Executive Summary

Beamlet leverages advanced algorithms to unlock high performance with low cost components, enabling the first affordable, reliable, and long range coherent LiDAR for the auto and drone markets. We are building an automotive-grade metavision system for superhuman perception and interference-free object detection and tracking. The system relies on an event-based camera and a vector-scanning FMCW LiDAR to identify relevant objects with class, depth and velocity in real time even in the most adverse scenarios.

- Autonomy and safety features are in great demand
- Interference-free, long range, reliable and low cost LiDAR is needed
- Our technology enables the lowest cost coherent LiDAR.

"Of all perception sensors, LIDAR is seen by most in the industry as a necessary element (for autonomy)." Wevolver AV technology report 2020

"...experts believe that semiautonomous driving will not become a reality until the industry has a cost-effective lidar system." McKinsey and Co.

Problem

While fully autonomous vehicles remain years ahead in development, the advanced autonomy and safety features are added every year. Significant automaton (e.g. GM supercruise, Tesla Auto Pilot assist, level 2-3) can be achieved with cameras and RADAR. Yet, the industry consensus mandates long range LiDAR for L3-L4 autonomy, especially at highway speeds. LiDAR has enabled autonomy since the Darpa Grand Challenges in 2004-2011. Today, the AV brands with the most advanced autonomy (e.g. Waymo, Cruise) rely on LiDARs, which scan the environment with an invisible laser beam. Moreover, automotive market leaders such as BMW, Audi, Daimler, Volvo, Caterpillar, Continental etc. now have pilot programs with LiDARs in production vehicles. The market is saturated with the time-of-fight (TOF/ flash) LiDAR products which are faced with a challenge of combining long range performance with eye safety standards. The high cost of LiDARs makes them unsuitable for deployment at scale. FMCW LiDAR combines advantages of TOF LiDAR and RADAR. The FMCW coherent detection method is fundamentally more sensitive than TOF detection, leading to lower laser power and better data quality at longer range. In fact, RADAR is an example of a coherent sensor. Its price is low and the market is growing. In coherent LiDAR, the number of detected points is not affected by ambient light or interference from other LiDARs. It provides velocity and "reflectivity" in every pixel (5D), and works with black and transparent surfaces. Market trends favor this technology – promising FMCW LiDAR startups were acquired at the prototype stages (Blackmore by Aurora, Strobe by GM/Cruise). However, building a practical – low cost, reliable and mass-producible - FMCW LiDAR has been challenging. There is a tremendous opportunity for a low cost coherent sensor. The opportunity is especially attractive for an event-based LiDAR, capable of targeting only the relevant objects. Such high resolution, region-of-interest scanner can be combined with an event-based metacamera for object detection and tracking capability.

Solution

Most FMCW LiDARs use expensive and complex laser sources that are not easy to produce at scale to meet the needs of the auto and other markets. As a result, there is no affordable FMCW LiDAR on the market today, while the need remains. We have invented a new laser frequency sweep linearization method that works with very simple and low cost optical hardware. This enables a robust and low cost FMCW LiDAR with of-the-shelf components. Our prototype measures velocity in every pixel and generates high resolution long range point clouds (see here and here and in our pitch decks). As a company, we are extremely cash-efficient. Our proof of concept (POC) prototype is the lowest cost FMCW LiDAR in the world, standing at under $20K for the **total** project costs. The off-the-shelf parts in the sensor head are under $1.4K, quickly scaling down to under $200 already in a volume of 1000. It operates at 1550 nm wavelength which is optimal for sensing in most weather conditions and is eye-safe. The architecture is designed to provide over 12 dB SNR from 10% targets at 200 m. The simplicity of our optical hardware directly translates into improved robustness, reliability, and small size, enabling rugged sensors suitable for applications on the road, at sea and in space. Our solution does not rely on fragile fiber optics or power hungry amplifiers or modulators. Our optical core is built with components found *inside* other telecom products, resulting in a very compact footprint. This allows us to bring a competitive product to market quickly. At the same time we are working with our partners to built the most advanced coherent LiDAR transceiver on a chip. Materials will cost only $5 in volume, and will feature a narrow linewidth laser integrated on the same chip. This approach supports multi-channel architecture and is easier to qualify for the automotive applications because such lasers can operate at high temperatures. Telecom industrial companies have been using similar technology to ship millions of data center transceivers so far. We are relying on R&D and industry experience of our team and advisors to create a product that fully implements the advantages of FMCW technology. We will create a wave of change in the ADAS market and drive the transition to coherent sensors.

Why now

Despite the abundance of TOF LiDAR startups and products, there is no cost-effective and eye-safe solution that works well at up to 200 m distances. A few TOF LiDARs that manage to reach long range are costly (e.g. >$60K Velodyne Alpha Prime VLS-128, 2020) and are still limited by the fundamental physics of the TOF detection method. In FMCW detection method, the signal strength drops slower with distance compared to TOF, making it fundamentally more sensitive and allowing to detect points more reliably and at longer range. We have found an economical way of making coherent LiDAR, uniquely positioning our company to fill the long range (200m) sensing market gap. The COVID-19 crisis has slowed the industry and will accelerate LiDAR industry consolidation. By starting the FMCW LiDAR development now we will benefit from the expanded labor pools and lower overall costs due to this slowdown. The demand for LiDAR products will significantly increase by 2023 when industry will recover.

Market size

The total addressable market (TAM) is represented by the advanced driver assistance systems (ADAS) and autonomous vehicles (AV) markets. The global ADAS market size was valued at $40B in 2018 and is projected to reach $135B by 2027. The serviceable available market (SAM) is the market for LiDARs that will be used in vehicles with high levels of autonomy (ADAS and AV). IDTechEx Ltd., sees strong growth in the automotive 3D lidar market, with revenue growing at a compound annual growth rate

(CAGR) of 29%, to $5.4 billion by 2030. LiDAR ADAS market is our main focus. There are also other LiDAR markets, including drones ($400M by 2025). Generalized LiDAR market will exceed $2B by 2024. The global Automotive RADAR Market is valued approximately at USD 6 billion in 2019 and is anticipated to grow to 13B in 2030. Low cost coherent LiDAR can partially disrupt that market as well.

Competition

As of 2019, there were over 100 LiDAR startups (40+ in the USA), most of which implement TOF. Only a few companies have been developing the FMCW technology. The current funding levels validate general interest to FMCW LiDAR. **Yet, all the competitors use unproven, risky or high cost solutions.**

Blackmore originated from Bridger Photonics in Montana. The prototype demonstrated impressive technical specifications and the company was sold to Aurora for $230M in 2019. As of June 2020, a small number of Aurora trucks have started to collect LiDAR data. However, Aurora/Blackmore LiDAR uses expensive lasers and these LiDARs are not available to the general market. Based on the disclosure in Blackmore patents, the technology is very complex, expensive and hard to mass-produce.

Scantinel collaborates with Bridger and Zeiss to build a discrete optics FMCW LiDAR. They use wavelength tuning for fast dispersive scanning, which requires expensive broadly tunable lasers, similar to Insight LiDAR. It is also a challenge to achieve narrow linewidth with such lasers, which may explain the short range demonstrated in their second generation prototype. It's likely that the multichannel version they are building will be expensive, as they acknowledge limitations of integrated photonics that is available to them.

Strobe LiDAR originated from R&D work by OEWaves in Pasadena, CA. The company was acquired at the prototype stage for $36.5M by GM/Cruise in 2017. The prototype relied on optical resonators and was estimated to cost $20K each, similar to Blackmore ($37K). Cruise shut down Strobe in May of 2020, amid the COVID-19 pandemic. Strobe resonators were not mass-producible and LiDAR was expensive.

Aeva raised over $60M since 2017 and is developing a solution involving some level of photonic integration and fiber-optical components. Publicly available marketing information is very limited. From their patent applications it follows that their technology is risky and will be difficult to make affordable even with volume production. The phase-modulated coherent LiDAR approach requires high power for long range.

Insight raised over $100M since 2016. The prototype was based on the "akinetic" laser developed by parent Photonic Solutions for other (OCT) applications. According to patents, that laser is very complex to control, and similar lasers are known to be expensive. As of 2020 the company was working on miniaturization and demonstrated promising results, however no specs or prices are available.

SiLC technologies was founded in 2018 and initially planned to sell chip-scale component to LiDAR developers. It raised $12M seed round in early 2020. It has recently obtained long range point clouds. It is not clear if those were obtained with a production prototype or a specially tailord demo unit. Not having a laser integrated on the PIC platform means difficulties in mass prodution and unstable laser operation due to back-reflections.

Voyant was founded in 2018 and raised $4.3M in 2019 to develop optical phased array (OPA) LiDAR on a chip. Current state of the art OPAs experience high losses and require significant power to operate. Moreover, they can't be made at scale yet. State of the art results have been demonstrated in research facilities which are much more expensive than production foundries. Significantly, heavily funded state of the art demonstrations of OPAs fall short of being useful for practical applications.

Analog Photonics demonstrated prototypes of a lidar on a chip complete with the optical phase arrays (OPA) after using nearly $30M research funding from DARPA. Their OPA typically use FPGA and other complex circuitry for operation and still have high loss and other limitations as noted above. Production requires state of the art research facilities and long range operation has not been demonstrated, remaining in the research phase.

Point.Cloud has an impressive specification sheet, which still falls short of a long range performance that a coherent LiDAR is expected to achieve. Their main focus is robotic vision at shorter distances. They have implemented a new beam scanning approach alternative to OPA, but their laser source cost was over $200K. Their work is at the R&D stage and many lossy components are used.

Psyonic is targeting automotive LiDAR application among others. However, their technology originates from a high end Doppler LiDAR developed for NASA research. Such technology is not easy to make low cost and adapt to the imaging ADAS/AV application.

Laserradar.cn appears to have implemented technology analogous to Blackmore, which is not easy to miniaturize and mass-produce.

As of August 2020, it becomes clear that a growing number of business entities are initiating internal coherent LiDAR development. These include Intel, some TOF LiDAR market leaders and others.

A note on PIC and OPA.

It's worth noting that some of our well-funded coherent LiDAR competitors rely heavily on risky and unproven photonic integrated circuits (PIC). It is attractive to take advantage of coherent transceiver PIC development that has recently taken place for data center and medium-haul interconnects. In fact, a coherent QPSK transceiver is almost identical in structure to a coherent LiDAR transceiver. This approach becomes even more attractive for silicon photonics platforms that include OPA for beam steering. However, one key difference between transceiver applications and LiDAR application is that LiDAR is much less tolerant to optical losses. State of the art transceivers typically show up to 8 dB fiber-detector loss (not counting the extra beam-splitting loss). An industrial number is 2.4 dB "3 sigma" per-interface loss in production when fiber coupling is used. Every component of a PIC has loss (e.g see AIM PDK), which becomes a critical differentiator in LiDAR applications. For long range imaging LiDAR only a handful of photons are received per pixel. Moreover, wall plug efficiency of lasers can be 15% in C band. Together with eye-safety requirements and heat dissipation issues, this limits the attempts to compensate PIC losses by increasing optical emission power. Finally, OPA technology is not ready for commercial deployment at large scale despite showing good performance in well-funded labs. This is again due to the high losses of emission and collection of light with OPA structures. The absence of optical on-chip circulators necessitates splitting transmit and receive OPA structures into separate components. 2D scanning with OPA requires narrow linewidth, broadly wavelength tunable (100 nm) lasers that are expensive. Finally, advanced lab performance of OPAs was achieved with fabrication quality not available through mainstream cost-efficient foundries. The industry trend is to use MEMS mirror-based approach for beam scanning.

We will develop a compact and robust optical core based on high quality discrete micro-optics components. This will enable high performance and short time to market. At the same time we will work with one of the most advanced PIC platforms in the world that includes integrated lasers. It makes sense to transition to PICs in the long run as they can lower the cost in larger volumes and replace most of the discrete optics. This will also facilitate automotive grade qualification and mass production of multi-channel coherent sensors.

Team

Ivan S. Grudinin (Linkedin) has a Ph.D. in Physics from Caltech (2008). He has over 20 years of R&D experience in areas including coherent detection, nonlinear and quantum optics, cavity opto-mechanics, optical resonators, precision measurement, scientific instrument design. He has over 50 peer-reviewed publications. Ivan developed and demonstrated optical technologies for NASA, Caltech and General Motors (Cruise). His creativity was marked by numerous NASA awards and he was one of the most active inventors at Cruise while working on the first resonator-based FMCW LiDAR. No Cruise/GM IP is or will be used in this project. Ivan is the CEO/CTO and founder of Beamlet and will be responsible for the optical design, among other duties.

Andrei Deev (Linkedin) has a Ph.D. in Physical Chemistry from Caltech and over 25 years of experience in laser spectroscopy, design of field-deployable scientific instruments and embedded software. Andrei was a co-founder at a Rio Grand technologies, developing opto-electronic gas chromatograph instruments for oil well characterization. Andrei is a co-founder and will work as a systems and embedded software engineer.

Our plan is to hire an FPGA software engineer, an RF engineer, a mechanical engineer, and an administrative staff. Additionally, a business development expert will work with us and ensure that we are prepared to contracts with auto companies and Tier 1 suppliers by the time our prototypes are ready.

Technology development

Our initial technology development plan includes system architecture, optical core improvement, RF and mechanical designs, FPGA architecture, FPGA software and firmware, assembly and test. The PIC prototype will be developed by our business partner. We will also develop a metavision system prototype. The costs include office and lab space, legal (IP/CPA), equipment and licenses, salaries.

Long term vision and marketing

We will target unit cost of under $300 in mass production and seek contracts with the auto companies and Tier 1 ADAS suppliers. It is projected that 2 million cars with L2-L4 autonomy could use LiDAR by 2025. Capturing 5% of that market will result in 100,000x$1000=$100M in sales. Our long term vision is to become the leading brand for the automotive and robotic sensors.