Echodyne announces EchoGuard High-Performance 3D Radar

Fiber Laser

- Sequoia China Invests $32million in Baraja >>
- Luminar debuts affordable Iris lidar >>
- AEye reportedly using powerful fiber laser >>

On the Road to Autonomous Trucks

Commercial Vehicles are also moving towards platooning and driverless through technology adoptions, collaboration, etc.

NEW

Push for Autonomy in CVs

- Volvo's Vera autonomous trucks will transport DFDS goods on public roads
- Startup Aurora Partners With FCA to Develop Autonomous CVs
- Uber acquires autonomous truck startup Otto
- Hyundai Motor demonstrates level 3 autonomous truck driving technology
- UPS invests in TuSimple, a startup focusing on LiDAR less autonomy
- PlusAI, self-driving truck startup, close to raising $200 million
- Starsky Tests Unmanned Robo-Truck On Florida Highway
- Daimler Trucks acquires autonomous vehicle software maker Torc Robotics
- Volvo, NVIDIA developing advanced AI for autonomous trucks

Other Exploratory Areas For Vision System Suppliers

Mining

NAVTECH RADAR

BANNER

Warehouse

PEPPERL+FUCHS

ZF

LASE Industrielle Lasertechnik GmbH

Terminals

AINSTEIN

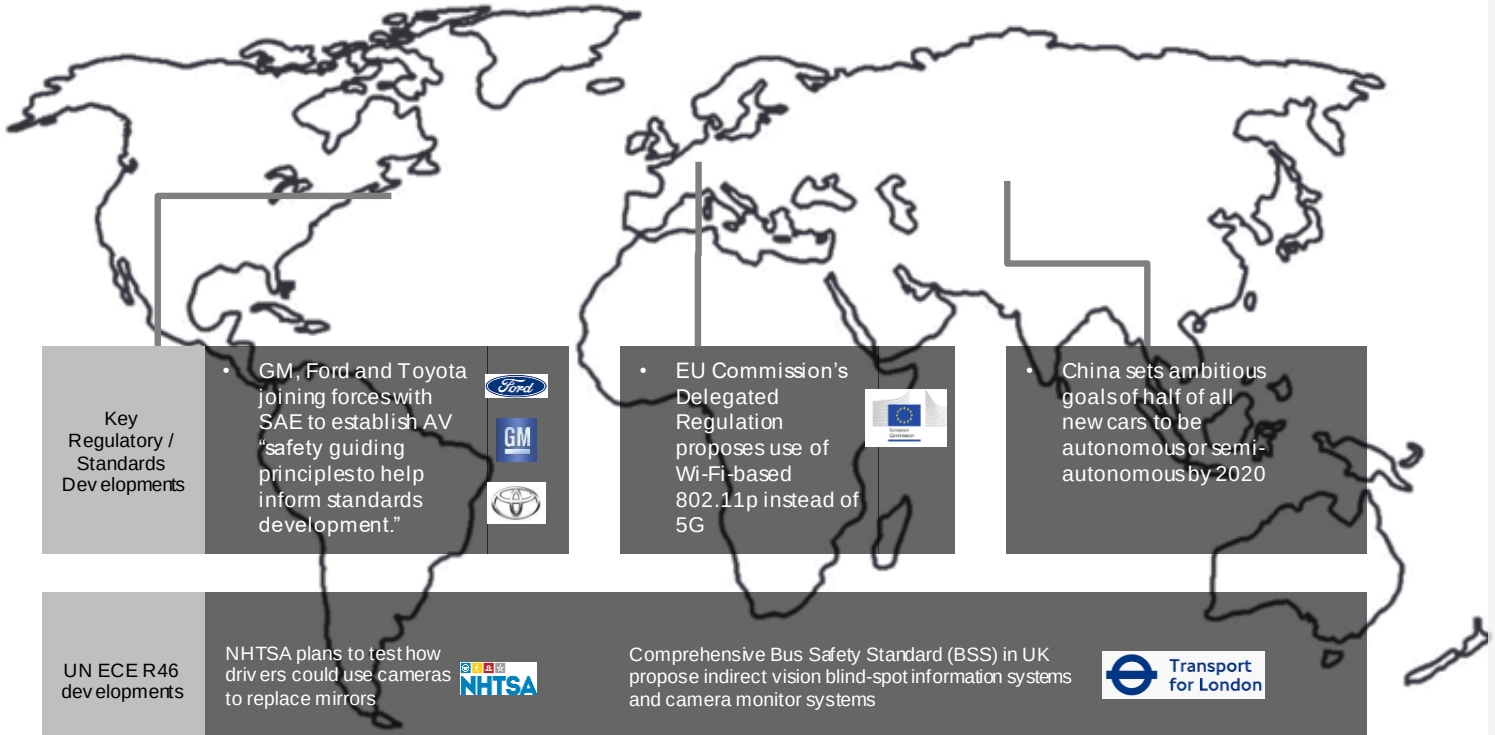
SICK Sensor Intelligence.

TOPOSENS

Regulatory / Standards Update

Most regulators are getting readied for standardizing autonomous vehicle testing and rolling out in early 2020s

NEW



Key Regulatory / Standards Developments	• GM, Ford and Toyota joining forces with SAE to establish AV "safety guiding principles to help inform standards development."	• EU Commission's Delegated Regulation proposes use of Wi-Fi-based 802.11p instead of 5G	• China sets ambitious goals of half of all new cars to be autonomous or semi-autonomous by 2020
UN ECE R46 developments	NHTSA plans to test how drivers could use cameras to replace mirrors	Comprehensive Bus Safety Standard (BSS) in UK propose indirect vision blind-spot information systems and camera monitor systems	

Challenges in Regulating AV

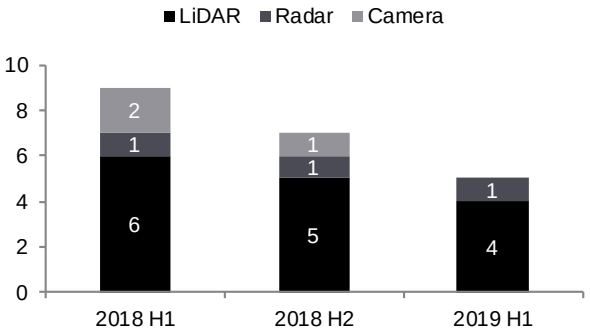
IP Laws – Patenting activity in driverless vehicle technologies, could become a rat race where the largest firms race to patent every conceptual design

Lack of Standards / Guidelines – Regulators (e.g. in US) has shown concern that the AV technology is yet to mature and will require more tests

AI as inventor? – Liability issues remains, related to Artificial Intelligence based application to account for liability / ownership

Collaboration Trends

Breakthrough sub-technologies of vision system is being integrated through many collaborations



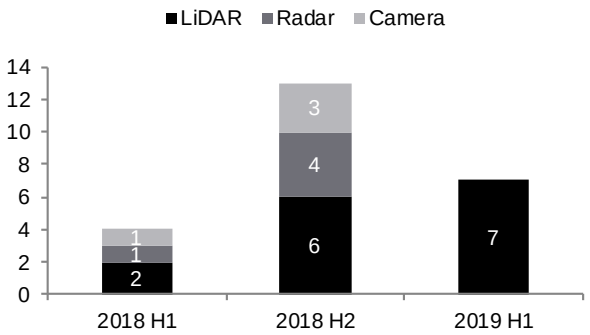
- Sensor manufacturers are collaborating with optics, beam steering experts for backward supply chain integrations, e.g. Pioneer & Canon | ZF & ams
- Also, sensor manufacturers are collaborating with ADAS & AD features providers, integrating with the forward supply chain
- Collaborations for localization services was also observed in H1 2019

H1 2019

INNOVIZ TECHNOLOGIES, HARMAN	here, NAVINFO	Pioneer, Canon	CEPTON, DATASPEED inc. making mobile easier	ZF, ibeo automotive, ams Sensing is life.	KEYSIGHT TECHNOLOGIES, CALTERAH
Innoviz's LiDAR will enhance HARMAN's existing ADAS and AD initiatives	HERE's regional collaboration for offering regional services in China	Co-develop Micro Electric Memory Systems (MEMS) 3D LiDAR	Advanced 3D perception in Dataspeed's X by wire and AD features	Develop advance solid-state LiDAR technology using VCSEL technology	Development of new gen automotive mm wave radar chipset

Funding Trends

Breakthrough startups are getting more and more funds as part of larger industrial competition to pioneer autonomous technology



- Majority of funding activity concentrated on LiDAR and specifically on fiber laser based 3D sensing, e.g. Baraja and Luminar
- Investment from suppliers was also seen in new technologies (e.g. Bright Way Vision' Gated sensor technology)
- Further, later rounds funding was aimed mass scale production – Ouster and Luminar

H1 2019

BARAJA

Baraja raised a **$32 million** funding for LiDAR system

Brodmann17

Brodmann17 raises **$11 million** in a Series A round funding

OUSTER

Ouster raised an additional **$60 million** in funding

INNOVIZ TECHNOLOGIES

Innoviz closed its Series C funding round with US **$170 million**

SENSE PHOTONICS

Sense photonics raised **$26 million** in series A funding

BWV Bright Way Vision

Brightway vision gets **$25 million** from Koito and Magenta

LUMINAR

Luminar Lands **$100 million** funding to ramp up LiDAR

IP Activity Summary

IP activity shows not only major OEMs and suppliers, but also new mobility entrants are actively filing patent in last one year time

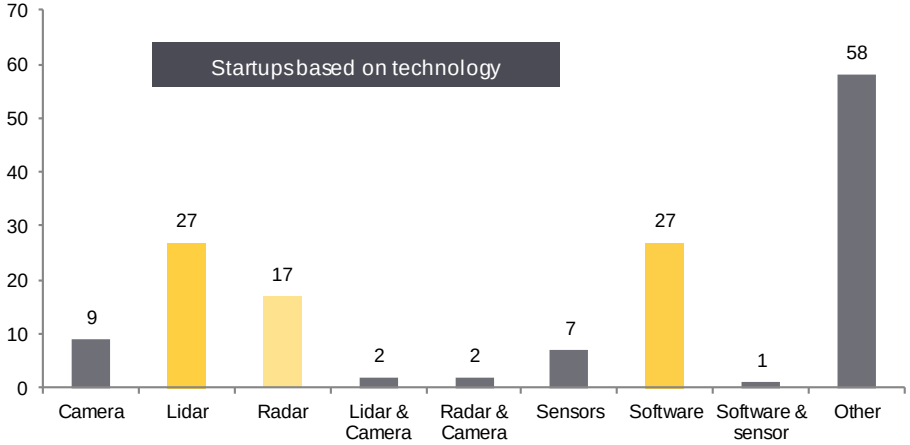
IP activity (July 2018 to June 2019)

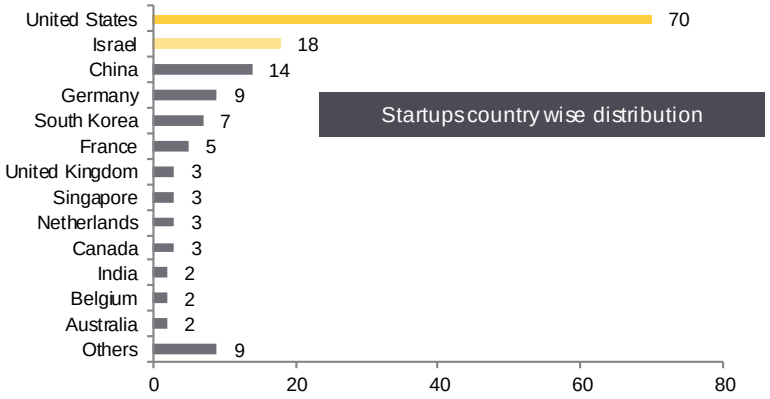
- Ford is leading sensing technology IP filing for last one year (in camera, LiDAR and radar)
- New mobility entrants like Waymo, Uber, etc. are also actively filing patent for vision sensors
- Lag of 18 months of patent publishing in public domain may be the reason for many vision sensor startups not showing up many patents
- Among suppliers Mobileye is leading while Bosch, Continental, Aptiv, etc. are also actively filing patents for vision system

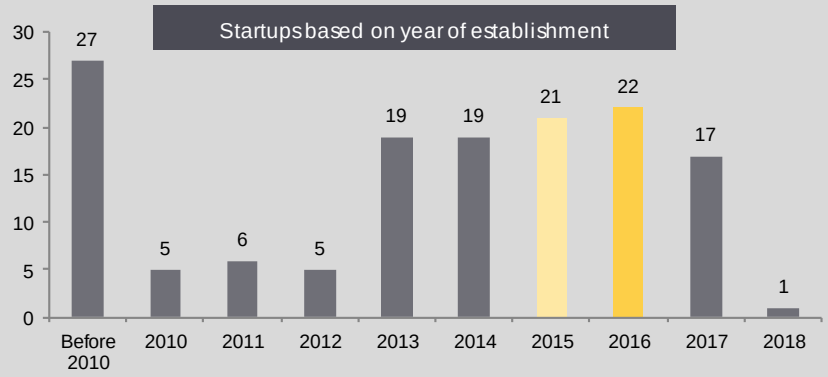
Company	Camera	Lidar	Radar
Ford	191	138	79
INRIX	50	0	4
Mobileye	38	1	6
Volkswagen	16	0	0
GM	21	9	12
Mando	21	0	12
Bosch	15	0	6
JLR	12	3	6
Siemens	5	0	0
Continental	8	0	0
Peloton Technology	3	3	3
Waymo	5	30	18
Deepmap	13	24	0
TuSimple	14	9	0
Aptiv/Delphi	9	1	6
Koito	0	2	0
Uber	10	16	1
Denso	2	0	0

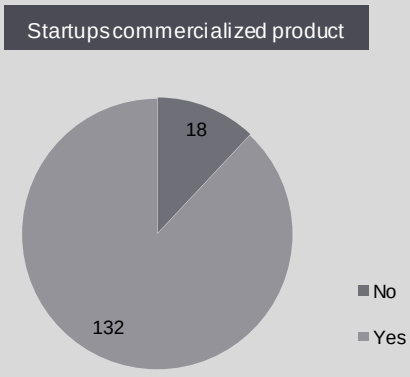
Startup Tracker Summary: H1'19

Vision sensor technology is being enhanced by companies for higher range, reliability, smaller size and lowering cost









Key Startups of H1 2019

- UHNDER → First Digital Automotive Radar-on-Chip
- mapper → High precision HD Maps
- autox → Camera first autonomous driving technology
- SAIPS → Machine learning algorithm for Vision System

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