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THE TECHNOLOGY BEHIND AUTONOMOUS VEHICLES

Autonomous vehicles may be the greatest innovation of our generation, and optimists like me foresee watching the football game while a self-driving car takes me to a corporate event (…ugh…). As someone who was diagnosed with epilepsy, I understand how liberating a self-driving car may be for people who currently cannot drive for medical or age-related reasons. Still, getting to that level of autonomy is not a guarantee, and to understand where we are going, it is good to look at all the incredible advances we have made in the underlying components that make up an autonomous vehicle.

By Charles Spencer Buchanan, CPA, CFA.

"The only way to have a clear view of the future is to have a healthy dose of skepticism."

The above quote is attributed to Nassim Taleb, and I believe it is how we should view any predictions of how and when we will eventually arrive at fully autonomous vehicles (AVs). Even the Society of Autonomous Engineers, a US-based group of global engineering professionals that provide the six levels of autonomy (SAE 0 – fully manual to SAE 5 – fully autonomous), may give us the false perception of the linearity of the progress of AVs over time.

The purpose of this article is therefore not to look at the future of AVs, but rather look at how the developments in the key components that produce present-day AVs have coalesced to make what once looked like science fiction into a potential reality. We also learn that the future of AVs is exciting but difficult to forecast. The ingenuity and mind-numbingly complex science that led to some of the most important technological advances covered in this article are astonishing, and therefore, I hope the readers find this brief look into the underlying components supporting the future of AVs enjoyable.

What layers make up an autonomous vehicle?

Although the underlying technology can be quite sophisticated, the three broad core competencies of an AV can be understood in very simple terms: *perception, planning, and control*. Perception detects the moose; planning decides to brake to not hit the moose; and control activates the hydraulic system to execute the braking.

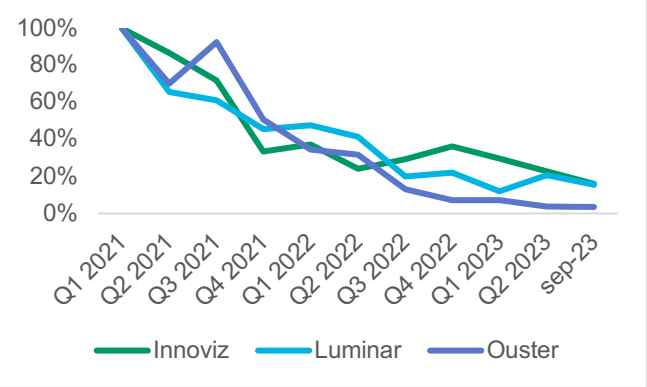
1. **Perception Layer**

"LIDAR is a fool's errand. Anyone who relies on LIDAR is doomed."

When Elon Musk made this prediction at Tesla's Autonomous Day in 2019, he was expressing his belief that LIDAR, a technology used by most current AV producers, is too expensive for widescale adoption, and will ultimately be unnecessary and dispensable. Elon's bet is that advances in computer vision, cameras, and other cheaper perception sensors will be sufficient.

LIDAR: LIDAR is light-based RADAR. Where RADAR uses radio-waves to detect objects and their location (Radio Detection and Ranging) LIDAR sensors send out short pulses of invisible laser light, and times how long it takes to see the reflection. From this you learn both the brightness of the target and its distance with good accuracy. Velodyne, a company that is seen as one of the pioneers in the use of LIDAR in AVs, entered a vehicle in a driverless car race funded by DARPA called The Grand Challenge in 2005. Despite creating a lot of interest in the product and 15 more years of development, 5 years ago they were still selling their LIDAR unit for USD 75,000. Looking at the performance of 3 public LIDAR companies, including Velodyne which merged with Ouster in early 2023, it appears investors agree with Elon's assessment. Innoviz (INVZ), Luminar

(LAZR) and Ouster (OUST), have suffered immense decreases in value over the previous few years (-85%, -85%, -97% since Jan 2021).



However, some analysts believe these decreases may also reflect general concerns about startups that don't generate net income. The "growth at all costs" methodology that was popular in Silicon Valley startups is becoming increasingly less attractive as interest rates rise and investment capital becomes scarcer. Consequently, the drastic decreases in value of these LIDAR startups may be more a product of risky balance-sheet management than a poor product. Also, companies like Alphabet-owned self-driving company Waymo produce their own LIDAR sensors internally, so the future of the LIDAR industry is anyone's guess. This article doesn't dive into the finances of these individual companies or compare their prices to similar risk companies in different industries, but if investors correctly anticipate these LIDAR focused startups turning around, they may be able to pick up these stocks at a steep discount.

Computer Vision (Cameras): Unlike LIDAR, which presently has few niche applications outside of AVs (ex. agriculture and pollution modelling), computer vision has a vast array of uses such as medical image analysis to detect cancer, QA/QC in manufacturing, surveillance, and facial recognition. However, because computer vision still requires algorithmic breakthroughs and sensor improvements to make them adequately safe for broad AV adoption, it is difficult to predict when and if we will ever be able to turn over our keys to camera equipped AVs without the use of LIDAR sensors.

Other Perception Systems: Optical perception systems (LIDAR and Camera) have limitations with heavy dust or fog. As a result, complementary technologies like RADAR and SONAR are added to the AV technology stack to improve performance. RADAR is not new, and in fact, in 1925 Houdina Radio Control demonstrated what may be considered the first AV as a radio-controlled car was able to follow a predetermined path. However, companies like Uhnder, a name CEO and co-founder Manju Hegde says comes from "under the radar", are coming forward with plans to transform old legacy analog RADAR technology and create "the first digital automotive RADAR" to meet the needs of modern AVs. Long-wave infrared cameras (LWIR) is another old technology first developed in the 1970s with the U.S. Department of Defense for surveillance defense and border control, but may also be experiencing a renaissance with the AV industry. It is being adopted by AV companies like Waymo and Plus.ai to address gaps with LIDAR, RADAR and visible-light cameras in recognizing animals and humans in fog, smoke, and steam.

Sensor Fusion: If different types of sensors have different strengths and weaknesses, why not mix them together and produce a super perception system; computer vision and LIDAR together? Truthfully, this remains the goal of many AV teams, however it presents a few engineering complications. If LIDAR says to brake while the camera says to accelerate, who gets the final say? With improvements in AI and deep learning algorithms, the creation of a functional priority system seems like a very achievable goal, but whether engineers can ultimately create sensor fusion that becomes *profitable* will likely prove to be the more difficult problem to solve.

2. Planning Layer

"Artificial Intelligence, deep learning, machine learning, if you don't understand it, learn it." – Mark Cuban

Sensors at the perception layer may get all the credit, but it's the AI behind the scenes that ultimately runs the autonomous ship! The story behind the technology required to perform these information intensive AI

calculations is remarkable. When NVIDIA was founded in 1993, its goal was to develop advanced graphics processing units (GPUs) for the gaming and computer graphics markets. Unlike CPUs, which compute sequential tasks, GPUs can handle parallel tasks. This proved ideal not just for graphics, but also for AI, which needs to perform multiple calculations simultaneously. However, few predicted GPUs to be the future of computing. Intel, a company whose co-founder Gorden Moore became famous for his prediction that the number of transistors on a semiconductor will double every two years (Moore's Law), has been a leading firm in Silicon Valley for over 50 years. Nonetheless, Intel missed the opportunity to be a pioneer in GPUs as it focused on improvements in CPUs. Most recent CPUs may use semiconductor chips with up to 20 billion transistors 7 nanometers (nm) wide. To understand how small that is, the average human hair has a diameter of 50,000-100,000nm, and 7nm is smaller than most bacteria and viruses (SARS-CoV2 has a diameter between 50-140nm). To make these transistors, they must be carved on a silicon wafer by using an extreme ultraviolet (EUV) light source generated by focusing high energy lasers on tin droplets in a vacuum chamber to vaporize them and form a high-temperature plasma up to 10,000°C (the surface of the sun is only about 5,500°C). This scientific achievement was made possible by the investment of billions of dollars in R&D by governments and firms like Intel. But, as anyone who bought NVIDIA stock 10 years ago knows, the companies that ultimately benefited the most from Intel's investment were GPU producers like NVIDIA (NVIDA stock value increased over 11,000% since January 2013). Without these advanced GPU chips, the computations required for AVs decision layer are impossible. It should then come as no surprise that NVIDIA has jumped into the AV industry with NVIDIA DRIVE Hyperion™, a platform that incorporates NVIDIA chip-based AI to help AV developers produce better planning layers.

3. Control Layer

You can have the best sensors and brightest AI algorithms, but like anything, communication is key, and in this case, data communication between the different electronics. Drive-by-wire (DbW) is a vehicle control system that replaces mechanical linkages with electronic sensors and actuators. Instead of your steering wheel being connected to the wheels through a column and a shaft, your wheel will be connected to pressure sensors that then communicate information based on the movement of the wheel to the electronic control unit (ECU) that manages steering. DbW technology has advanced immensely since the 1980s and 90s when the automotive industry began adopting it with the introduction of the electronic throttle control. Now, modern vehicles may contain over 80 ECUs, tasked with managing everything from essential functions like engine or power steering control, to comfort features like window or seat adjustments. Electric vehicles (EVs) require special ECUs to manage the power supply and rely entirely on electronic control for propulsion, braking, and steering, and AVs require highly advanced electronic control for navigation, collision avoidance, and passenger safety. To manage how all these different ECUs communicate with each other in a peer-to-peer network, a Controller Area Network (CAN bus) protocol was developed by SAE (the same group that released the six levels of autonomy). A more recent protocol, CAN FD (flexible data-rate), allows for transmission of larger amounts of data per message and up to 8x faster data transfer rates. In the AV industry, some companies "retrofit" non-autonomous vehicles by implementing their own perception technologies onto a vehicle's existing CAN bus network. This allows companies to focus on the development of AV technology without requiring the enormous CAPEX to manufacture their own vehicles. This greatly increases the number of potential competitors and leads to a more dynamic industry.

4. Support Layers

"5G will have an impact similar to the introduction of electricity or the car, affecting entire economies" – Steve Mollenkopf (ex. CEO Qualcomm)

Networks:

The Chinese firm Huawei took the world by storm with the deployment of its 5G technology. It joined firms like Ericsson and Nokia as a major leader in the industry, and in doing so caused panic in some leaders in the

West. This is because 5G technology is not just about cell-phone service, but in the mobile transmission of all types of data. If we look at the timeline and innovations of the previous 4 generations, we understand why:

1G (1980s) voice only.

2G (1990s) voice and texting.

3G (2000s) mobile data and limited internet.

4G (2010s) high-speed internet and streaming

5G (2020s) ultra-fast speeds, low latency, massive device connectivity. It supports IoT, AR/VR, and autonomous systems, and completely revolutionizes the communication industry and allows data collection from the most unassuming objects like a kettle.

Networks communicate over radio-waves, not unlike radio stations in the first half of the 20th century. However, unlike old radio stations, new 5G network technology can send vast amounts of data over each available radio-wave, and even find space in the narrowest wave of radio spectrum (think radio channels 95.5 and 95.6). Unlike old radio stations that beamed signals in general directions, beamforming can be used to aim transmission directly to the intended recipient and avoid interference. With better signal and less interference, managing the incredible amount of data required for AVs is made possible, and this may be just the beginning as 6G is expected to be deployed in 2028.

Satellites:

Figure 1 A SpaceX Falcon 9 rocket rests on the deck of a drone ship shortly after launching 22 Starlink satellites on Sept. 19, 2023. (Image credit: SpaceX)

On September 20, 2023, SpaceX deployed 22 satellites, the 6th deployment of the month adding to its total of 5135 satellites launched. There are now over 10,000 satellites orbiting the earth, and in the case of Starlink, the objective of SpaceX is to provide high-speed internet to every corner of the planet.

Aside from internet connectivity, some satellite constellations are used for navigation. A satellite constellation is a group of satellites that work together as a system, and in the 1970s and 80s, USA's Global Positioning System (GPS) was launched to help allow for global navigation. There are now several global navigation satellite systems (GNSS) such as GLONASS, Galileo and BeiDou operated by different space administrations, Russia, Europe, and China respectively. However, using "raw" GNSS signals from their satellites for positioning is not sufficient for autonomy because they only provide positioning that is accurate to within a few meters. To provide the level of accuracy required for AV positioning, real-time kinematic (RTK) and precise point positioning (PPP) are used to provide up to centimeter level accuracy. Companies like Hexagon Autonomy & Positioning (previously Novatel) are hoping that with its RTK From the Sky™ technology, it is possible to provide centimeter-level accuracy not just in open-sky environments, but also in challenging hard-to-reach locations with obstacles like buildings and foliage.

Conclusions

We may look at AV as a single product being produced by companies like Waymo or Tesla, but the total AV revolution is the result of incredible advances in many next-generation technologies. From networks and chips to AI algorithms and sensors, achieving fully autonomous vehicles requires improvements in all these fields. With all the intellectual power and ingenuity being focused on these areas, the result may be very different than what we can predict now. However, as we saw with the disappointingly slow advance of space travel following the moon landing, progress is not a guarantee. Recognizing this uncertainty, I choose to remain optimistic, and I greatly admire all the engineers who are taking chances at creating what may be one of the most important innovations of our generation.