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Automotive Embedded Systems

Key Technologies, Innovations, and Applications

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ISSN 2522-8595 ISSN 2522-8609 (electronic)
EAI/Springer Innovations in Communication and Computing
ISBN 978-3-030-59896-9 ISBN 978-3-030-59897-6 (eBook)
https://doi.org/10.1007/978-3-030-59897-6

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

Over the last two decades, various functions of a vehicle are performed by using electrical and electromechanical systems, which were performed by mechanical linkages in conventional automotive systems. The concept of using electronic control systems as replacement for mechanical control systems in automobiles is called as drive-by-wire or x-by-wire. The main functions such as acceleration, braking, and steering are controlled by the use of mechanical, pneumatic, and hydraulic components in conventional vehicles where are more prone to wear and tear. Thus, the efficiency and performance of such vehicles deteriorates over a period of time. In contrast, the drive-by-wire technology uses sensors, electrical motors, and electromechanical actuators to perform vehicular functions. Moreover, the subsystems in the drive-by-wire technology have a dedicated Electronic Control Unit (ECU) to monitor and control vehicle parameters with the help of appropriate sensors and actuators. These subsystems are called as Automotive Embedded Systems. Embedded systems in automobiles are basically classified into five domains such as Power Train, Body Electronics, Chassis, Human–Machine Interface, and Telematics.

The main objective of Industry 4.0, the Fourth Industrial Revolution is to make everything smart and connected with each other. The tremendous growth in automotive electronics and wireless communication technology has paved a way for new technology called Connected Cars through which many innovative features have been added in a typical car to enhance the comfort of the stake holders.

This book starts with automotive safety systems which is one of the major functional domains. The book discusses the importance of software in automotive systems followed by an insight into Automotive Software Standards, MISRA Coding Standards, and Model-based Software Development Approach. The book further discusses vehicle diagnostics and over-the-air software update processes. The book also illustrates the role of sensors and artificial intelligence in automotive systems. Various innovative applications involving the concept of Internet of Things are also presented in this book. This book is intended for academicians, researchers, and industrialists.

Coimbatore, Tamil Nadu, India — M. Kathiresh
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Acknowledgment

We would like to thank Mr. Imrich Chlamtac, the Series Editor and Ms. Eliska, the Managing Editor at European Alliance for Innovation, for giving us this opportunity to edit a book in the Series of Innovations in Communication and Computing, Springer. We express our sincere thanks to the authors for their contribution and whole-hearted cooperation in the making of this book. We also thank the reviewers for their constructive criticism and comments which enriched this work. We are grateful to PSG College of Technology, Coimbatore, India, for the constant support and encouragement. Finally, we would like to acknowledge with gratitude, the support, and love of our family members and colleagues, without whom this book would not have been possible.

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Automotive Safety Systems

S. Hamsini and M. Kathiresh

Introduction

Road traffic crashes lead to an estimated death of nearly 1.25 million people in a year and millions more succumb to injuries [1]. In order to reduce such gruesome road traffic fatalities and injuries, various measures grounded on evidence have been formulated by the World Health Organization. A critical role is played by safe vehicles to avert crashes and minimize the probability of serious injury. Safety standards for automobiles are set by the United Nations World Forum for Harmonization of Vehicle Regulations along with the legal framework for which voluntary application by member states is possible. Vehicles that abide to these safety standards are less prone to accidents, and on the occurrence of road traffic crashes, the injuries are far from life-threatening [2].

Though there are various contributing factors to accidents, the major single reason points towards the driver as human errors contribute to a major percentile of accidents. Modern vehicles include various safety features that assist the driver in various possible ways. The modern vehicle design is focused on better safety features for the driver and the passengers.

The systems that get activated in retribution to an abnormal event such as a safety problem are termed as active safety systems. These systems are triggered in anomalous circumstances by human operators or spontaneously by an intelligent computer system. The systems that act in a favorable manner in response to dangerous events by relying on the laws of nature are named as passive safety systems. This safety

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M. Kathiresh, R. Neelaveni (eds.), *Automotive Embedded Systems*,
EAI/Springer Innovations in Communication and Computing,
https://doi.org/10.1007/978-3-030-59897-6_1

system may be a physical feature or an added internal system or design modifications that enhance the driving of the vehicle.

Vehicle Safety Systems

When the design of a vehicle is considered, one amongst the various important aspects is its safety both in the vehicle as well as in its features. Automobile safety is the scientific domain related to the study, design, construction, and regulation of technology mainly focused on minimizing the occurrence and consequences of road traffic accidents. Vehicle occupant safety can be generally categorized into two areas: firstly, active safety, which is basically designed for crash avoidance, and secondly, passive safety also known as crash worthiness where in the worst case that a crash happens, protection of occupant is ensured [3]. The various active safety and passive safety features are depicted in Fig. 1.

The assistance provided by technology for the prevention of a crash is termed as active safety, whereas the various physical components of an automobile that collectively help to protect the inhabitants when a crash occurs are referred as passive safety. Figure 2 illustrates the timeline pertaining to the active safety and passive safety.

Fig. 1 Active and passive safety features

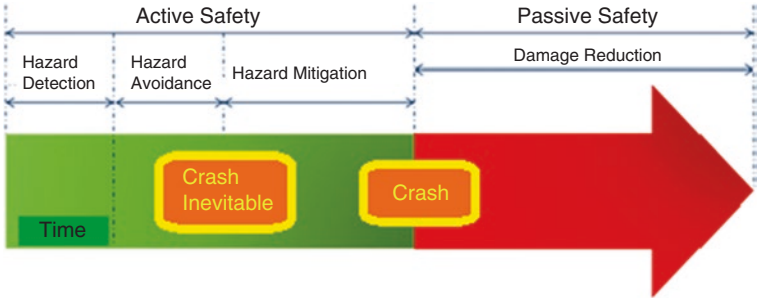

Fig. 2 Vehicle crash timeline of safety

Active Safety Systems

The features of a vehicle that help to mitigate or prevent road crashes are basically active safety features. These features mainly focus on prevention of the crash or reduction of severity of a crash that is unavoidable in nature. One or more aspects of an automobile are monitored constantly by the active safety features for potential hazards. In the instance where a problem occurs, the situation is rectified autonomously by active safety features. Protection that is offered is increased by active safety features. The devices and systems used for active safety are generally automated. Few basic active safety features are discussed below.

Braking System

A brake is basically a mechanical device that operates by inhibiting motion by means of absorbing energy from a moving object. It is generally intended for decelerating or altogether stopping an automobile in motion, its wheels and axle, and this is frequently accomplished through friction. The rapid advancements in vehicles and modern road infrastructure facilitate faster driving habits. In this scenario, when hard brake is applied to a moving vehicle, the wheels may get locked up and end up sending the vehicle to spin out of control. In order to avoid those mishaps, an anti-skid system involving the brake was developed which is now improved as Anti-Lock Braking System (ABS).

Movement of vehicle is the result of friction between the vehicle's tyres and the road. A torque is applied in the opposite direction to that of the friction, thus ultimately leading to the wheel halting the rotations. While braking, ABS allows the vehicle's wheels to maintain tractive contact based on driver inputs with the road surface. Avoidance of uncontrolled skidding and prevention of locking up of wheels are attained.

The principles of threshold braking and cadence braking that were in practice by experienced drivers formerly are employed in the ABS as an automated system. Due

to the automation, ABS acts in a considerably faster rate and in a very effective manner than manual operation. Enhanced vehicle control and reduced stopping distances is provided by the ABS on dry and certain slippery surfaces, but the performance is comparatively diminished, and the braking distance may increase on loose gravel roads or surfaces concealed with snow. Initially ABS was introduced for production vehicles; hence the sophistication and effectiveness of these systems have increased. Not only the prevention of wheel lock under braking is attained but also alteration of the front-to-rear brake bias is accomplished. Illumination of a warning light located on the vehicle instrument panel indicates a fault within the ABS. Until the fault is resolved, the ABS will be incapacitated. The modern ABS involves a dedicated microcontroller controlling all the four wheels by means of a control system consisting of hub-mounted sensors to apply individual brake pressure. Due to rapid escalation of popularity of the electronic stability systems due to the massive reduction in cost of vehicular electronics in the recent years, the ABS is present as a standard entity in most of the vehicles nowadays. A study has proved that automobiles with ABS are less likely to go through fatal accidents by a percentage of 37%.

Brake lights are another feature of braking that is relatively less technical and more of a handy feature while driving. Brake lights are simple indicating lights usually red to enhance visibility even in daytime. These lights glow brighter, indicating the vehicle following that the brakes are applied and the vehicle is going to decelerate or stop. It is more of a traffic feature that facilitates fellow drivers to adjust to the traffic when someone applies brakes.

Parking brakes also known as hand brakes are another feature that is used to secure the vehicle motionless when parked. The general idea is to restrict the uncontrolled movement of the vehicle due to slope or external impacts when parked, but historically it also acted as a secondary emergency brake in situations where the main brake fails. But with improved braking systems like ABS, the parking brakes are needed only when the vehicle is parked.

As seen with the ABS and cruise control, the brake assist system helps a driver in many ways from applying emergency brake pressure to preventing collision and skidding. The modern brake assist is integrated with an anti-collision system where brakes will apply automatically on detecting a possibility of collision. It also gives warnings about the health of brake system.

Visibility

Visibility to the driver is a major factor while plying on roads. Features including rearview mirrors, wipers, and clear windshields enhance the visibility for the driver to see.

Seating position of the driver is a key parameter as it decides the visibility of the road and surroundings to the driver. One should choose minimum or no blind spot position to sit while driving. Many features like adjustable seat position, height, and

adjustable steering columns help in achieving a comfortable seating position for driving.

Though the feature of automatic climate control is more of a comfort feature to control temperature and humidity inside the vehicle, it also plays an important role in preventing formation of fog in windows and windshields. Thus, it improves visibility during winters and rainy season.

Rearview mirrors give access for the driver to see the sides and rear side of the vehicle. It helps the driver to decide before changing lanes or attempting a turn and helps to monitor the entire vehicle. Advanced rearview mirrors also have features like electronic adjustments to counter parallax errors and some vehicles have camera sensors that capture the video and display it in the screen inside the vehicle.

Headlamps facilitate the drivers to drive the vehicle during nights. However, advanced features in headlamps such as adaptive focus and brightness facilitate the driver with a better and comfortable visibility [4].

Wipers are a simple link mechanism that helps in wiping the water in the windshield while raining. During rains, it is difficult for the driver to get proper visibility due to water creating refraction with the windshield glass. Advanced features in wipers include automatic rain sensing where the wiper gets activated on sensing raindrops on the windshield.

There is another aspect of visibility where the vehicle needs to have some added features to have better visibility to be seen by others.

Recent standards for vehicles after BS IV and Euro IV made it mandatory for the vehicles to have running headlamps even during the day. The idea is mainly to make the vehicle more visible even from a distance. With advancements in headlamps after the introduction of LEDs and their minimal cost for installation and maintenance, it is quite a handy feature of the vehicle.

Parking lights are used when the vehicle is pulled over in highways or some work is happening around the vehicle that is parked. It should not be used when the vehicle is moving.

The color of a car has been a debatable study for the past decades as to how it plays a role in road accidents. Some of the latest studies essentially suggest that cars with brighter colors such as white are relatively less prone to accidents than the ones with black or gray. Apart from the study being under scrutiny to be proven factual, it is a general idea that a better visible color enhances the visibility of the vehicle.

Another significant instance when it necessitates to get the attention of fellow drivers on the road is especially when taking turns or going reverse, and the accessories that aid for this are turning indicators and reverse signal indicators. These indicators give the signals by glowing intermittently, sometimes combined with a buzzer or tune to alert the presence to fellow drivers.

Horns and tunes are used to grab the attention of fellow drivers to indicate the action to be performed by the vehicle.

Minor Design Aspects

Bumpers fitted in front and the rear of the vehicle absorbs impacts during minor collisions, preserving internal major components and thereby reducing repair cost. However modern safety standards suggest using soft bumpers to enhance pedestrian safety.

The intended design function of a spoiler which is an aerodynamic device is to "spoil" hostile air movement across a moving vehicle, generally termed as drag or turbulence. Spoilers employed in the front of an automobile are termed as air dams. Spoilers are frequently attached to sports cars of high performance and to vehicles intended for racing, though nowadays it is a common accessory in passenger cars too. Few spoilers that are employed in the cars are predominantly for styling purposes and aid very less towards aerodynamics. The wing in a vehicle refers to a device intended to generate downforce when air passage occurs around it and to not disrupt the existing patterns of air flow. Thus, instead of decreasing the drag, automotive wings in reality increase drag.

Cruise Control

Cruise control also known as speed control automatically maintains the speed of the vehicle by taking over the throttle of the vehicle and maintains steady speed. This feature is especially helpful on highways and expressways where a steady speed needs to be maintained over a long period. Figure 3 illustrates the operation of cruise control system present in vehicles.

More advanced adaptive cruise control mechanisms integrate features like radar-based dynamic cruise control and automatic braking system on detecting potential forward collision, and this is essentially a principal step towards autonomous vehicles where a vehicle varies its speed through intelligent radar-based sensor system

Fig. 3 Cruise control

and also stops on detecting collision probability with near-zero human interventions [5].

Speed governors are actually an optional feature which restricts the vehicle from going beyond certain prescribed speed limits.

Autopilot is an advanced active safety feature envisioned for advanced driver assistance to enhance the safety and convenience of the driver behind the wheel. A few autopilot systems include a suite of driver assistance features like traffic aware cruise control, auto lane change, summoning where the car navigates in a parking lot to an intended location while maneuvering around objects that hinder its navigation otherwise and full self-driving capability among various other features.

Stability

Physical stability of the vehicle is more of a design aspect of the vehicle that provides mechanical stability to the vehicle while driving. Proper wheel balancing, sturdy and rigid chassis, optimum tire pressure, distribution of body weight, steering system, and suspensions majorly contribute to the physical stability of the vehicle. Stringent standards and guidelines are provided for the manufacturers to ensure these design aspects [6].

Electronic stability control (ESC) is a computerized technology which is intended to detect and reduce loss of traction that results in skidding and thus overall improves the stability of a vehicle, and it is also known as dynamic stability control (DSC) or electronic stability program (ESP). Brakes are applied automatically when loss of steering control is detected by ESC, and it steers the vehicle where it is supposed to go according to the driver's intention. Braking is applied automatically to the wheels separately, namely, the outer wheel in the front as a counter for steer and the inner wheel in the rear to handle understeer. Engine power is also reduced by a few ESC systems till control is attained. The cornering performance of the vehicle is not improved by ESC, but the loss of control is minimized with its help. ESC is a computerized system that involves various sensors such as wheel speed sensors, steering angle sensor, accelerometer, etc.

A vehicle can be steered when it veers or slides out of the intended path due to natural hindrances such as rain or snow. The path of a vehicle in both the instances where ESC is present and not when loss of traction occurs is depicted in the Fig. 4.

Traction control system is an active vehicle safety feature which is actually a secondary feature of electronic stability control and kicks in when the vehicle's speed increases and prevents loss of traction of the wheels driven on roads. This active safety feature is activated while driving when the throttle input and the engine torque do not match.

Other key stability warnings are tyre deflation warnings which prompts the driver that the tyres are either deflated or not in the optimum pressure for the drive and air suspension warning system which essentially warns about faulty functioning of suspension due to various reasons.

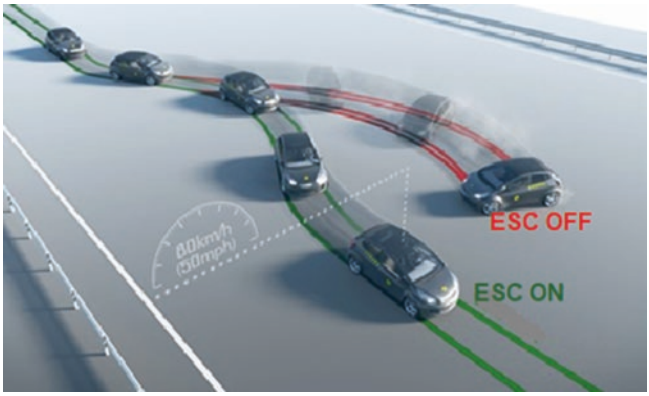

Fig. 4 Electronic stability control

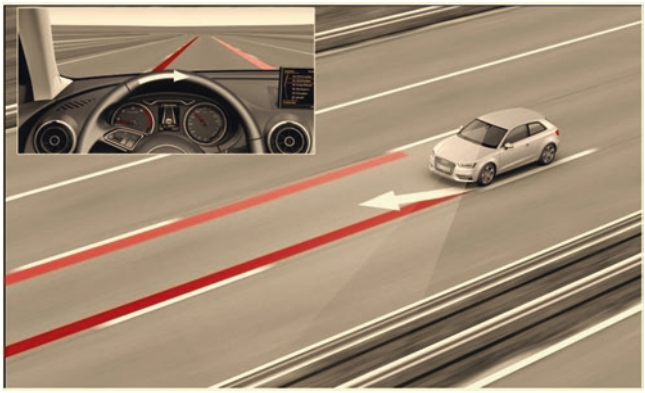

Fig. 5 Lane departure warnings

Lane Departure Warnings

A lane departure warning system has the intended purpose of monitoring the lane markings and detecting the drifting or veering of vehicles out of its own lane. These systems then warn the drivers through an audio alert or a visual illustration regarding the unintentional lane shifts and to navigate the automobile back into its intended lane. Figure 5 represents the lane departure warnings that arise when the driver changes lanes along with the outline of the current lane where the vehicle is navigating.

Park Assist and Reverse Assist

The most complicated aspect of driving involves parking of the vehicle properly in a narrow space. Only skillful drivers can perform this parking without much difficulty. Therefore, an assist to facilitate all the drivers to park the vehicle is introduced in modern cars. The intelligent park assist can steer itself into a parking space with no or minimum input from the driver eliminating minor accidents. Another notable feature is where the reverse assist essentially helps the driver to park when the vehicle is put on reverse. It is integrated with a reverse camera and sensors, and the view is displayed to the driver through a screen that enables him to perform complex reverse maneuvers easily. There are various sensors such as ultrasonic sensors to detect the proximity of various objects within the vicinity of the vehicle in the rear and warn about it.

Door Open Warning

Door open warning systems encompass a sensor that detects any approaching vehicles in the rear when an individual is opening the car door and prevents the opening of the car door when vehicles are detected within the vicinity and also warns the approaching vehicle by means of cautioning lights and buzzers. The door open warning system is depicted in Fig. 6

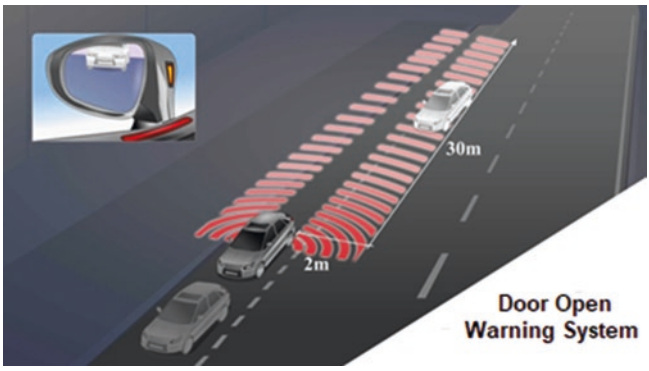

Fig. 6 Door open warning

Dashboard Warning Signs for Various Aspects of ECU and Component Failure

There are a lot of other warning signs in the dashboard that facilitate the driver to have a tab over various aspects of the vehicle. Key features include door not closed warning sign, low fuel indicators, seat belt warnings, overheating of component or engine warnings, headlamp status, indicator, and much more. Some the warning features in the dashboard in a modern vehicle are illustrated as in Fig. 7

Passive Safety Systems

Apart from various active safety features, there are many passive safety features of the car which is also known as crashworthiness of the car. These features are actual lifesavers when in unfortunate circumstances the vehicle is subjected to a crash. Many crash tests are carried out on a regular basis to improve the passive safety system that will reduce the fatality rates even after the crash.

When a crash has occurred, then in that instance protection is provided to the occupants from further injury through various features, and these features are called as passive safety features. The protection of the driver and passengers from several crash forces is ensured by the passive safety features. Life space is the protected area surrounding the occupants of the vehicle in which likelihoods of dodging with negligible injuries are possible. Passive safety features help to ensure that the life space exists safe and secure along with the occupants and they remain in this space during the crash.

Fig. 7 Dashboard warning signs

Airbags

Airbags are considered one of the most important and key safety features nowadays. These airbags inflate into cushioning bags essentially saving the driver and the passengers from the crash and from sustaining fatal injuries. Advanced vehicles come with multiple airbags to prevent injuries and to provide maximum protection. Even though airbags do not offer complete protection, it reduces the impact in such a way that the person has a better surviving chance.

Seat Belts

Seat belts along with the pretensioners prevent the person from moving forward suddenly due to inertia when met with a forward collision. This not only prevents the person from being ejected forward but also holds them in a position for the airbags to operate effectively for the safety. Wearing seat belts is mandatory for driving in almost every country, and there are warning lights to indicate if the driver or the driver side passenger doesn't wear it. Modern vehicles include seat belts for the passengers in the rear seats too.

Sturdy Front Design

Another important design feature is a sturdy and rigid front design which will absorb most of the impact on the collision, so that the person inside the vehicle can have better chance of surviving. Careful placing of mounting brackets and other metal or sharp construction away from the areas that are potential to hit the passengers is preferred that in the off chance when a crash is inevitable. Preference is given to leather or soft material usage in areas like dashboard, instrument panel, and other areas of contact.

Non-shattering Windshields

The usage of laminated windshields enhances the visibility, but also the glass comes with a non-shattering feature which breaks into minute particles on crash, thereby avoid breaking into sharp pieces. This in turn reduces the fatal injuries incurred during the crash.

Pedestrian Protective Soft Bumpers

This feature is to prevent sustaining injuries to the pedestrians who may accidentally get hit by the vehicle. Hard front bumpers can inflict severe injuries to the person who gets accidentally hit by the cars. Therefore, relatively softer bumpers are preferred. Redesigning of bumpers, hoods, and windshield to be energy absorbing will actually reduce the impact on pedestrians during pedestrian-car crashes.

Collapsible Steering Column

Steering columns are found to be fatal in sustaining injuries to the driver as it is rigid and immediately contacts the driver when in crash. Therefore, a modification in the design has been brought in where the columns automatically collapse down on high impact, thereby preventing the driver from engaging with a rigid column on crashing.

Cargo Protection

Many SUVs, AUVs, and other utility vehicles have the feature to securely fit the cargo, avoiding it from throwing off or moving while on crash. This also helps from people suffering any injuries from heavy cargo or luggage on the road.

Security

Automotive industry is inching towards superior integration and virtualization by escalating the number of functions and complexity in terms of the software. The reason for this inclination is that the wiring harness has reached its upper boundaries to accommodate ECUs as cars incorporate nearly 100 ECUs nowadays. This results in a broad spectrum of digital and electronic attack surface available where contact is present with various built-in systems along with numerous widely ranging external networks such as Wi-Fi and cellular networks.

A collaborative effort between the supply chain and the comprehensive ecosystem along with a holistic approach is required where their involvement and contribution matters highly to attain security in the complex systems specified above. To attain effective security, it is very important to deal with the components and threats along with the attack points as a whole entity instead of considering them individually. In the context of security, both physical and the cyber worlds should be considered to be compromising as any one of them may lead to devastating results

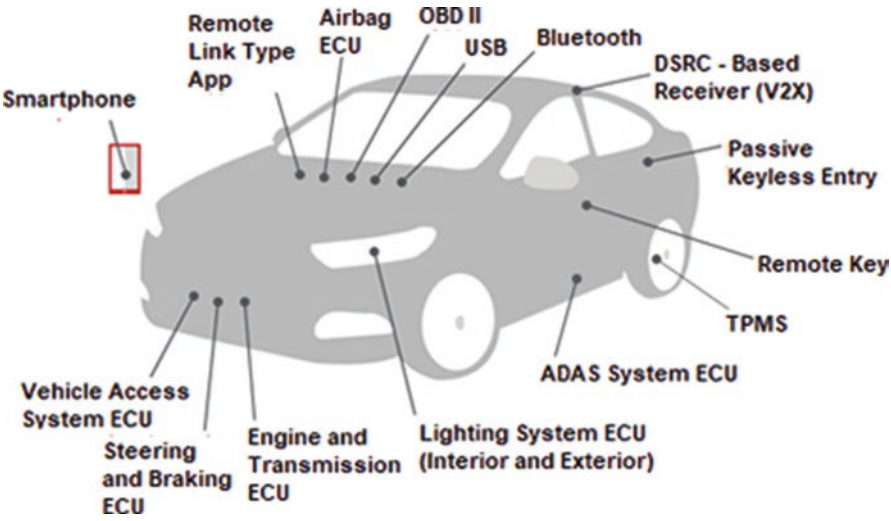

Fig. 8 Surfaces prone to attack due to exposure and hacking on a next-generation car

collectively to a vehicle's systems. The surfaces prone to attack due to exposure and hacking on a next-generation car are illustrated in Fig. 8.

Layers of Security

The three layers that constitute the security in an automobile are, namely, hardware security, network security, and software security.

Hardware Security

The hardware security systems offer physical protection in a car such as the firewall to the engine, seat belts, and airbags. They offer protection to the operating components in case of accidental or intentional damage. Various building blocks of hardware security are used in wide ranges to secure the ECUs and the buses. A few of these hardware security features are described here.

Secure Boot Along with Software Attestation Product keys and digital signatures are checked, thereby detecting tampering if any in the boot loaders as well as critical operating system files. The invalid or tampered files are blocked from execution, providing a trusted foundation on operating ECU, much before it gets infected from tampered files.