COMM018 - Internet of Things

Course Work 01

IoT Case Study on Tesla Autopilot System

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Abstract

Tesla's Autopilot system, which combines edge computing, AI, and IoT, revolutionized car automation and safety. This case study examined the FSD system's unique AI chip, which makes real-time decisions and interprets surroundings. The study also examined Tesla's embedded system architecture, driven by its in-house AI engine, sensor fusion, and neural network processing. It highlighted Tesla's difficulties, including hardware constraints, dependence on vision-based AI, and regulatory barriers. The system's shortcomings included the need for increased processing capacity, AI education, and safety regulations. Future improvements include the introduction of the HW5 AI chip, the Dojo supercomputer for enhanced training, and better integration of vehicle-to-vehicle and vehicle-to-infrastructure communication. This analysis provides insights into Tesla's Autopilot system's state, challenges, and future advancements in IoT-driven autonomous vehicles.

Acknowledgement

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1. Introduction

Tesla Inc., which was established in 2003 by Martin Eberhard and Marc Tarpenning and now governing by the and currently Elon Musk, as the CEO of this company, is a leading player in the development of autonomous driving systems. The Tesla Autopilot system, an advanced version of the autopilot system, combines machine learning, artificial intelligence (AI), Internet of Things, and sensor fusion to assist with steering, braking, acceleration, and lane changing on highways and well-marked roads (Tesla, 2025). The system continuously gathers and analyzes real-time data to improve efficiency, safety, and navigation for vehicles. Tesla's Full Self-Driving (FSD) system expands this functionality to include features like automatic lane changes, parking assistance, and the ability to navigate on city streets.

The company has made significant investments in IoT-driven products, such as AI-enhanced robots, Powerwall energy storage, and Tesla's FSD system. Tesla's contribution to the Internet of Things goes beyond transportation by incorporating AI-driven automation and smart energy solutions into its ecosystem. Autopilot systems have evolved significantly since their invention in the early 20th century, progressing from basic mechanical controls to sophisticated AI-driven automation in the automotive, maritime, and aviation sectors.

In contrast to earlier aviation autopilot systems, Tesla's system is AI-driven and uses real-time processing to adjust to actual driving situations. While Tesla's system is still developing and requires driver supervision, aviation autopilots have almost fully automated certain functions, aiming to improve safety and lessen human effort for completely autonomous travel. Contemporary IoT-enabled systems incorporate real-time data for improved automation, efficiency, and predictive safety measures, while older autopilot systems functioned independently with little connectivity. This breakthrough opens the door for completely autonomous cars and airplanes by enabling contemporary autopilot technology to dynamically adjust to changes in the environment.

This paper provides a technical analysis of the Tesla Autopilot system, focusing on its embedded system architecture, application, power management, communication protocols, and data analysis for improved efficiency and safety.

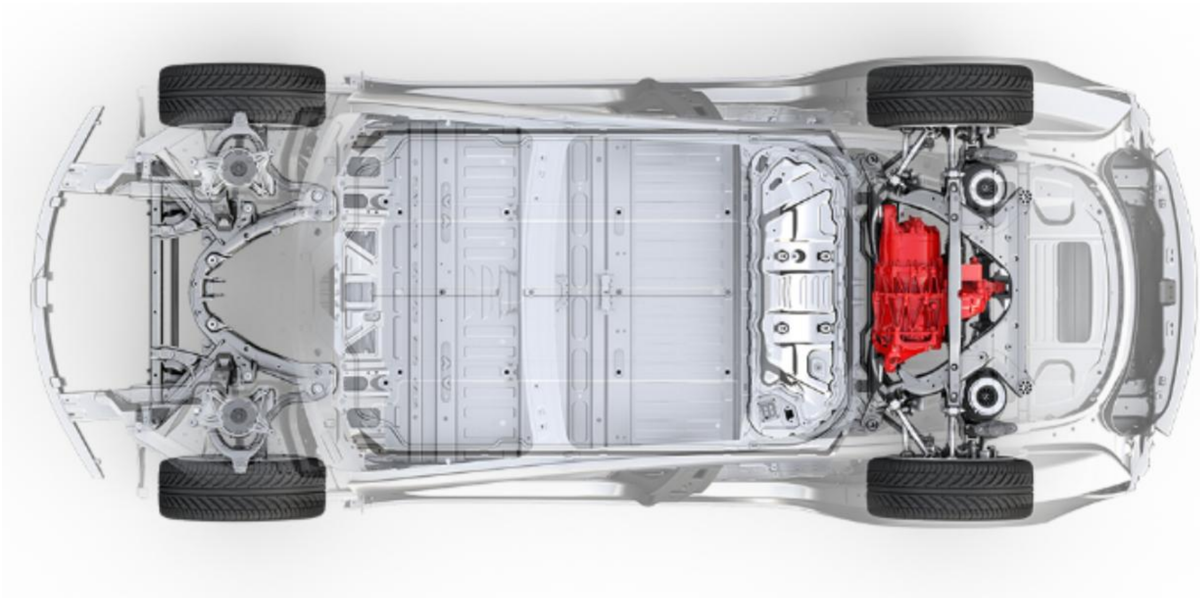


Figure 1- Tesla Autopilot Model 03 (George, 2018)

2. Overview of Key Components

The foundation of the Tesla Autopilot system is a strong integration of several essential parts that cooperate to provide autonomous driving. These elements consist of data analysis frameworks, communication protocols, power management techniques, application functionality, and the embedded system. For the vehicle to make safe, effective, and wise decisions, each of these components is essential. The technical details of these essential parts are examined in this section, along with their importance in Tesla's Full Self-Driving (FSD) system.

2.1. Embedded Systems:

Embedded systems are specialized computing systems designed for specific tasks within larger systems, ensuring high efficiency, reliability, and real-time performance. Commonplace gadgets like home appliances, industrial automation, automobile control units, and medical equipment contain them. The Internet of Things (IoT) relies heavily on embedded technologies to link physical objects to the internet for processing and gathering data in real time. In the Tesla autopilot system, can identify few embedded systems as (Tesla, 2025),

Hardware Architecture

- Custom AI chip - Tesla Full Self-Driving (FSD) Computer (Also called HW 3.0 or HW 4.0 in newer models)
- Sensors & Cameras suite
- GPU and CPU
- Media Control Units

Software Architecture

- Tesla Autopilot Neural Network (Neural processing unit (NPU))
- Operating System
- Autonomous Driving Algorithms with Edge computing capabilities (Dojo Computer)

Tesla's Autopilot system uses the Full Self-Driving (FSD) computer for semi-autonomous driving, enhancing real-time data processing and intelligent driving behaviors. The FSD Chip and Neural Processing Unit provide high-performance acceleration for deep learning tasks. The system's sensor suite includes eight cameras, twelve ultrasonic sensors, radar, and GPS integration. The FSD computer incorporates redundant safety architecture for a safer driving experience (Emil

Talpes, Debjit Das Sarma,Ganesh Venkataramanan, Peter Bannon,Bill McGee, Benjamin Floering, Ankit Jalote,Christopher Hsiong, Sahil Arora,Atchyuth Gorti, and Gagandeep S. Sachdev, 2020).

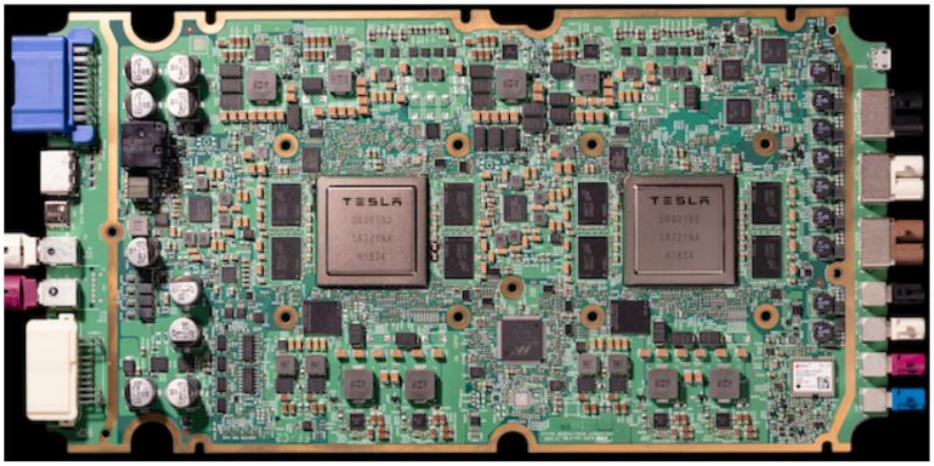


Figure 2- FSD computer with two tesla FSD chips- (Anon., 2023)

2.2. Applications:

This autopilot system is with several use case applications related to the practical life scenarios and this device was able to address some highlighting practical applications which consumers may directly expect from these domain developments as,

- Autonomous Driving
- Traffic-Aware Cruise Control (TACC)
- Summon & Smart Summon
- Auto-park
- Full Self-Driving (FSD) Beta

Tesla's Autopilot system has significantly impacted various industries, improving driver convenience and safety through adaptive cruise control, automatic lane changes, highway driving, and lane-keeping. It also offers features like Summon and Smart Summon, which enable cars to drive short distances in parking lots, and Traffic-Aware Cruise Control (TACC) that adjusts vehicle speed based on traffic flow. Auto-park and Full Self-Driving Beta further enhance vehicle autonomy.

This automated driving practices are not only using the private transportations but also for the logistic and transportation industries. This autonomous trucks and self-driving taxis like Tesla

Robotaxi are just two examples of how Tesla's technology is revolutionizing the logistics and transportation industries. Although the goal of these developments is to increase efficiency and streamline freight operations, sudden acceleration and braking occurrences in ride-hailing services have raised safety concerns (By Akash Sriram and Abhirup Roy, 2024). Although this behavior has sparked safety concerns and highlights the need for strong safety measures and regulatory frameworks, ride-hail drivers are increasingly operating improvised 'robotaxis' utilising Tesla's FSD software.

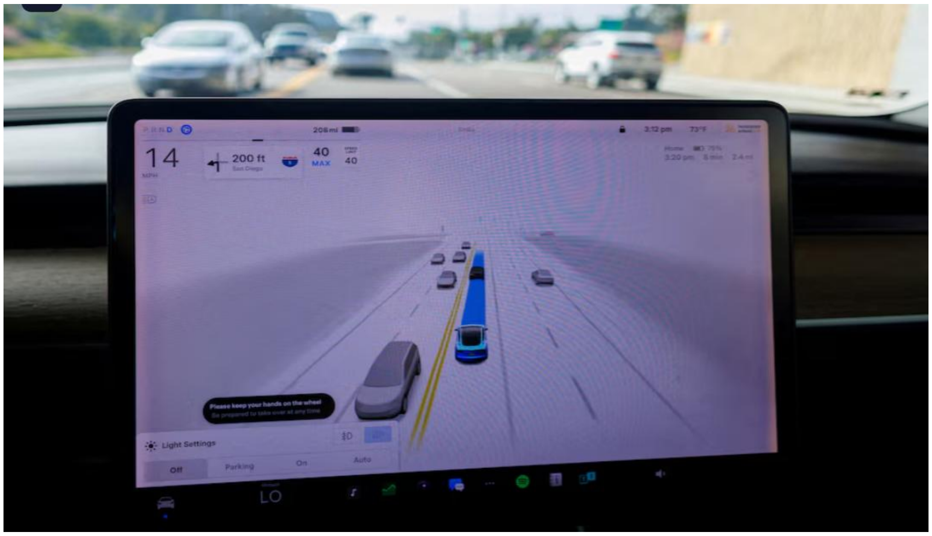


Figure 3- self driving car navigation board snaps in loss Angelis- (By Akash Sriram and Abhirup Roy, 2024)

2.3.Power Management:

Power management of the device is very critical phase and when it comes to the mobile or transportational device is more significant. For the tesla autopilot system also manufactures and device designers had utilized number of power management strategies. A key component of Tesla's semi-autonomous driving capabilities, the Autopilot system is energy-efficiently engineered to reduce its influence on vehicle range. The Full Self-Driving (FSD) computer, which includes Hardware 3.0 and the next Hardware 4.0, uses between 72W and 100W of electricity. This approach makes sure that the overall energy consumption of the vehicle is not greatly impacted by the computing needs of processing data from cameras and sensors. For the proper power management for the Tesla battery, there is a BMS (Battery Management System) board.

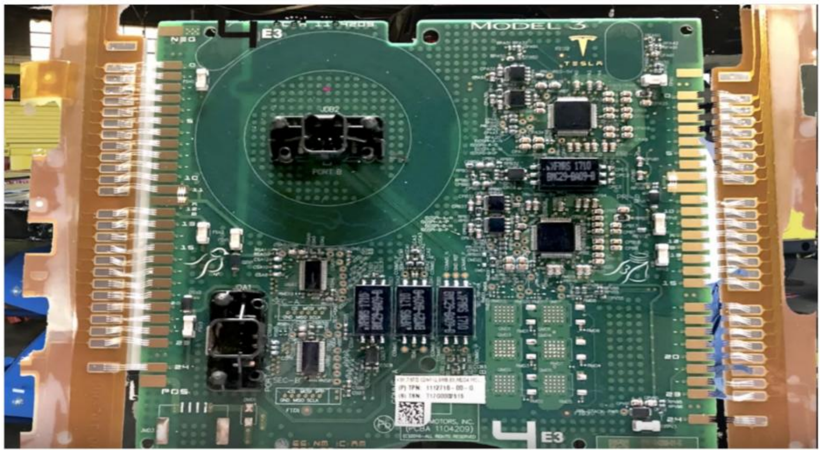


Figure 4-The BMS board mounted on the Model 3 cells- (George, 2018)

For this Tesla battery there are three power sources as Primary, Regenerative and in future Solor panels to use solar power. As the primary power source is the main battery pack of the vehicle and it is Lithium-ion battery. Regenerative braking power source allows to recover energy when slowing down the vehicle.

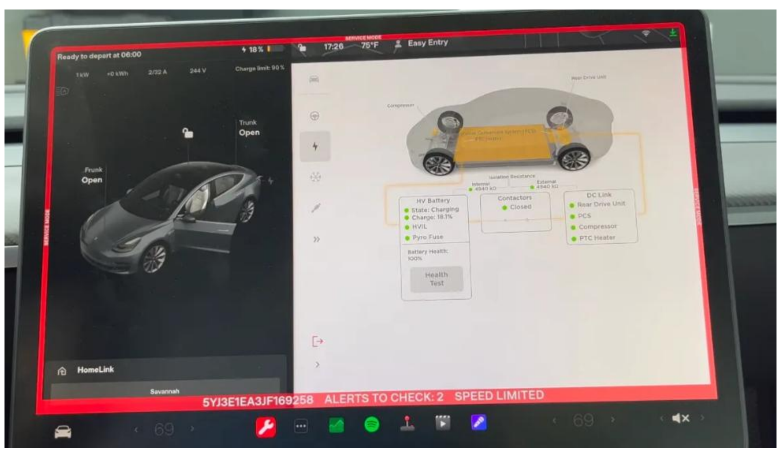


Figure 5- Tesla Battery optimization and dashboard

Tesla autopilot system power management strategies are,

- Battery Optimization
- Efficient AI Chips
- Sleep Mode & Low Power Standby

To further improve energy economy, Tesla incorporates regenerative braking technology in addition to these design considerations. This method increases driving range and lessens the need for frequent recharging by recovering energy that is normally wasted during braking and transforming it into electrical power stored in the battery. According to studies, regenerative braking can recover and repurpose up to 70% of the energy lost when braking, greatly increasing a vehicle's overall efficiency (Evans, 2025).

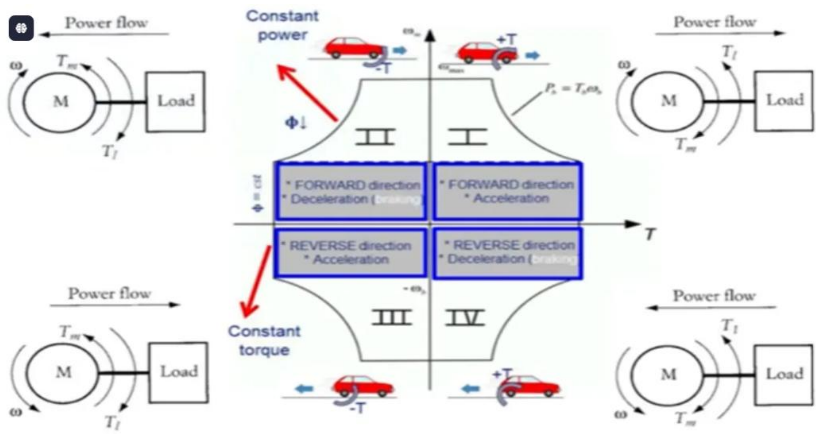


Figure 6- Power flows of Tesla auto pilot system

Collectively, these characteristics highlight Tesla's dedication to striking a balance between cutting-edge autonomous driving technology and environmentally friendly energy use, making sure that improvements in vehicle intelligence don't come at the expense of economy.

2.4.Communication Protocol:

Communication process of the tesla autopilot plays critical role and it enables internal communication among vehicle components and external communication with both external devices and tesla’s cloud servers. For this communication process they use number of communication protocols and these protocols enables the tesla autopilot system accurate functionalities.

For the external communication process Tesla’s Autopilot system is using Wi-Fi and 4G connections to enable Over-The-Air (OTA) software updates. Rather than these communication protocols, advanced communication protocols are used by Tesla's Autopilot system to enable smooth data transmission between internal and external networks. High-speed Ethernet connections are used to transfer data from cameras and sensors to the Full Self-Driving computer, and the Controller Area Network (CAN) is used for real-time communication between oecus. For over-the-air software updates and real-time data transfer to Tesla's cloud infrastructure, Tesla cars are also equipped with Wi-Fi and cellular connectivity. In order to improve safety and autonomous driving capabilities, Tesla intends to integrate Vehicle-to-Vehicle (V2V) and Vehicle-to-Everything (V2X) communication (Syed Adnan Yusuf, Arshad Khan, Riad Souissi, 2023).

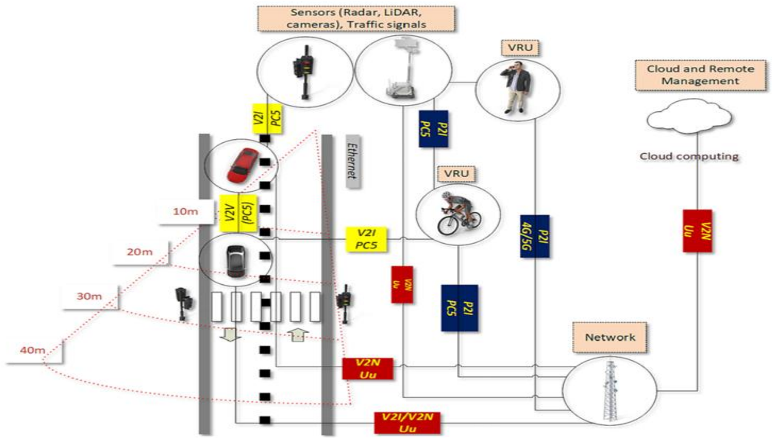


Figure 7-An indirect C-V2X scenario with the VRU and data exchange in context.

2.5.Data Analysis:

Data analysis and data processing is much needed aspect in the IoT based devices and for the systems like Tesla Autopilot it is very critical because it is used in practical situations and also it has to deal with different components in different situations. Due to that advanced data analysis is used by Tesla's Autopilot system to gather, evaluate, and use enormous volumes of data for continuous improvement and real-time decision-making. Radar is used to identify impediments, while cameras, GPS, IMU, radar, and ultrasonic sensors are used to record road conditions in real time. This data is managed by Tesla Vision, a proprietary computer vision system that recognises lane lines, traffic signs, pedestrians, and cars (Lambert, 2020). The system's interpretive capabilities are improved by sophisticated neural networks and deep learning models that were trained on Tesla's global fleet. One significant achievement in this area is Tesla's Dojo supercomputer, which speeds up the creation of autonomous driving capabilities. By combining input from several sensors, sensor fusion techniques increase the system's perception and decision-making processes' accuracy and dependability (Lambert, 2020).

The AI continuously forecasts the state of the roads and modifies driving tactics accordingly. Real-world driving data is gathered as part of Tesla's continuous learning strategy in order to gradually enhance AI capability (Lambert, 2022). This approach guarantees that the Autopilot system develops and adjusts to novel driving situations, especially when combined with over-the-air software upgrades. The foundation of Tesla's approach is the idea of fleet learning, which improves the overall functionality and safety of Autopilot features by combining data from millions of cars globally.

3. In-Depth Analysis of Custom AI chip in Tesla FSD Computer

Tesla Autopilot utilizes AI-powered technology, with two recent versions, model 3.0 and model 4.0. Edge computing is crucial for low-latency decision-making in autonomous cars. Because of its specially created AI chip, Tesla's Full Self-Driving (FSD) Computer marks a major advancement in autonomous car technology. Since its creation, this chip has experienced significant development, including cutting-edge technologies to improve Tesla's autonomous driving capabilities.

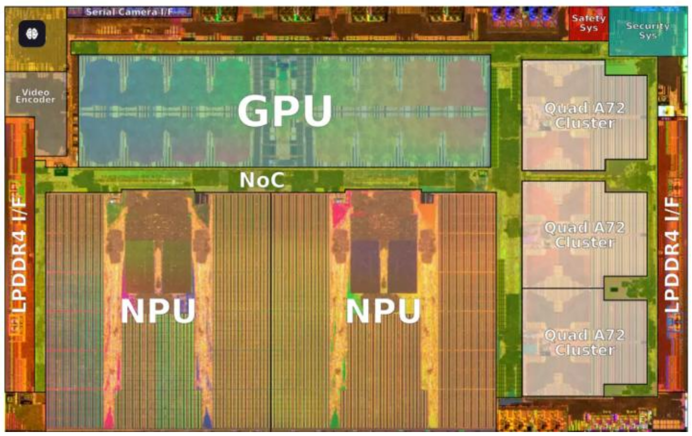
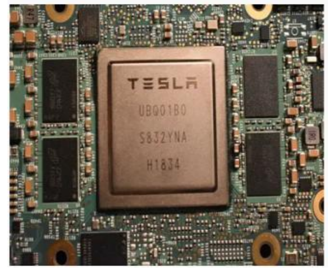
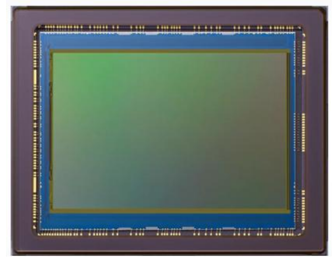
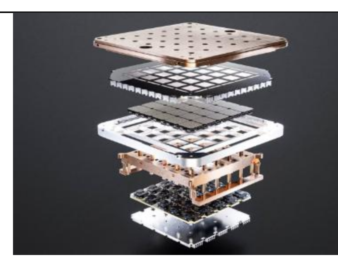


Figure 8- Tesla FSD computer Board view

Figure 9- FSD computer with two FSD tesla chips

Table 1- Tesla Autopilot system FSD computer sample component's purpose and example devices- (Anon., 2025)

Component	Purpose	Example Sensor/Chip	Image
FSD AI Chip	Neural network processing	Tesla Custom FSD Chip	
Vision Cameras	Object detection	Sony CMOS Sensors	
Radar Sensor	Distance measurement	Bosch 76GHz Radar	
Ultrasonic Sensors	Close-range detection	Tesla Parking Assist Sensors	
Edge AI Processor	Real-time decisions	Tesla ARM-based AI Core	

3.1. Tesla Custom AI Chip

To lessen dependency on other hardware and ensure optimal performance, Tesla started working on an AI chip specifically designed for autonomous driving in 2016. As a result of this effort, the Hardware 3 (HW3) platform—which included Tesla's first proprietary FSD Computer—was released in 2019. This system was created to be a drop-in replacement for current hardware, offering noticeably more computing power while consuming comparable amounts of electricity.

Figure 10-Tesla Custom AI Chip (Anon., 2022)

NVIDIA's Drive PX2 platform from previous models has been replaced by Tesla's FSD Chip, which marks a significant advancement in AI-driven automotive technology. Features like lane detection, adaptive cruise control, obstacle recognition, and real-time driving decisions are made possible by the chip's special optimisation for running Tesla's neural network models (Evans, 2025). Tesla has demonstrated its dedication to attaining complete autonomy by improving performance, efficiency, and control over its self-driving hardware by switching to its own proprietary AI processor. Bellow table clearly indicated the key specifications of the Tesla custom AI chip for their FSD computer.

Table 2- Key specifications of the AL chip- (Anon., 2022)

Specification	Details
Processor	12-core ARM Cortex-A72 (2.2 GHz)
Architecture	ARMv8.0-A

Manufacturing	14nm CMOS (Samsung)
Memory	8GB LPDDR4-4266
Bandwidth	63.58 GiB/s
TDP (Power)	36W
Transistor Count	6 billion
Die Size	260 mm²
Package	FCBGA-2116
Error Correction	ECC Memory Support

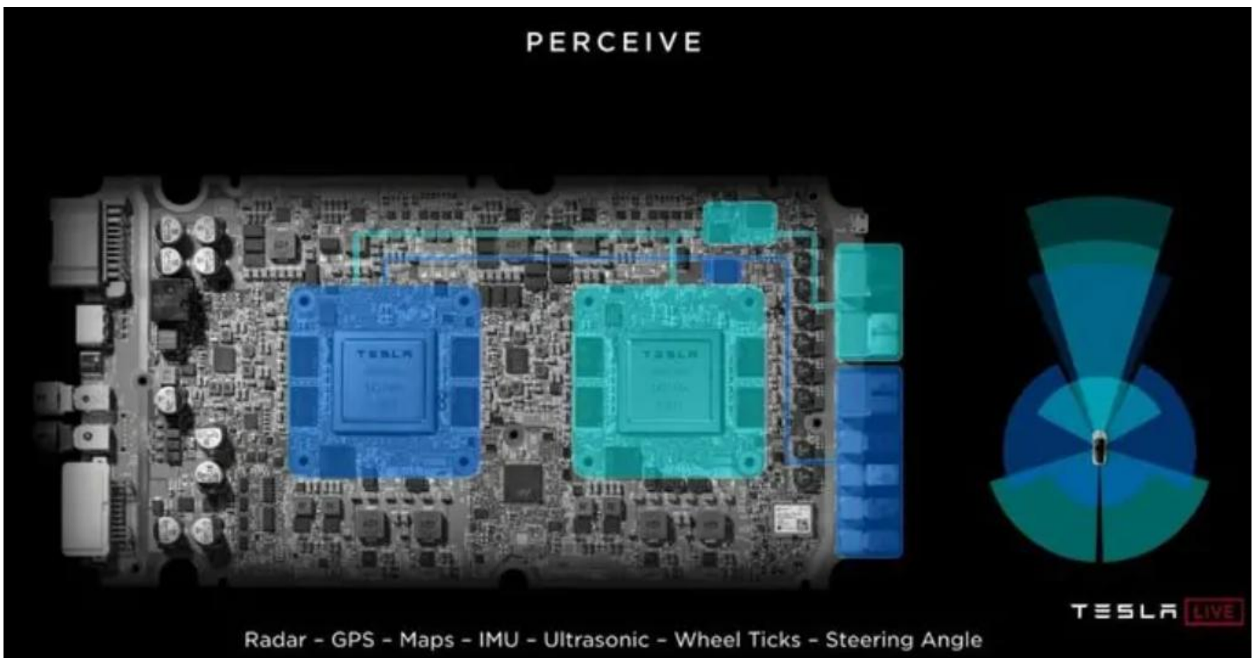


Figure 11- Inputs to the AI chip

3.1.1. Significance and technical insights of the Tesla FSD AI chip

Neural Network Accelerators, which are specialised circuits designed to handle deep learning computations, were among its most important innovations. These accelerators provide real-time decision-making for Tesla's Full Self-Driving (FSD) system by outperforming conventional GPUs in terms of speed and energy efficiency. In order to improve reliability, the Dual-SoC (System-on-Chip) Architecture was also used. This architecture uses two AI chips operating in parallel to offer redundancy, which means that the system can still work even if one of the chips has a problem. In applications involving autonomous driving, where dependability and safety are critical, this redundancy is essential. Additionally, the car can process enormous volumes of sensor data instantly thanks to Tesla's AI chip's high computing throughput, which can perform up to 144 trillion operations per second (TOPS).

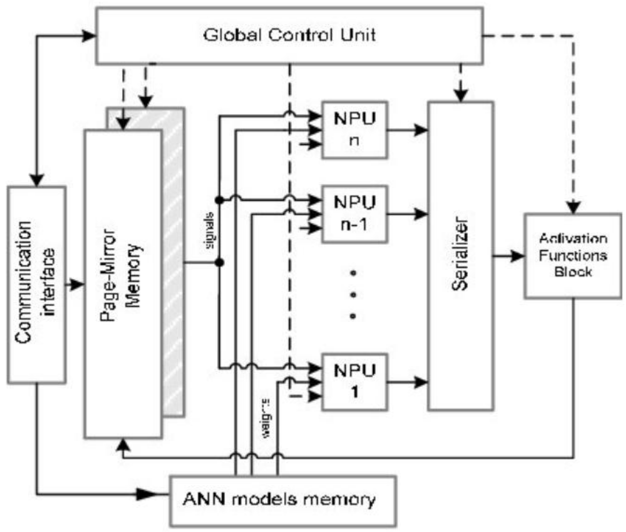


Figure 12- Nural Network accelerator- (Pietras, 2014)

The primary processing unit for Tesla's autonomous features is a unique AI chip that combines data from multiple sensors and uses deep neural networks to analyse actual driving situations. With little assistance from a human, the car can now anticipate driving conditions, identify obstructions, and recognise traffic signals because to these neural networks. As millions of Tesla vehicles provide driving data to hone neural network models, the AI-powered system continuously improves its overall performance through fleet learning. Tesla has introduced Hardware 4 (HW4), which enhances decision-making and environmental perception by incorporating more sensors. HW4 improves object detection, lane identification, and path planning, aiming to enhance autonomous capabilities and strengthen Tesla's self-driving technology in challenging urban and highway conditions, building on the developments of HW3 (Anon., 2023).

From an IoT standpoint, Tesla's AI processor plays a key role in data processing and car connectivity. One of its primary features is Over-the-Air Updates, which enables Tesla to remotely apply software upgrades that boost vehicle performance, introduce new features, and fix security flaws without needing to visit a service centre in person (Emil Talpes, Debjit Das Sarma,Ganesh Venkataramanan, Peter Bannon,Bill McGee, Benjamin Floering, Ankit Jalote,Christopher Hsiong, Sahil Arora,Atchyuth Gorti, and Gagandeep S. Sachdev, 2020). Furthermore, real-time data collection is made easier by the AI chip, which uploads sensor and driving telemetry data to Tesla's cloud infrastructure. After that, this info is examined to develop AI models for the complete fleet, guaranteeing that advancements gained from the experiences of a single vehicle benefit the whole Tesla network. Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication may be incorporated into future versions of Tesla's AI-driven ecosystem, allowing automobiles to exchange data regarding road hazards, traffic situations, and navigation difficulties (Syed Adnan Yusuf, Arshad Khan, Riad Souissi, 2023). These developments would greatly enhance autonomous mobility solutions' overall usefulness, traffic efficiency, and driver safety.

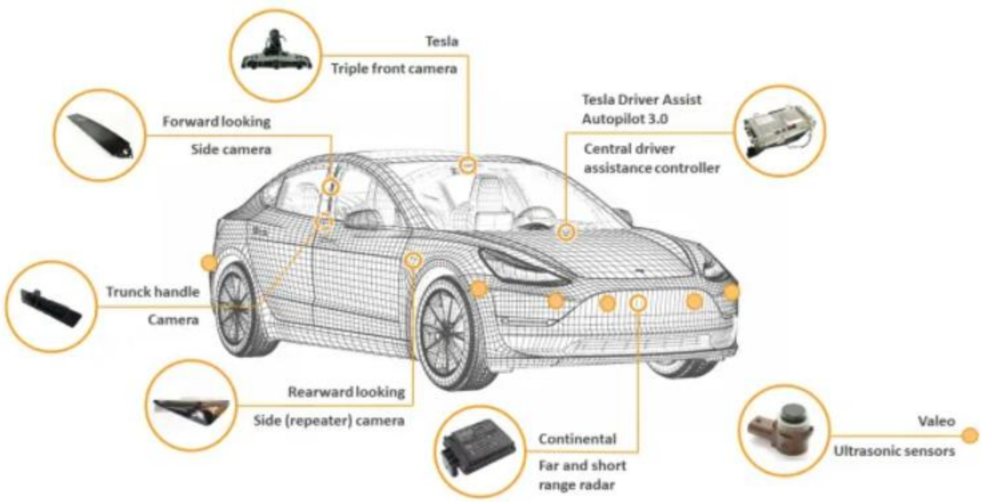


Figure 13- Tesla Model 03 sensors and computing- (Tesla, 2025)

4. Challenges and Future Improvements

A key part of Tesla's Full Self-Driving (FSD) computer, its proprietary AI chip has greatly improved autonomous driving capabilities. It does, however, have a number of significant drawbacks and restrictions, including issues with software, hardware, safety, and regulations (Shakir, 2025).

4.1.Hardware and Software challenges and limitations

- Processing Power Restrictions: The Tesla AI processor still has computational limitations for processing large volumes of real-time driving data, even with its high-performance architecture.
- Thermal Management: To avoid overheating and preserve system dependability, high-performance AI computations produce a lot of heat, necessitating effective cooling solutions (Alvarez, 2025).
- Absence of Redundant Lidar Support: For economic and efficiency reasons, Tesla does not use Lidar and instead uses just camera-based vision, in contrast to rivals like Waymo.
- Complexity of Neural Network Training: Deep learning models trained on large datasets are processed by the AI chip. The unpredictability of real-world driving situations, however, makes it difficult for the algorithm to generalise under all circumstances.
- Edge Cases and Unexpected Situations: The AI has trouble handling uncommon or surprising occurrences, including odd pedestrian behaviour or construction areas.

4.2. Safety and Ethical challenges

- False Positives and Negatives: If the AI misinterprets an item, it may brake unnecessarily (phantom braking) or fail to recognise impediments, which might result in accidents.
- Fail-Safe Redundancy: Although overall system resilience may be jeopardised by the absence of varied sensor modalities (like Lidar), Tesla's dual-chip design improves dependability.
- Legal Compliance: Different legal frameworks need Tesla's AI chip to adhere to autonomous driving standards, which slows the implementation of FSD in some areas (Shahan, 2024).
- Accountability and Liability: In the event of an accident, it is still unclear who is at fault—Tesla, the driver, or the authorities, which presents moral and legal conundrums.

- Network Dependency: The AI chip uses Tesla's cloud to update its software and learn about the fleet, even if it analyses data locally. Connectivity problems, including inadequate LTE/5G coverage, might cause important updates to be delayed.

4.3. Suggested future improvements

Tesla is strategically investing in a number of important areas to solve the current limits in its autonomous driving technology. It is anticipated that the next AI5 computer platform, formerly known as Hardware 5 (HW5), would provide a tenfold boost in capabilities over the existing HW4 system. By greatly increasing processing power and energy efficiency, this improvement seeks to improve the functionality of Tesla's Full Self-Driving (FSD) features (Alvarez, 2025).

As per the strategic application of overcome the processing power restrictions and complexity of neural networks training Tesla is creating the Dojo supercomputer, a specially constructed machine intended to train deep neural networks using enormous volumes of video data from Tesla vehicles, to supplement hardware developments. Dojo wants to improve Tesla's autonomous systems' ability to make decisions in the actual world by offering scalable and power-efficient AI training infrastructure (Bellan, 2025). Furthermore, Tesla is working with legislators to create safety guidelines and legal frameworks for AI-powered self-driving systems in tandem. By working with regulatory agencies, Tesla hopes to make sure that its autonomous driving technology satisfies safety standards and is more widely accepted, which will make it easier to incorporate self-driving cars into the current transportation infrastructure.

5. Conclusion

The Full Self-Driving (FSD) computer, which powers Tesla's Autopilot system, is a ground-breaking advancement in autonomous car technology. Large volumes of real-time data from cameras and sensors may be processed by the FSD computer, especially its special custom AI chip, which makes it possible for sophisticated driver-assistance functions like adaptive cruise control, automated lane changes, and lane holding. The vehicle's perception and decision-making skills have been boosted by the substantial improvements in computational efficiency, sensor integration, and AI processing capabilities brought about by the transition from HW3 to HW4.

But even with these developments, there are still a number of issues with Tesla's Autopilot system and FSD technology. The accuracy of object recognition in low visibility situations has been questioned due to the dependence on vision-based AI without LiDAR. Discussions over the changes required to achieve complete autonomy have been sparked by HW3's hardware restrictions. Deployment is made more difficult by national regulatory barriers as well as ethical and legal issues with autonomous driving. Furthermore, there are still significant challenges with over-the-air updates, fleet learning effectiveness, and vehicle-to-vehicle (V2V) communication integration.

In nutshell, to improve autonomous driving, Tesla's Autopilot system makes use of edge computing, IoT, and AI number of advanced technologies and Tesla plans to improve its FSD computer with advanced AI chips, Dojo supercomputer training, and real-time data sharing. Future improvements may include improved redundancy, sensor fusion, and regulatory compliance, aiming to achieve full autonomy and safer self-driving systems.

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