Tesla's Effort for a Safer Future

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Abstract:

This report covers Tesla's advancements in full-self-driving (FSD) capabilities, focusing on their efforts in developing a safe navigation and obstacle avoidance system. Tesla stands as one of the top companies racing to achieve FSD, utilizing complex artificial intelligence (AI) systems. The goal is to highlight Tesla's approach to overcoming challenges brought to autonomous driving and how they make sure their FSD can be safe for all drivers on the road. Tesla's use of neural networks per camera allows it to analyze raw images trained on the most complicated scenarios from millions of customers' vehicles in real time. Each sensor creates accurate and large-scale models to build a decision-making system for real driving situations. With FSD developing under Tesla, a publicly traded company, the people have control over ensuring that a safer future is achievable on the road with AI.

Keywords:

Artificial Intelligence; Autonomous; Computer Vision; Full-Self Driving.

I. Introduction

Autonomous vehicles are slowly making their way to being independent on the road. Before any of these vehicles take a spin on the road, they are first regulated by the Society of Automobile Engineers (SAE). SAE levels of driving automation regulate vehicles and their behaviors on roadways in six different tiers, see figure 1 and 2. SAE levels zero through two mean the human is the driver. This is defined as constantly controlling support features such as steering, braking, or accelerating as a means of safety [1]. Levels three through five are when AI is in control of the vehicle. Level three differs from levels four and five as AI can request the driver take control of the vehicle. Levels four and five, on the other hand, will not require the driver to hand over control to AI [1]. The goal of autonomous driving is to reach level 5, where an AI can drive a vehicle anywhere and in all road conditions. Tesla's vehicles are classified as SAE level two. Tesla's newest capabilities feature FSD capabilities but require the driver to supervise controls, which does not qualify their vehicles as level 3 or above [2].

The history of autonomous vehicles dates back a century. The first vehicle without a driver was developed by the army using a radio controller in August 1921 [3]. This spark in development led to a century of innovation. The earliest development closest to our time was a robotic Mercedes-Benz in 1994 that was capable of driving up to 80 mph on highways around Paris [3]. Today, almost every automotive company is developing new autonomous features for their vehicles. For Tesla, their introduction into the autonomous industry for their consumers was in October 2015, with Tesla releasing version 7.0 and adding Autopilot. Their first version of Autopilot had the capabilities to steer in a lane, switch lanes, and use traffic speed awareness for cruise control [4]. The new Autopilot features relieve drivers from the need to find parking spaces, provide parallel parking, and help avoid collisions on the front and sides of the vehicle [4]. Just three years later, in October 2018, Tesla announced navigate on Autopilot. Navigate is a guidance feature for Enhanced Autopilot models that initially allowed drivers to traverse highways with ease. With safety in mind, navigate came with stalk confirmation for lane changes to ensure drivers were paying attention [5]. This was only the beginning of Tesla's driving technology for Autopilot.

Tesla is still developing newer technologies to overcome both safety and technological challenges. They're committed to opening up the roads to FSD, not only for a more efficient and sustainable life on the roads but also to traverse safely. These technologies help contribute to a future where road accidents are less common due to human error and traffic flows smoothly from fewer cars breaking. Tesla's systems are programmed on the foundations of latency, correctness, and determinism [6]. The latency foundation is for a faster system capable of seeing the world around the car in an instance. Correctness is to ensure the car's reliability on the road. Lastly, determinism ensures that the predictions made by AI systems can be trusted by the consumer. With new updates to their systems, they can easily ensure each model is supported with over-the-air updates that allow a more reliable car to be on the road in case any technological errors occur. Each sensor on Tesla's cars captures high-volume data that is shared across multiple CPU processes without latency. With each sensor ready for action, core AI algorithms generate a real-life representation of the world around the car. These algorithms plan the trajectories the car should take when in control. Each Autopilot car has 48 neural networks that create roughly 1,000 predictions per timestep [6], allowing for an advanced driver assistance system, see figure 3.

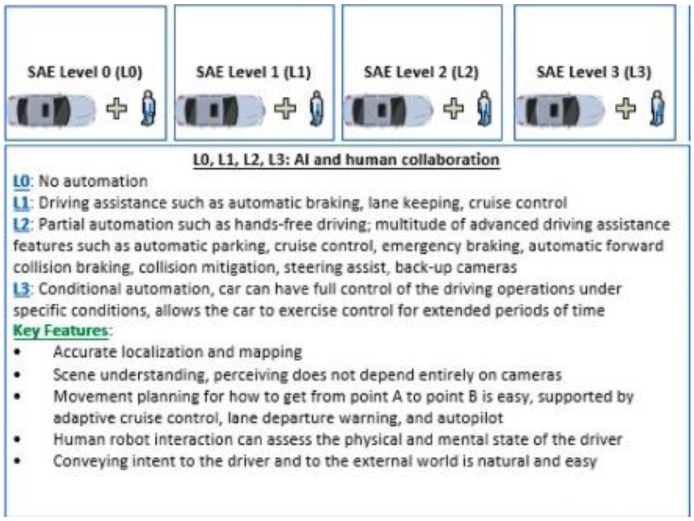

Fig. 1 Source: [18].

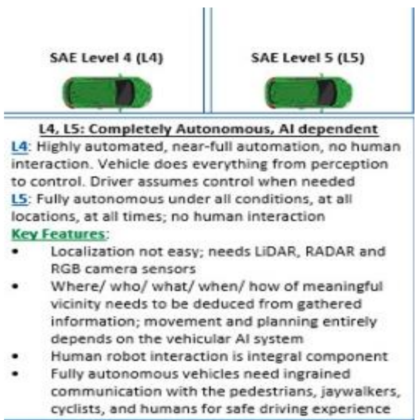

Fig. 2 Source: [18].

Fig. 3 Source: [6].

II. ALGORITHMIC VEHICLES

There are many challenges faced in vehicle automation. Utilizing powerful machine learning technologies that are capable of providing an optimal solution to facing these challenges head-on. Tesla and many other car manufacturers are developing and implementing AI-assisted driving and autonomous technology into their vehicles, which means every year new applications and research are being performed on the many different algorithms used.

A. Computer Vision

Computer vision is one of the oldest and most popular subsections of machine learning. Scientists wanted to replicate how humans see into a process for machines [17]. An AI with sight can easily automate and assist human work with many different possibilities. Computer vision has many different processes for image and video processing. These processes are combined with each other to form what autonomous cars "see" on the road. With the use of these technologies combined with the input from multiple different sensors, autonomous cars can assist drivers and ensure safety on the road. Modern-day machine learning models that are able to process computer vision tasks are deep neural networks and convolutional neural networks [17].

There are multiple ways an image can be processed in computer vision models. The main types of processes are classification, identification, object detection, object localization, object segmentation, and pose estimation for rigid and non-rigid bodies [17]. Computer vision classification is the process of assigning labels to images, see figure 4. By training a model with data that matches labels to images, a computer vision classification system is capable of taking in images and only being able to predict labels it already knows from training [17]. For example, a car with a built-in object classifier can "see" if the surrounding 3D objects are other cars, trucks, pedestrians, or other objects found on the roads. Object identification, on the other hand, is a computer vision model that predicts specific instances of a class [17]. For example, a car with a built-in object identification model can detect an instance of a stop sign from a class of road signs. These techniques are useful, but they do not directly apply to the ML used in today's AI-assisted vehicles, as this is not all done in real-time.

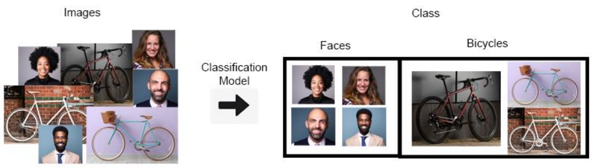

Fig. 4 Source: [17].

In order to utilize computer vision in real-time, vehicles must be engineered with machine-learning video model types. These models are capable of processing a live feed or video frame-by-frame, see figure 5. Computer vision models for video are able to do instance tracking, action recognition, motion estimation, and 3D reconstruction [17]. Instance tracking is similar to how object detection works. For instance, a model built for tracking is able to detect objects within a frame and then continuously track them wherever they go in the frames that follow [17]. In vehicles, this can be used to understand where surrounding objects on the road are and to help other systems make predictions for when to merge, speed up, or even break. In order to predict the motion of surrounding objects, a vehicle's computer vision model can utilize action recognition. Action recognition predicts the motion of an object by recognizing similar actions the model was trained on [17]. For instance, if the model was trained to understand if a car is driving, slowing down, speeding up, or is stopped, then an action recognition model would be able to predict these motions for surrounding vehicles. Motion estimation is similar but instead tracks the velocity and trajectory of an object [17]. Motion estimation is capable of capturing the direction of other vehicles on the road, allowing the AI assistant to be aware of any on-coming collision.

Computer vision models are a modern-day advancement in AI technology. By engineering computer vision models for the road, autonomous cars are able to use all their sensors for obstacle avoidance and navigation. Not only are the driver's two eyes on the road to ensure safety, but so are computer vision models capable of predicting a collision that a human driver couldn't see coming.

Fig. 5 Source: [17].

B. *Convolution Neural Networks*

Convolutional neural networks (CNN) are a computer vision architecture that is capable of finding patterns in images to locate objects [18]. CNN models work by feature extraction. Feature extraction is when a CNN model takes a window of an image, the receptive field, and applies weights to the pixels in that window [17]. The result of the weights applied to the pixel in the receptive field is then added to a feature map. A feature map is the product of a CNN model striding throughout an image until it has reached the end [17]. In figure 6, you can see the window of pixels the weights are being applied to and where in the feature map the result is saved. Striding is the number of pixels the CNN model will move from left to right until it reaches the bottom right of the image. This image can be a picture or a frame from a live feed that is being captured every second. There are three main layers when it comes to engineering a CNN model [17]. The convolution layer, which is where the model will do the feature extraction steps, The pooling layer takes the result of the convolution layer and reduces the complexity, so the next convolution layer does not have to process the same amount as before. The last layer is typically a dense layer, which is used as the output for making predictions based on all the feature extraction processing done to the image. The ability for a CNN model to "see" is the result of the steps done in the convolution layer, making it one of the most important steps.

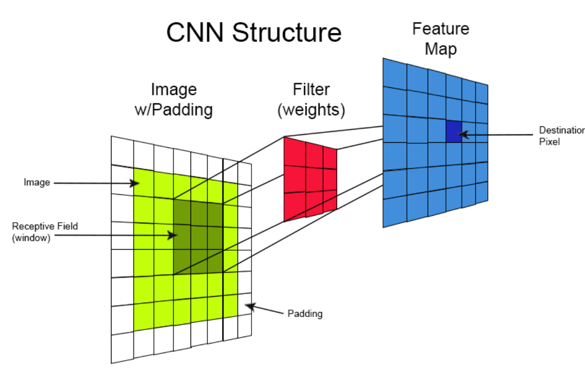

Fig. 6 Source: [17].

C. *Object Detection Utilization*

In order for a car to safely assist and take over driving, it must be able to navigate and avoid obstacles while following the rules of the road. The backbone of an autonomous car is computer vision, which is utilized for object detection. In order for the car to see a 3D representation of the world around it, the computer on board must be able to classify objects and map them to the world with localization. Object detection can be narrowed down to region selection, feature extraction, and classification [19]. There are many different scenarios an autonomous vehicle can come across. It would need to consider the different types of traffic, pedestrians, and any other liability on that road that can cause an accident. The main challenges an autonomous car faces when utilizing computer vision techniques are: view, occluded objects, multiple objects, object perspective, time of day, road conditions, weather conditions, road lines, traffic lights, and object invariancy [19]. To humans, all these are considered with ease as the brain puts all the pieces together for itself. A machine, on the other hand, needs to ensure that the training data takes all these considerations into account. If a vehicle is only trained on data in sunny, clear weather conditions, then a major accident could occur during a rainy night, see figure 7.

CNN models were the start of something greater. Many machine learning engineers needed a model that produced outcomes at a faster rate. For vehicles, the speed of these models—R-CNN, fast R-CNN, faster R-CNN, YOLO, and SSD—is still capable of a low error chance during real-time driving scenarios [19]. If at any moment a prediction is off, an accident can occur for the driver or other vehicles on the road. No model is perfect and will have 100% accuracy, but by being engineered to be fast enough for real time and having multiple models on board, like deep learning models, to compare results or offload tasks, autonomous driving can be capable with computer vision.

Deep learning, like computer vision, is a sub-category of machine learning. Deep learning is a neural network of three or more layers that tries to mimic the behavior of the human brain [20]. By mimicking how the brain learns, deep learning can process big data and look back on previously learned instances. Computer vision for autonomous cars faces many challenges. By pairing computer vision with deep learning, some of the challenging tasks can be offloaded to it, like localization, understanding the environment, object labeling, and unseen driving scenarios [18]. Not only is it great for the precision and accuracy of the data the car is predicting, but it is also used as an extra measure for safe driving. By mapping the environment for the vehicle's navigation using what the vehicle "sees," the computer process on board is able to ensure that all systems are working properly.

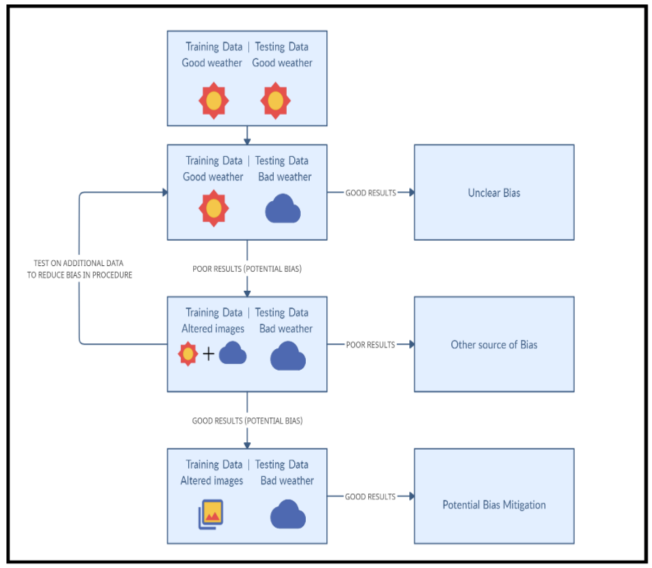

Fig. 7 Source: [21].

III. Bias Data Collection

In order for machine learning models that utilize computer vision to "see" on the road, there needs to be data collected for training. Companies can either collect the data themselves, like Tesla, or they can outsource to publicly available datasets. The data used for training would be considered a memory for a human to look back on to know and understand the different objects around the vehicle. This ability for a machine is great; however, it comes with some challenges. Since a model is trained on data from a human, there can easily be biased information. See figure 8, where human labeling images can cause confusion as different objects can have similar names. When there is bias in the data used for training, a model will carry out its trained tasks with bias [21]. For object detection in autonomous driving, biased data like light illumination and certain road or weather conditions in images can hinder the ability of the machine to perform accurately. For example, if a computer vision model is only trained on images captured for sunny and rainy weather conditions, then the vehicle won't perform well when it snows or is foggy. Machine learning tasks that involve many safety measures, like vehicles on the road, that are influenced by bias training can lead to accidents or even death [21].

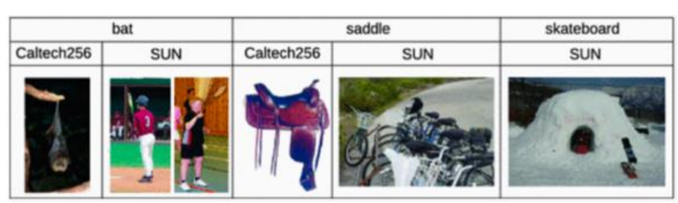

Fig. 8 Source: [24].

A. Bias Mitigation

In order to have a safer vehicle on the road, AI is now assisting drivers with the majority of their driving tasks, with the plan of evolving AI to the point of autonomous driving in the future to make driving easier. However, before AI is safe enough for the road, the data the machine learning model uses for training needs to be considered. A key component of human-AI relations is trust. For a human to rely on an AI system for handling a vehicle in all driving conditions and challenges, there must be trust. Bias mitigation helps foster this trust by ensuring that the information used during training is transparent and clear of any biases [22].

IV. FEATURE CAPABILITIES

Tesla vehicles built after September 2014 are equipped with new hardware and more powerful processing. These older models come with Autopilot hardware but are ineligible for the latest FSD capabilities. New models, built after October 2016, come with the Standard Autopilot [2]. Users are able to upgrade to Enhanced Autopilot for $6,000 or FSD capability for $12,000.

A. Standard Autopilot

With each new model coming with the Standard Autopilot, each car comes with enhanced safety and convenience. All new North American market models use Tesla Vision, a camera-based occupancy network Autopilot system, to replace radar technology that used ultrasonic sensors for inputs, see figure 9. Tesla Vision offers the ability for each car to identify and differentiate between objects [7]. At the time of Tesla Vision rolling out in October 2023, their blog post said that they were certain this new methodology would bring safety to their consumers [7]. Before enabling the Autopilot system, drivers must agree to always keep their hands on the steering wheel. This ensures that the driver is still in control and complies with SAE regulations for safety reasons.

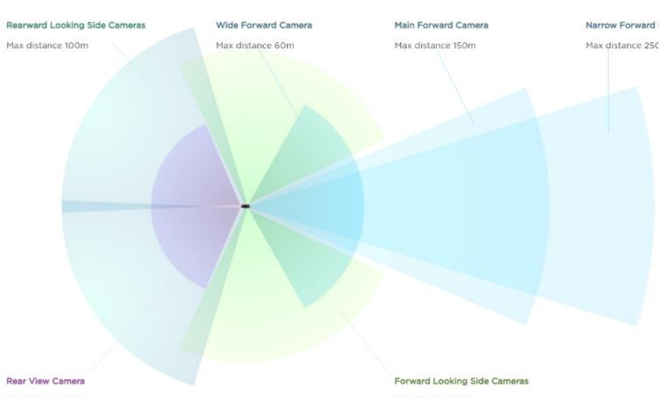

Fig. 9 Source: [25].

Tesla's Standard Autopilot gives the customer a less stressful and safer experience than a typical car. It includes a traffic-aware cruise control system and autosteer [2]. Traffic-aware cruise control allows Autopilot cars to match the speeds of surrounding traffic. As of now, this mode must be manually activated, as the car does not switch to traffic-aware cruise control on its own like an autonomous vehicle. Autosteer allows the car to automatically steer for the driver on city streets with hands on the steering wheel, see figure 10. Autosteer is an addition to the traffic-aware cruise control system. Ensuring the vehicle is in the driving lane at all times. It's capable of detecting lane markings, other vehicles, and objects to ensure drivers stay inside the lane [8]. Autosteer automatically reflects the speed limit for highways with the driver's custom offset. A speed-limiting safety feature built into Autosteer is enabled for residential roads. This feature is great for an area where pedestrians are more common than on the highways. To ensure the driver is always aware of their surroundings and still watching the road, Autosteer requires the driver to still hold the wheel [8]. This steering wheel detection is done by recognizing resistance as the steering wheel turns or if the driver assists the steering wheel by slightly turning it. Drivers who do not follow the rules of maintaining attention and control will have autosteer disabled for the remainder of the drive. If it gets to the point where the driver will not take the wheel back, then the car will turn on the warning flashers and slow the vehicle to a stop [8]. With the Standard Autopilot having only two main features, it's still classified as SAE level two. With that in mind, how different could an enhanced version be while all features are classified as SAE level two?

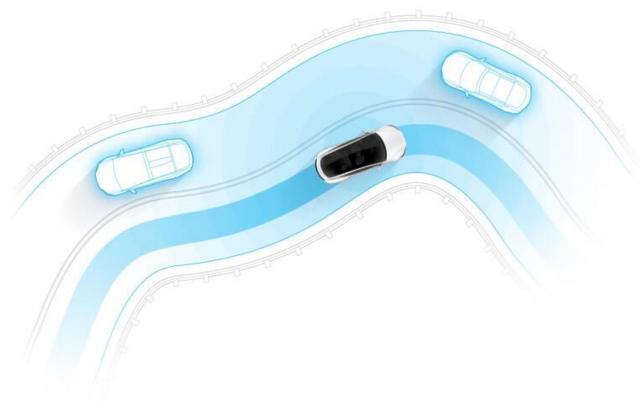

Fig. 10 Source: [25].

B. *Enhanced Autopilot*

Tesla's Enhanced Autopilot contains the functionality of the Standard Autopilot but offers a wider range of upgrades and easements. One of the first is the ability to change lanes on the highway when the Autosteer is engaged, see figure 11. Even though autosteering is built with lane and vehicle detection, it's still required for the driver to perform visual checks for a safe lane change. The car is only signaled to do so when the turn signal is activated. Features that are new to an Enhanced Autopilot car are Autopark, Summon, Smart Summon, and Tesla's Navigate.

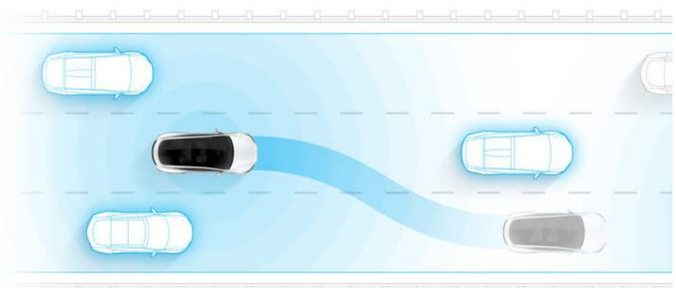

Fig. 11 Source: [25].

Both summon and smart summon features act the same, but the key difference between the two is obstacle avoidance. Summon will move a driver's car out of very tight spots where they may be unable to access the car's door. Smart summon, on the other hand, allows the driver's vehicle to navigate around objects in a parking lot or similar environments to find them [2], see figure 12. The driver can send a smart summon car to their phone's GPS or a random location they want. However, this feature will only work if the driver is within 213 feet of the car [9]. Since there is no driver in the car and Tesla must follow public safety regulations, they set more than just a distance precaution. Smart summon is not meant to be driven on anything other than paved surfaces. To ensure smart summon isn't driving on public roads, drivers are cautioned to only use it for parking lots and driveways on private property. Each driver who summons their car needs to safely watch the vehicle's path for any unpredicted objects in the environment, like pedestrians. If, for any reason, the driver needs to stop the vehicle from summoning, they can release the summon button on their phone [9].

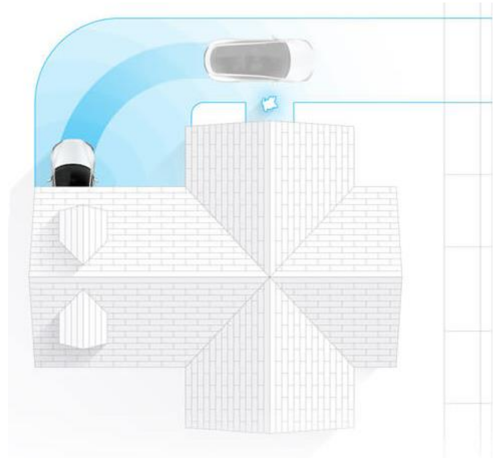

Fig. 12 Source: [25].

With the ease of unparking your car with a summon, drivers can also use the autopark to simplify their parking needs. Autopark uses data to assist with parallel and perpendicular parking. For parallel parking, the maximum speed must be 13 mph in order to better determine the parking space. Also, to better help the car parallel park, there needs to be a visible curb and a car in front of the space [10]. For perpendicular parking, the driver's speed must be even slower at 8 mph. In order to have a perpendicular park, the spaces must have three visible lines to use a guide. Road surfaces like brick and cobblestone could mess up the Autopark's detection, so Tesla recommends only using it on a smoother surface [10]. Some Tesla cars can have a tow hitch installed. Those that do have installed hitches need to use caution, as autopark will not be cautious about it when parking [10].

One of Tesla's biggest safety milestones is Navigate on Autopilot. Navigate on Autopilot takes away the driver's anxiety by assisting their drive from the start of a highway all the way to the exit. It suggests when the driver should change lanes, utilizing the auto lane changer feature when the driver acknowledges the lane change is safe. It will even ensure that the driver takes the correct exit to stay on the correct navigation path. Tesla plans to allow the driver to waive the need to confirm lane changes with Navigate, but until regulations are met and they reach autonomous driving, drivers remain in control [5]. The main design of Navigate on Autopilot is to find and follow the best path to the driver's point of interest. Navigate will utilize two different ways to change lanes. One is for staying on the desired path to the destination, while the other is for staying at the driver's desired speed. There are four different modes of speed-efficient lane changes the driver can pick from: disabled, mild, average, and mad max [5]. Navigate will detect the speeds of vehicles in all adjacent lanes to predict a more optimal lane to traverse. Each mile driven with Navigate will lead to a more capable and efficient self-driving future.

C. Full Self-Driving

Vehicles with FSD not only include all of the previous features mentioned in Autopilot and Enhanced Autopilot but also include two new features. Autosteer on city streets as well as traffic and stop sign control. These new features allow the AI to drive you with minimal intervention. Now, Tesla still remains at SAE level two, so with that in mind, it still means the driver is in control. Since driver supervision is a requirement, the vehicle is not autonomous or considered FSD yet.

As of writing, Tesla's FSD is currently in limited beta. Originally, Standard and Enhanced Autopilot were meant to enhance driving on multi-lane roadways, like highways, but Tesla's newest steps in autonomous driving bring AI easement to all roads. Their FSD is different by driving to the driver's destination by using the curves in roads, following intersection rules, turning left and right, properly using a roundabout, and taking highway on-ramps to the exit [11]. FSD systems are designed to use input from all cameras to build a life-like model of the surrounding area, process it through multiple neural networks, and make a prediction of the next route to take for safety in getting to the driver's destination. With all the features offered by Tesla, full driver awareness is a must. The rule still stands for drivers to keep their hands on the steering wheel at all times. With the rise of drivers adding weight to their steering wheel to trick the safety system, Tesla is implementing cabin monitoring with the inside camera [11]. These safety precautions are not only for the driver's safety but also for all of those on the road, including cars, cyclists, and pedestrians.

Traffic light and stop sign control uses cameras to detect stop signs and traffic lights. If Autopilot is enabled, the car will slowly come to a stop when proceeding towards a stop sign or red light. It will not automatically proceed, so the driver must signal to the car that it is safe to continue [2]. On the car's interior display, a visualization of the 3D world is shown, with all traffic lights, stop signs, and road markings detected [2]. Future updates will come with auto-turning, but as of now, the driver is in control of turning the car as well as signaling others with their blinker, see figure 13. To ensure the driver knows when FSD is coming to a stop, an estimated distance of when they'll approach a stop sign or traffic light will be displayed. Tesla still has not made a FSD vehicle, but they are closer than ever.

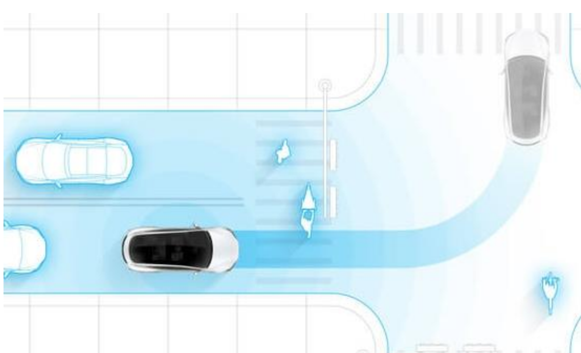

Fig. 13 Source: [25].

D. Safety Features

All the latest safety features come standard on all Tesla vehicles built after September 2014. For over ten years, Tesla has taken safety into consideration for all drivers on the road. Active safety features are utilized by all Autopilot hardware and software but can't ensure safety in every situation. That's why it's important for the driver to always be in control of the vehicle when getting assistance from AI. Like all drivers on the road, Tesla drivers still require their full attention on the road. A pair of eyes go a long way when watching the road, even with eight cameras assisting them.

A Tesla vehicle is designed to avoid collisions as best as possible. The car can determine if it will hit other cars or obstacles, then apply an automatic break. If the vehicle isn't moving or going at a slower speed, it will sound a warning system from the front or side of the vehicle to inform the driver about potential object collisions, for example, a shopping cart. When the driver wants to change lanes, the vehicle will monitor the driver's blind spots for safer lane merging. For drivers swerving and losing control of their vehicles, Tesla applies steering to stay in the intended lane, as well as steering the vehicle back into the lane if it detects the car lane switching with a possible collision [2]. Each piece of software developed for safety is trained on millions of Tesla vehicles. Data is used to visualize how collisions start and to stop them from happening in the first place. Tesla's data-driven safety can easily be updated for all vehicles with their over-the-air software updates for a safer drive every time the driver gets on the road [12].

Besides software, the vehicles themselves are engineered to be the safest on the market [12]. The goal of the design is to ensure a low probability of the car rolling as well as injury to any of the passengers and driver. With the car being all electric, the battery pack is placed very low. With a lower center of gravity, the vehicle has a low chance of rolling over, see figure 14. Tesla has a patented side structure that is engineered to absorb energy from impact to ensure safety for occupants and the battery [12]. The battery and structure of the car are fortified for greater impact absorption. With this design helping prevent damage inside the main cabin, airbags have a higher chance of inflating and protecting [12]. Even with a fortified battery, there are cases of damage happening. Tesla engineers designed a system for fire safety, spreading heat away from the main cabin to prevent fires and keep occupants safe. This architecture is proven to be ten times less likely to cause fires starting per mile driven compared to gas vehicles from 2012 to 2020 [12]. In 2013, Tesla's Model S received a five-star rating in every category from the National Highway Traffic Safety Administration (NHTSA). In 2018, the Model 3 and Model X received a five-star rating from the NHTSA. In 2019, the Model 3 received a top safety pick award from the Insurance Institute for Highway Safety (IIHS). Lastly, the Model Y received the same reward from IIHS in 2021 and received a five-star rating from NHTSA [12]. A five-star rating from NHTSA indicates how well the vehicle performs in crash tests. The NHTSA performs four different crash scenarios when evaluating a vehicle's safety: frontal crash, side barrier crash, side pole crash, and rollover resistance [13]. With each Tesla model receiving a five-star rating from the NHTSA, consumers can be reassured their vehicle is safer than what is required by federal law.

Fig. 14 Source: [12].

V. TECHNOLOGY MADE FOR PRECISION

In order to achieve a fully autonomous vehicle, Tesla utilizes the latest technology for fast computing and data processing while using all hardware onboard for a safe and efficient journey. From their FSD chip, a microchip built for processing their AI technology, to their Dojo chip, a microchip made to train their fleet of neural networks, and the cameras as input systems, Tesla's technology has always been a leader in cutting-edge technology.

A. *FSD Hardware*

The current version of Tesla's FSD hardware is hardware version 4, an impressive upgrade from hardware version 3. In 2016, Tesla started development for the Hardware 3 (HW3) chip for their FSD computing [14]. It took them two years for the first FSD technology to roll out into production, in 2018. HW3 was engineered to control Tesla's Autopilot for AI-assisted driving. The fabrications of HW3 were Samsung's fourteen-nm process that incorporated three quad-core processors on both sides, computing at 2.2 GHz. Built in is a custom-engineered NPU for the neural network system that computes 36 trillion operations a second [14]. Before HW3, Tesla used the NVIDIA DRIVE PX 2 AI for their vehicles. Tesla engineer HW3 because no hardware was available to compute their needs. HW3 outperformed the NVIDIA system by fifteen trillion operations a second, unlocking the ability for their systems to evolve significantly [14]. With HW3 shipped in cars around April 2019, Tesla was able to develop Navigate on Autopilot, Summon features, and FSD beta features [14]. Although HW3 was powerful, this computing would not be enough for a fully autonomous vehicle.

Hardware 4 (HW4) not only upgraded HW3 abilities but also came with an all-new sensor unit. HW4 is the latest development for Tesla's FSD computing and processing of sensors. The original eight cameras on the vehicle were upgraded to have a higher resolution. Some of the cameras, depending on the location, have a wider field of view or view from sideways angles [14]. At the time of release, it was rumored to be an extra three cameras installed on HW4 models, but this is yet to be determined. This was rumored because a camera connector on the HW4 board had a label, "spare," which many believed to suggest more cameras added onto future models. The new and improved FSD computer is estimated to be two to four times faster than HW3 [14]. Still utilizing a Samsung architecture, the newer board is built with twenty CPU cores on each side, with a frequency of 2.35 GHz. HW3's custom-engineered NPU processed 36 trillion operations a second, but the newly-engineered neural network chip is capable of processing 50 trillion operations a second [14], see figure 15. From the original NVIDA system to HW4, Tesla's neural network computing has increased by 29 trillion operations per second. With improvements to the HW4 board, there are two nodes that both do the same calculations and then compare results [14]. This is perfect for the safety of all predictions made and allows the vehicle to notice any faults or errors. These two nodes were removed from HW3 for processing power, but Tesla is constantly improving ways to ensure safety on the roads.

Fig. 15 Source: [14].

B. *Dojo System*

Tesla, as a hardcore technology company, not just automotive, is building the Dojo system. The Dojo system is a supercomputer that started development for substantial improvements to AI training latency for Tesla's Autopilot team. The neural networks used for Tesla's Autopilot technology take over a month to train, causing massive delays in evaluating new approaches [15]. To find a solution for speeding up training in a cost-efficient and energy-efficient manner, Tesla set their sights on engineering a computer chip capable of arithmetic units. The goal was to use this technology at a very high level. Originally studying the possibility of this technology performing with DRM in various packaging, it was later rejected at the end of testing due to failures [15]. The next approach for the system was using embedded SRAM inside the chip. SRAM has great storage, is much faster, and draws less power than DRAM. Tesla favored SRAM for its very low latency and high bandwidth, which achieved their goals of strong utilization for the arithmetic units [15]. This also led to no interruptions as the accelerator is engineered from stripped hardware that is compiled to a compiler made to schedule in a terminist way [15]. The training methodology Tesla went for with the Dojo System is model parallelism. Model parallelism is where the training model's layers and tensors are run across separate cores, see figure 16. Today's machines utilize data parallelism, which takes the same model onto each core. Tesla favored model parallelism as it doesn't consume additional memory capacity [15]. With these focuses in mind, the Doja system was born, which is different from any other on the market, see figure 17. To ensure that the new system will be fit for current generation FSD and future generations, they designed the Dojo system for ways of growth. With no limitations besides the physicality of the computer, Dojo grows with each new technology discovered [15].

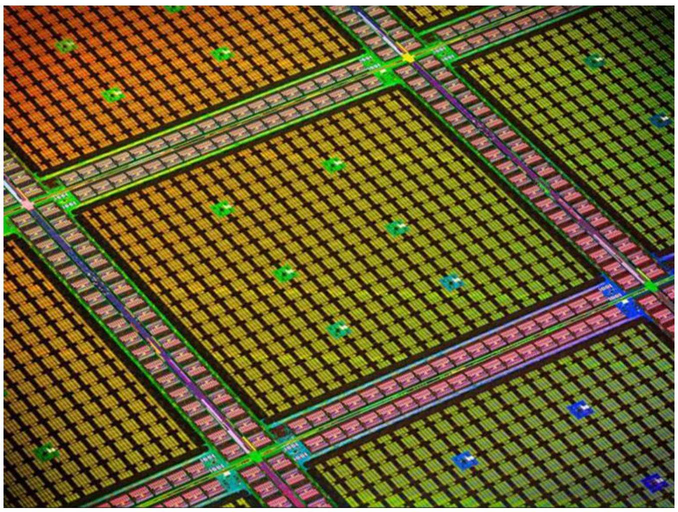

Fig. 16 Source: [6].

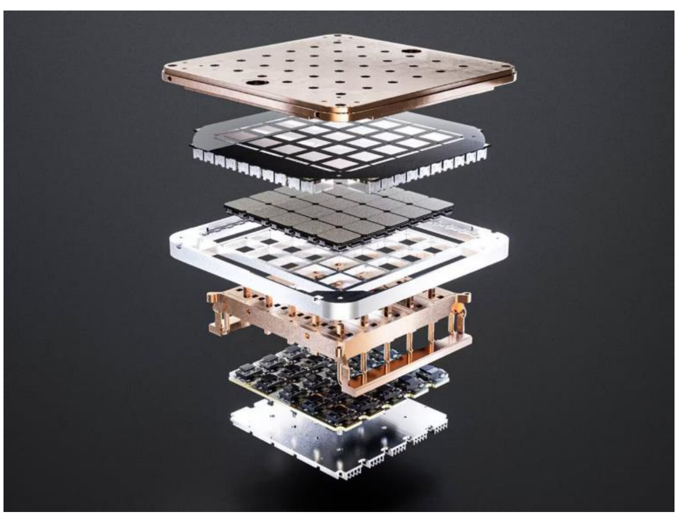

Fig. 17 Source: [6].

Tesla's datacenters are now utilizing the Dojo System. Each chip gives maximum performance, throughput, and bandwidth for training. Where verification and validation methods are designed with pre- and post-silicon [2]. Control loops and system monitoring all scale together with high-level software APIs, which makes Dojo one of the top competitors for AI computing.

C. Cameras

As of right now, Tesla uses cameras only for Autopilot. With the new Tesla Vision integration into Tesla vehicles, sensors used for Autopilot were removed. Ultrasonic sensors were used for Autopilot's parking assistance, but now it relies on cameras, see figure 18. The standard in the industry is to use Lidar with HD mapping. Lidar works by range-finding objects around the vehicle, resulting in a point cloud. The system would then take those points and create a pre-map with the car localized onto the map [16]. Tesla's approach is vision-based, where instead of pre-mapping, the data is considered the first time it's registered on a camera. Tesla doesn't use Lidar with HD mapping as it costs a lot to store map data for millions of drivers. Instead, using computer vision to train neural networks, once developed, works more efficiently and is more cost-effective [16]. With eight cameras as the input system, see figure 19, for Tesla Vision and a pair of human eyes, the roads are sure to be safer for avoiding crashes and major accidents.

Fig. 18 Source: [25].

Fig. 19 Source: [23].

VI. TESLA'S UNIQUENESS

Tesla is not the only company in a race to achieve a fully autonomous vehicle. Though Tesla is one of the leaders in the race, there are some notable competitors. Waymo, Mercedes-Benz, Lucid Motors, and other vehicle manufacturers are working to implement FSD, or AI-assisted driving. Waymo has a driverless taxi, Mercedes-Benz has Drive Pilot, which is similar to Tesla's FSD beta when tested in 2022, and Lucid Motors offers AI driver assistance at a pricey cost [26]. However, Tesla's approach to FSD and AI-assisted driving by using Tesla Vision sets it apart from others. Many competitors, like Waymo, utilize LiDAR systems for mapping out the vehicle's surroundings for their AI technology. Tesla's strategy to use a fully camera-based input system for their computer vision models makes them unique as they do not rely on laser sensors.

A. *Full Self Driving Race*

For a safe future on the road and allowing drivers to utilize extra measures of caution, fully autonomous vehicles have been researched and engineered throughout the decade. With multiple car manufacturers racing to develop the best AI features for the road, drivers have plenty of options to choose from. Some of the most popular companies developing AI technology inside cars are Waymo with its driverless taxi (see figure 20), Mercedes-Benz's Drive Pilot system (see figure 21), and Lucid Motor's AI driver assistance [26]. Tesla and these companies are constantly updating and developing the way driving and ride sharing function on the road. The goal is that each company is aiming for FSD capabilities, but with each taking their own approach, it is all down to a race.

Fig. 20 Source: [28].

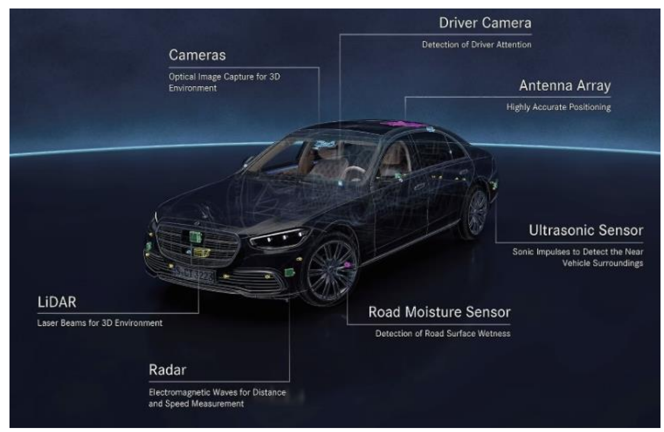

Fig. 21 Source: [29].

Tesla, a publicly traded company that keeps its shareholders' opinions in mind, is taking a different approach to the FSD race compared to its competitors. Tesla's competitors utilize LiDAR (see figure 22) and radar systems for 3D mapping, but Tesla switched to being the first to use a camera-only-based input system [16]. Tesla, taking this approach to give drivers eight extra eyes on the road, sets them apart from all other car manufacturers in the industry.

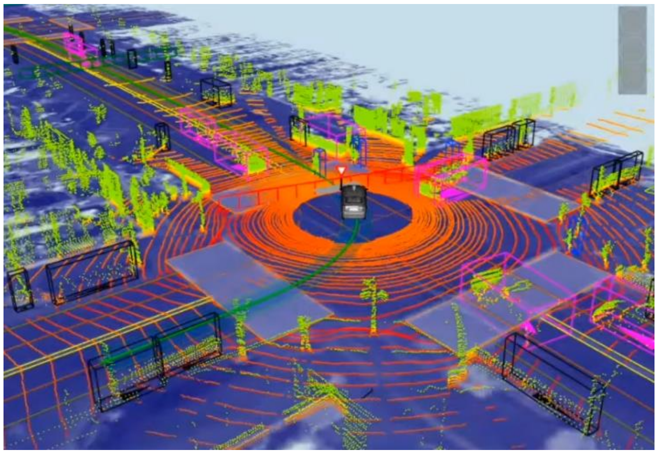

Fig. 22 Source: [16].

Waymo's driverless taxi is fully self-driven compared to Tesla, where the driver remains in control of the vehicle. Tesla's Autopilot is capable of traversing all types of roads, but Waymo's is only for small areas that Waymo picks [26]. Waymo's taxi takes a passenger from their pickup location to their destination while they sit in the back seat, with no one behind the wheel. Waymo is considered SAE level 4, one level above what Tesla is considered. Since no human driver is in control of the vehicle, it is level 4, but not level 5, because if the car needs human assistance, it will pull over. Waymo only uses training data in the cities of San Francisco and Phoenix for road conditions during the day and night, as these two cities are the only ones that they currently provide rides for, 24/7 a day [27]. Unlike Tesla, which uses GPS, Waymo has custom-built maps for the two cities they operate in (see figure 23) and uses their sensors for obstacle detection [28]. Tesla still uses GPS for navigation, as their vehicles can operate on any road or city. Having every city and town mapped can take a lot of storage and is nearly impossible to train for, so that might be the reason behind Waymo only being in two cities. Tesla utilizing computer vision with only cameras and not using sensors is more similar to how humans see the road to detect objects like other vehicles and road signs. With Tesla's approach, all resources and processing power can be used to train only for computer vision, so you won't need to worry about training and updating LiDAR and radar data.

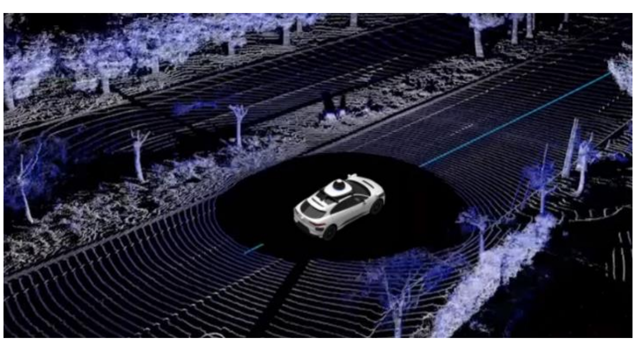

Fig. 23 Source: [28].

Conclusion

Artificial intelligence is no longer an "in the future" discussion. AI is being integrated into everyday life by humans gaining assistance from it or an AI fully autonomously completing tasks without human intervention. This means that AI systems are taking on the role of high-risk tasks like driving vehicles, medical diagnostics, and infrastructure. With AI helping take the wheel and assist drivers on the road, safety is the number one priority. Not only does an AI assistant driver need to process data in real-time, but they also need to make predictions to avoid objects and create a mapping of the 3D space around the vehicle. If at any moment something goes wrong with the machine's system, physical harm or even a loss of life can occur.

Tesla is still developing newer technologies to overcome both safety and technological challenges. They're committed to opening up the roads to full self-driving, not only for a more efficient and sustainable life on the roads but also to traverse safely. Tesla's strategy for a purely camera-based system might be the potential advantage to devoting processing power for safety and following all the rules of the road. Tesla's commitment to always making improvements in their systems can easily be updated for all AI-assisted cars with their over-the-air updates. With their eight cameras watching every angle of a driver's vehicle, there's more eyes watching the road, reducing human error, and offering the latest technology in driving assistants.

In conclusion, there is currently no autonomous FSD vehicle out on the road today. By continuously collecting data from all their cars deployed on the road, Tesla's system is constantly learning and growing to someday achieve the goal of a fully autonomous vehicle. But as of now, with safety in mind, Tesla ensures that drivers have their hands on the wheel at all times until their systems reach the capability for the safest drive from point A to point B. The future potential of fully autonomous driving is not only for easement but also proof that AI can help shape the future for a safer and more reliable way of transportation.

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