Sensors, Actuators and Control Systems in Electric Vehicles – part 1

Sensors and Actuators in Electric Vehicles

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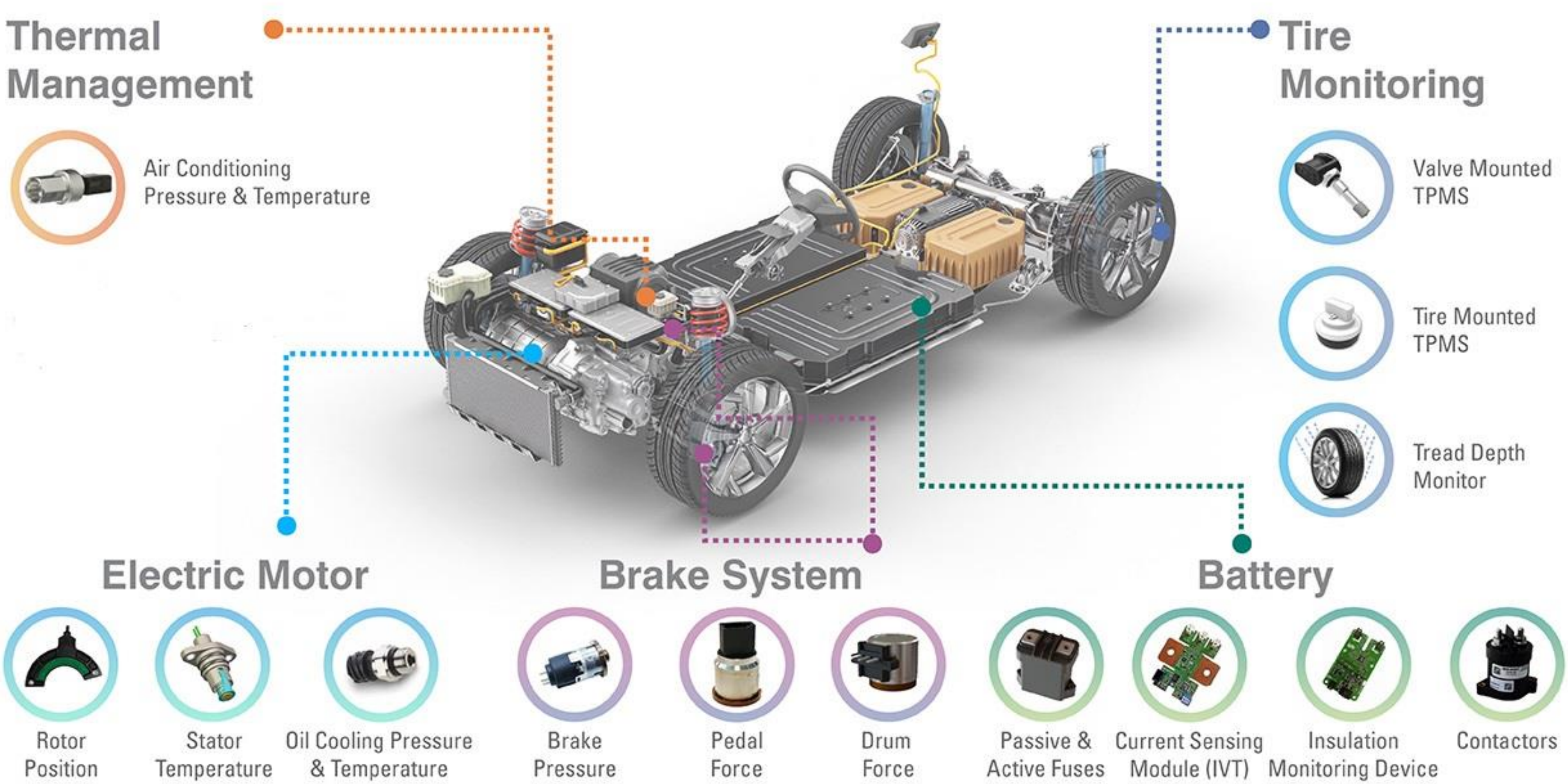
1. Sensors

- ✓ A car sensor is one of the essential parts of an electric vehicle (EV).
- ✓ It is an electronic system that monitors different parameters (temperature, coolant system, etc.), faults, and obstacles, alerting the driver and sending the signal to the ECU (Electronic Control Unit) or VCU (Vehicle Control Unit) to make appropriate adjustments.
- ✓ In the rapidly evolving landscape of EVs, sensors serve as the backbone of vehicle functionality and performance.
- ✓ These sophisticated devices are integral to monitoring and controlling various aspects of EV operation, ensuring optimal efficiency, safety, and reliability.

1. Sensors

✓ Sensors play a crucial role in electric vehicles, supporting:

- battery and thermal management,
- advanced driver-assistance systems (ADAS),
- personalized in-cabin experiences.



1. Sensors

1.1 Position sensors

✓ Gathering the mechanical motion data from the traction motors to guarantee that the system runs in harmony. After the angular position data is recorded, a motor controller or motor control unit (MCU) converts it into electric impulses to start the feedback loop.

Sensor type	**Location and Function**
Motor control position	Estimates the traction motor position using a resolver to control brushless DC operation.
Motor control angle	Estimates the traction motor angle using a resolver to control brushless DC operation.
Motor control speed	Estimates the traction motor speed using a resolver to control brushless DC operation.



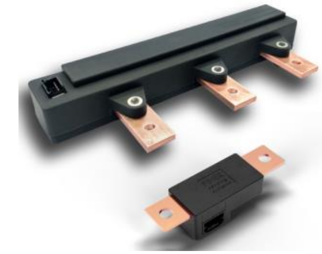
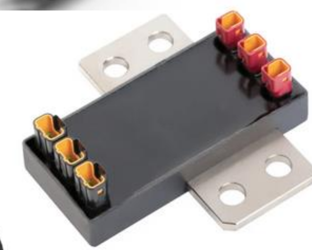

1. Sensors

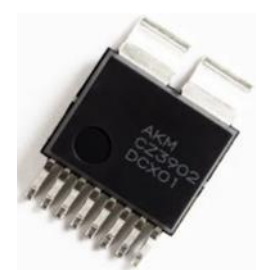
1.2 Current Sensors

- ✓ Current sensors are one of the key components in electric vehicles (EVs), as they enable accurate monitoring and control of electrical energy flow across various systems. Their main function is to measure how much current is passing through specific components, contributing to safety, efficiency, and optimal vehicle performance.
  - Battery system: Current sensors monitor the flow of electricity during battery charging and discharging. Based on this data, the system determines the State of Charge (SoC), State of Health (SoH), and manages charging dynamics.
  - Electric drivetrain: In motors and inverters, current sensors enable precise control of torque and power output. Without accurate current measurement, motor control would be inefficient or unsafe.
  - System protection: In the event of an overload, short circuit, or other electrical fault, current sensors quickly detect the issue and activate protection mechanisms to prevent damage.
  - Energy management: Based on input from current sensors, the system can optimize power distribution between various consumers (e.g., climate control, lighting, charging, propulsion), helping to extend driving range and improve energy efficiency.
- ✓ Modern current sensors use technologies such as the Hall effect or shunt resistors and are often integrated with digital controllers for fast and accurate data processing. Their reliability and precision are crucial for the overall performance of an electric vehicle.

1. Sensors

Sensor type	Location
Onboard charger current sensor	Located on the primary as well as the secondary side for control-loop operations and protection from overcurrent faults. Current sensing in power factor correction schemes improves the ON/OFF sequences.
DC/DC current sensor	Located mainly on the primary side as well as the secondary side for protection purposes on the primary side and for control-loop operations on the secondary side.
Battery-management current sensor	Stand-alone and onboard current sensors are required in battery management systems for state-of-charge and state-of-health calculations.
Traction motor current sensor	Located on the hot side for protection purposes and on the low side or in phase of the field-effect transistors for motor drive operations.
Motor current sensor	For various kinds of motors in the vehicle, current sensors on the low side are used for motor diagnostics and control loop operations.
Transmission current sensor	Proportional solenoids use current sensing to accurately monitor current and send the information to the microcontroller, where the PWM duty cycle percentage is adjusted to make the solenoid drive more efficient.



1. Sensors

1.3 Voltage Sensors

- ✓ Voltage sensors are an essential part of the electronic system in electric vehicles (EVs), as they provide accurate measurements of electrical potential between two points in the system. Their role is critical for battery monitoring, power management, and real-time fault detection.
    - Battery status monitoring: Voltage sensors measure the voltage of individual cells or the entire battery pack. These values are used to determine the State of Charge (SoC), allowing for accurate range estimation and optimized charging.
    - Fault detection: A sudden drop or spike in voltage can indicate a potential failure, short circuit, damaged cell, or poor connection. Voltage sensors enable fast detection and activation of safety mechanisms.
    - Energy management: In combination with current sensors, voltage sensors allow for power calculation, which is essential for efficient energy distribution throughout the vehicle.
    - System stability: Electric vehicles operate with complex energy systems involving different voltage levels (e.g., high-voltage systems for propulsion and low-voltage systems for electronics and lighting). Voltage sensors ensure that all subsystems receive stable and appropriate power.
- ✓ Modern voltage sensors in EVs are highly accurate, fast, and resistant to temperature fluctuations and electromagnetic interference. Their precision directly impacts the safety, performance, and longevity of the electric vehicle.

1. Sensors

Sensor type	Location
Onboard charger voltage sensor	The voltage sense monitors the voltage magnitude of the DC/DC input/ output. A resistive divider is normally used to divide the high voltage. Galvanic isolation is normally needed to prevent electric hazards from the high voltage.
DC/DC voltage sensor	The voltage sensor on the primary side monitors the voltage magnitude of the high-voltage battery. A resistive divider is normally used to divide the high voltage.
Battery-management voltage sensor	Battery monitoring ICs measure cell voltages along with current and temperature and perform cell balancing to monitor and protect the cells.

1. Sensors

1.4 Temperature sensors

- ✓ In a battery system, it is installed directly into the battery cells, giving accurate temperature measurements and regulating the heating and cooling processes to keep each cell operating within a safe range. In the case of overheating, continuous monitoring can initiate safety steps, such as disconnecting the battery or lowering charging rates, and enable the assessment of battery health.
- ✓ In an e-motor, it is used to measure the temperature of the motor windings (sensors with shrink tube insulation), the temperature in the bearings, and other parts of the motor. They also ensure the motor's dependability and ensure that there are no defects relating to torque production, control, or efficiency.
- ✓ In-cabin temperature sensors enable the driver and passengers to regulate the heat, ventilation, and air-conditioning (HVAC) system for maximum comfort.

1. Sensors

Sensor type	Location
Onboard charger temperature sensor	Temperature monitoring circuitry maintains the health of the power transistors during their active operation by checking the case or internal temperature depending on where the sensor is positioned. It immediately shuts down the system once the temperature is above the threshold.
DC/DC temperature sensor	Temperature monitoring circuitry maintains the health of the power transistors during their active operation by checking the case or internal temperature depending on where the sensor is positioned. It immediately shuts down the system once the temperature is above the threshold.
Battery-management temperature sensor	Battery monitoring ICs measure temperature and perform cell balancing to monitor and protect the cells.
Traction motor temperature sensor	IGBT’s temperature is monitored to protect the system from overtemperature faults.





1. Sensors

1.5 Pressure Sensors

- ✓ Pressure sensors play a key role in the safety and efficiency of electric vehicles. Their primary function is to monitor and detect pressure changes in various vehicle systems.

Sensor type	Function
Battery system	Pressure sensors monitor potentially dangerous changes, such as pressure buildup inside battery cells, which may indicate overheating or gas venting. Timely detection enables the activation of safety mechanisms.
Thermal management system	In cooling and heating systems, pressure sensors optimize the operation of pumps and fans, helping to maintain the powertrain and battery temperature within safe limits.
Pneumatic and braking systems	In vehicles that use pneumatic components or regenerative braking, pressure sensors ensure precise control and reliable operation.

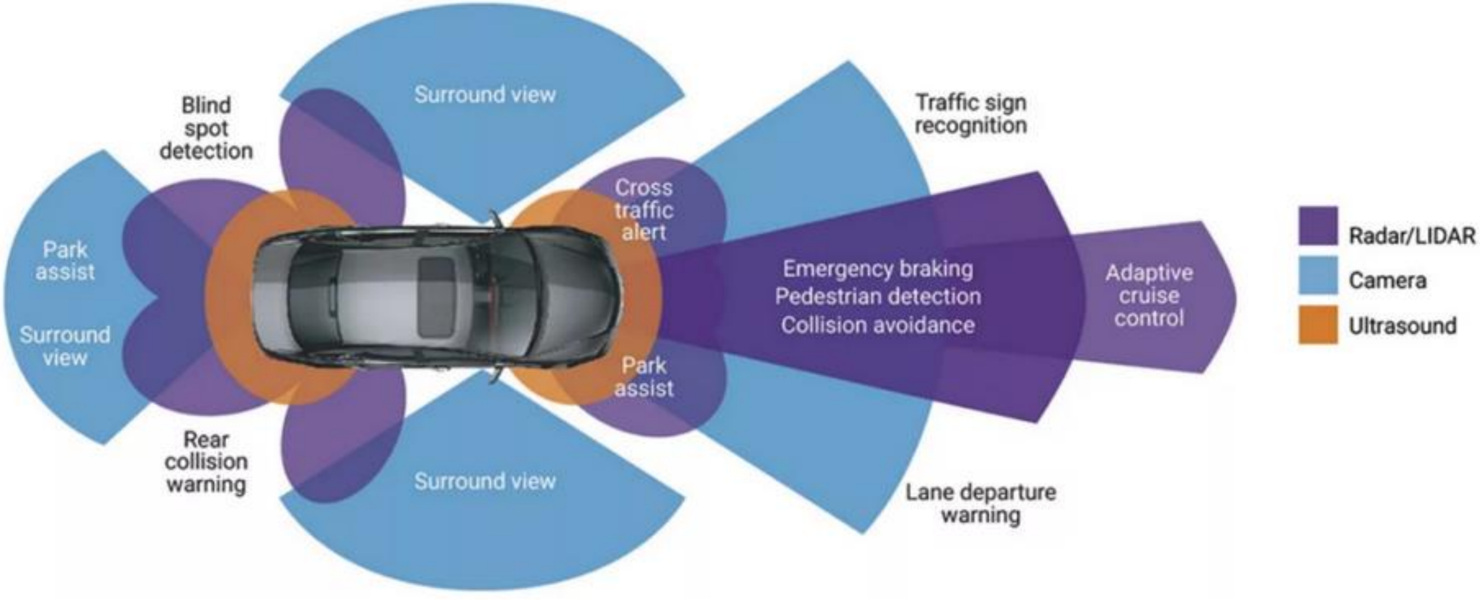
1. Sensors

1.6 Advanced driver-assistance systems (ADAS)

- ✓ Object and obstacle detection sensors in electric vehicles are crucial for vehicle safety, especially in the context of autonomous driving and driver assistance. These sensors allow the vehicle to recognize and react to various obstacles, whether it's other vehicles, pedestrians, cyclists, or static objects like traffic signs or barriers. There are several types of sensors used in electric vehicles for object and obstacle detection, each with specific advantages and applications.
- ✓ **Cruise control and autopilot:** Helps drivers maintain consistent speed and lane discipline while monitoring surrounding traffic to prevent collisions. Advanced cruise control and autopilot systems automatically accelerate, decelerate, and stop in response to traffic signals, vehicles, objects, or pedestrians.
- ✓ **Autonomous or assisted parking:** Guides drivers by incrementally turning the steering wheel and moving forward or in reverse to fit into tight spaces on city streets or in crowded parking garages.
- ✓ **Automatic emergency braking:** Identifies potential collision scenarios, alerts the driver, and activates braking systems. Advanced ADAS can take additional preventive actions, such as incrementally reducing speed or engaging adaptive steering to avoid accidents.
- ✓ **Crosswind stabilization:** Maintains stability by detecting and counteracting crosswind pressure, dynamically adjusting wheel motor control units (MCUs) and braking systems.

1. Sensors

- ✓ **Navigation:** Provides on-screen instructions and voice prompts, allowing drivers to follow planned or dynamic routes while keeping their eyes on the road. Most systems display real-time traffic data and suggest alternative routes to avoid congestion.
- ✓ **Adaptive light and beam control:** Adjusts headlights at night or during inclement weather. These systems detect the intensity of other vehicles' lights, modifying headlight strength, direction, and rotation accordingly.
- ✓ **Night vision:** Boosts visibility in low-light conditions, with active systems projecting infrared light and passive systems analyzing thermal energy from other objects.
- ✓ **Blind-spot monitoring:** Alerts drivers when objects are detected in traditional blind spots, including the areas directly behind the vehicle and rear sides.



1. Sensors

Ultrasonic Sensors

- ✓ Ultrasonic sensors use high-frequency sound waves to detect objects in close proximity to the vehicle. These sensors are often placed on the front, rear, and sides of the vehicle. They enable obstacle detection while maneuvering in tight spaces, such as parking lots, as well as at low speeds. Ultrasonic sensors are very accurate at short distances but are not effective over long ranges.

Radar Sensors

- ✓ Radar sensors use radio waves to detect objects at longer distances. These sensors are highly effective in poor weather conditions (fog, rain, snow) because they operate independently of visibility. Radar sensors allow precise measurement of the speed of objects, which is useful for adaptive cruise control and Automatic Emergency Braking (AEB) systems.

1. Sensors

LIDAR (Light Detection and Ranging)

- ✓ LIDAR is an advanced technology that uses lasers to scan the surrounding environment and map objects in 3D space. LIDAR allows high precision in detecting objects, even at long distances. This sensor creates a detailed map of the environment, which is essential for autonomous vehicles that require accurate information to navigate in complex traffic conditions. However, LIDAR sensors are more expensive than radar and ultrasonic sensors, which makes them less common in some types of vehicles.

Cameras

- ✓ Cameras provide visual information about the vehicle's surroundings, which is useful for recognizing objects, signs, road markings, and other visual markers. Cameras are used together with advanced image recognition algorithms and artificial intelligence (AI) for object detection and classification, such as pedestrians, cyclists, or other vehicles. Cameras are usually mounted on the front, rear, and sides of the vehicle.

2. Actuators

- ✓ Actuators are key components in electric vehicles (EVs) that convert electrical energy into mechanical motion, enabling control over various vehicle functions.
- ✓ They play a crucial role in the powertrain, braking, steering, and other systems, ensuring optimal performance, safety, and comfort.
- ✓ In automotive systems, actuators operate as a conduit between the physical actions occurring inside a car and the control systems. The effective selection of control techniques depends on accurate measurements and the assessment of electric vehicle operating conditions.

2. Actuators

✓ Types of actuators in electric vehicles can be classified as fallows.

2.1 Electric Motors (Drive Actuators)

✓ The primary source of propulsion in EVs, converting electrical energy from the battery into rotational motion.

✓ Synchronous and induction motors are commonly used, often with permanent magnets.

✓ Controlled via inverters that regulate speed and torque.

2.2 Linear Actuators (for Dampers, Valves, Clutches)

✓ Used for precise movement of components (e.g., regulating coolant flow).

✓ Examples: actuators for opening/closing valves in the battery system.

2. Actuators

2.3 Electromechanical Brake Actuators (Brake-by-Wire) .

- ✓ Replace traditional hydraulic braking systems (e.g., in regenerative braking).
- ✓ Improve energy efficiency by recovering kinetic energy back into the battery.

2.4 Steering Actuators (Steer-by-Wire)

- ✓ In advanced EVs, the mechanical link between the steering wheel and wheels is replaced by an electronic system.
- ✓ Enables precise control and adaptability (e.g., adjustable steering ratios).

2.5 HVAC Actuators

- ✓ Regulate airflow and cabin temperature.
- ✓ Powered by electric motors instead of mechanical valves.

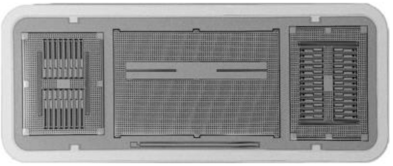
2.6 Active Aerodynamics Actuators

- ✓ Control movable elements (e.g., spoilers, grilles) to reduce drag.

3. MEMS Technology

- ✓ MEMS (Micro-Electro-Mechanical Systems) are miniaturized sensors and actuators that combine electrical and mechanical components on a silicon chip. In electric vehicles (EVs), MEMS play a critical role in enhancing performance, efficiency, and safety through precise sensing and control.

3.1 Inertial Sensors (IMU – Inertial Measurement Unit)



- ✓ Measure acceleration, tilt, and angular velocity.
- ✓ Used in:
  - Electronic Stability Control (ESC) – Prevents rollovers in critical situations.
  - Adaptive Suspension – Adjusts damping based on road conditions.
  - Autonomous Driving – Enables precise navigation and vehicle positioning.

3.2 Pressure Sensors

- ✓ Monitor:
  - Battery Systems – Track coolant pressure in thermal management.
  - Brake-by-Wire Systems – Detect hydraulic/electric brake pressure.
  - Tire Pressure Monitoring (TPMS) – Ensure optimal tire performance.

3. MEMS Technology

3.3 Gas & Air Quality Sensors

✓ Detect harmful gases inside/outside the cabin:

- CO, NOx, VOC – Trigger air recirculation or filtration.
- Battery Off-Gassing – Warn of thermal runaway (e.g., H_2, CO_2).

✓ Used in smart HVAC systems for automatic air purification.

3.4 MEMS Microphones for Noise Control

✓ Enable Active Noise Cancellation (ANC) by detecting cabin noise frequencies.

✓ Improve ride comfort in high-end EVs.

3.5 MEMS Actuators for Precision Control

✓ Adjust:

- Active Aerodynamics (e.g., spoilers, grille shutters).
- HVAC Flaps – Optimize airflow distribution.

3. MEMS Technology

Advantages of MEMS in EVs

- ✓ Miniaturization – Compact size allows integration in tight spaces.
- ✓ Low Power Consumption – Ideal for battery-powered systems.
- ✓ High Sensitivity & Fast Response – Critical for real-time safety systems.
- ✓ Cost-Effective Mass Production – Silicon-based fabrication reduces costs.

Challenges

- ✓ Temperature Sensitivity – Must operate reliably in extreme heat/cold.
- ✓ Long-Term Drift – Requires periodic recalibration.
- ✓ Cross-Sensitivity – Some sensors may react to multiple gases.

Future Trends

- ✓ AI-Enhanced MEMS – Machine learning for smarter gas detection and fault prediction.
- ✓ Wireless MEMS Networks – Reduced wiring complexity in next-gen EVs.
- ✓ Graphene & Nano-MEMS – Higher sensitivity and durability.

5. Conclusion

- ✓ In the future, the integration of multiple sensor types and advanced data processing algorithms will improve the accuracy and efficiency of detection systems, making electric vehicles even safer and smarter.
- ✓ With the development of autonomous driving and smart vehicles, actuators will become even more intelligent, integrating artificial intelligence for adaptive control. The trend is moving toward modular actuator systems that allow for upgrades.
- ✓ Actuators are the "muscles" of electric vehicles, enabling fast, precise, and energy-efficient operation.
- ✓ MEMS technology is a cornerstone of modern EVs, enabling smarter, safer, and more efficient vehicles. As EVs evolve toward full autonomy, MEMS sensors and actuators will play an even greater role in vehicle intelligence and environmental interaction.