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Understanding Vehicle E/E Architecture Topologies for Automated Driving: System Partitioning and Tradeoff Parameters

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Abstract

Highly Automated Driving is an active research and development area in automotive market for next generation series production. The development of automated functions like Highway driving or Parking gets partitioned across Edge and Central ECU's as part of vehicle E/E network. The paper introduces typical vehicle E/E topologies with emphasis on ADAS/AD domain with multiple intra/inters connectivity options. Within the ADAS/AD domain, various E/E system architecture topologies with multiple ECU partitioning are under exploration to optimize various parameters. The paper explains multiple topologies by analyzing two example system topologies. Topology-I enables incremental approach on the top of legacy ECUs, while topology-II enables cost optimized solution. The paper also explains functional partitioning of automated driving functionality (e.g. Highway driving, Parking) within ADAS/AD domain. This involves splitting of automated function in given topology across multiple ECUs in terms of perception (camera, radar & lidar), localization, fusion, driving policy, motion planning and control. The paper lists various parameters for considerations for given topologies e.g. Number of ECUs, intra domain connection bandwidth, functional safety, incremental development with legacy ECUs, cost and ease of software development. The paper ends with summarizing of these partitioning of functions and parameters tradeoffs enabling users to analyze custom E/E architectures.

Introduction

Automated driving (AD) functions, like highway driving and parking assist, are getting increasingly deployed in high-end cars with the trend moving towards the self-driving car. The car vehicle has sophisticated Electric and Electronic (E/E) topology as shown in figure 1 to address multiple functionalities [1]. The core of E/E topology is ECU, which consists of MCU, optional processor, sensor and actuator to enable a given function. To enable scalable, robust and maintainable solution, the E/E Vehicle topology consists of multiple domains, where each domain controls a group of functionalities. Within each domain, there are multiple ECUs, where each ECU controls an individual functionality or set of functionalities. The following is list of commonly used domains in E/E topologies.

- Chassis & safety domain: ECUs to control Steering, Break, Throttle of car.
- Power-train domain: ECUs to control Engine and Battery related functions
- Body Electronics domain: ECUs to control power windows, power mirrors, Air conditioning, Central locking
- Infotainment domain: ECUs to control displays (Head, HUD, Rear), radio, navigation, rear view camera.

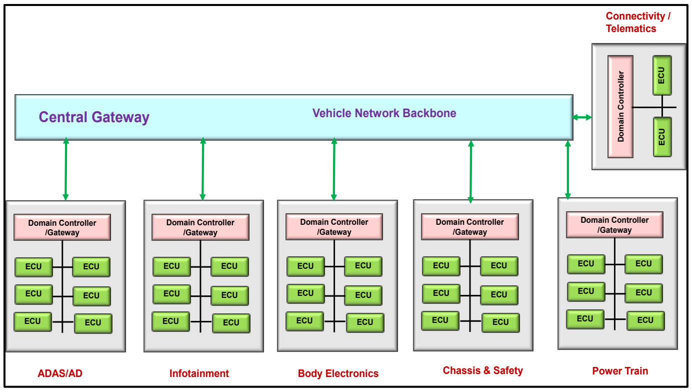

Figure 1: Typical Vehical E/E Topology

- ADAS/AD domain: ECUs to controls sensors (camera, radar, lidar), processing of data, decision making.
- Connectivity/Telematics domain: ECUs (consists of modem, V2X) to provide external connectivity to car e.g. mobile, cellular network, to other cars and infrastructure.

The ECUs within domain get connected using multiple connectivity cables and protocols e.g. CAN based communications are commonly used in chassis domain. All domains are connected using Central gateway, acting as backbone of entire communication network. Each domain has its own domain controller gateway to provide secure communication to Vehicle E/E network.

The ADAS/AD domains implement highway driving and value parking functions at multiple automation levels (L2-L5) [2]. The figure 2 shows the functional block diagram to achieve these functions. The key blocks for automated driving are namely Perception, Localization, Fusion, Driving Policy, Motion Planning and Control. The multi-modality perception (Camera, radar and Lidar) is used to gather environment information around car [3]. 'Fusion' module is used to give most reliable environment using Bayesian filtering among all modalities [4]. The 'localization' module is used to find exact position of vehicle in real world co-ordinates using HD Maps and perception data. The resulting environment model is used by 'Driving Policy' module to take decision e.g. stay in lane, lane change, yield, merge etc. The decision of Driving policy module is translated in actual car movement with 'Motion planning' module accounting kinematics and passenger's comfort. Lastly, typical 'control' module is used to track actual trajectory wrt to reference by controlling actuators.

There are multiple options for E/E topologies within ADAS/AD Domain to achieve desired goal of automated functions, which is explained using selection of two extreme ends. The section II covers example topology I with system partitioning, while section III covers example topology II with system partitioning. The section IV gives comparison of both topologies' with various tradeoffs with section V concluding the paper.

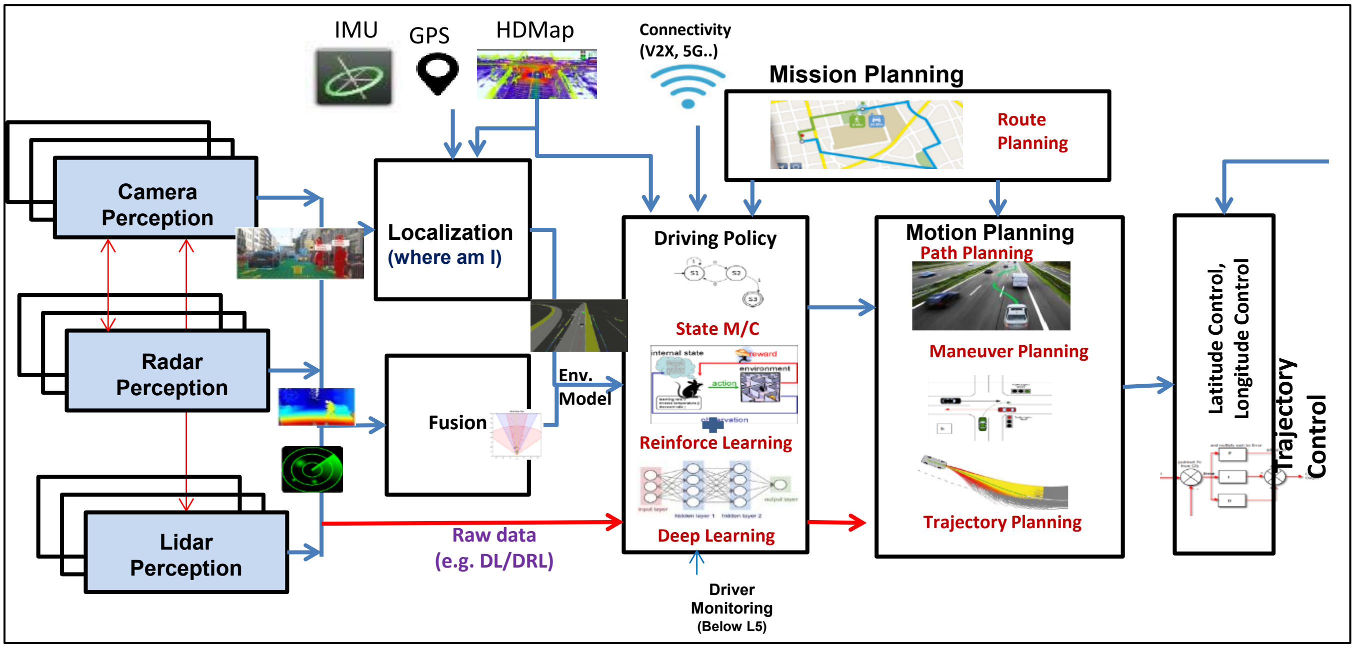

Figure 2: Functional Block Diggram for Automated Driving Function

Example Topology-I

This topology builds on traditional ADAS based functionalities e.g. LKA (Lane Keep Assist), Blind Spot Detections (BSD), Forward Collision Warning (FCW) built using Front Camera ECU [5][6], Central Radar ECU etc. as shown in figure 3. In this topology, typically object level data (e.g. list of object & distance– Pedestrians, cyclist, Vehicles and free-drivable space) are calculated using individual ECUs. This data is later passed to the Central Fusion ECU. The bandwidth requirements within ADAS/AD Domain are low in this topology, and thus can be handled using low speed interfaces e.g. CAN-FD etc. The central fusion provides fail safe (and/or fail operational) compute using two chips providing redundancy and ASIL-D MCU. The high level i.e. object level fusion is performed along with localization performed in Central fusion ECU. The Central fusion ECU also enables driving policy, motion planning and control of actuators (steering, break and throttle). The calculated control commands to actuators are sent to Chassis domain via central Gateway using domain controller.

There are many variations feasible in this example topology-II, with few listed as below.

1. The Auto-parking ECU typically uses surround Camera and ultrasounds. This can additionally integrate mirror cameras (CMS) to reduce cost [7].
2. The Auto-parking ECU typically uses only Ultrasound and object data coming from surround camera. In this case, surround cameras are interfaced and processed in infotainment domain.
3. The surround Lidar ECU: This is not shown in this diagram. In this case up-to 4-6 lidars are mounted across car for lidar based perceptions.

The table-I shows the typical system partitioning for example topology-I with ECU, sensors and functions.

Table-I System Partitioning for Example Topology-I

No	ECU	#of Sensors	Functionality
1	Front Camera ECU	Up to 3 Cameras	Camera Perception (Objects, depth, free space,…)
2	Front Radar ECU	Up to 2 Radars	Radar Perception (Objects, depth, velocity,…)
3	Lidar ECU	Up to 2 Lidars	Lidar Perception (Objects, depth, free space,…)
4	Central Radar ECU	Up to 4-6 Radars with 360 degree coverage	Radar Perception (Objects, depth, velocity,…)
5	Auto-Parking ECU: Surround View ECU (+ Optionally integrates contains Camera Mirror System CMS ECU)	Up to 4-8 Cameras & Up to 12 Ultrasounds with 360 degree coverage + Optionally up to 3 mirror cameras (left, right & rear)	Camera & Ultrasound Perception along with following functions 1) SLAM based localization 2) Object fusion 3) Optionally, Motion planning for parallel or perpendicular parking
6	Central Fusion ECU	V2X, HDMaps, GPS, IMU	Fail Safe /operational compute for following functions 1) Map based Localizations 2) Object fusion 3) Driving Policy 4) Motion Planning 5) Control
7	Domain Gateway	Nil	Interface & Protocol conversion

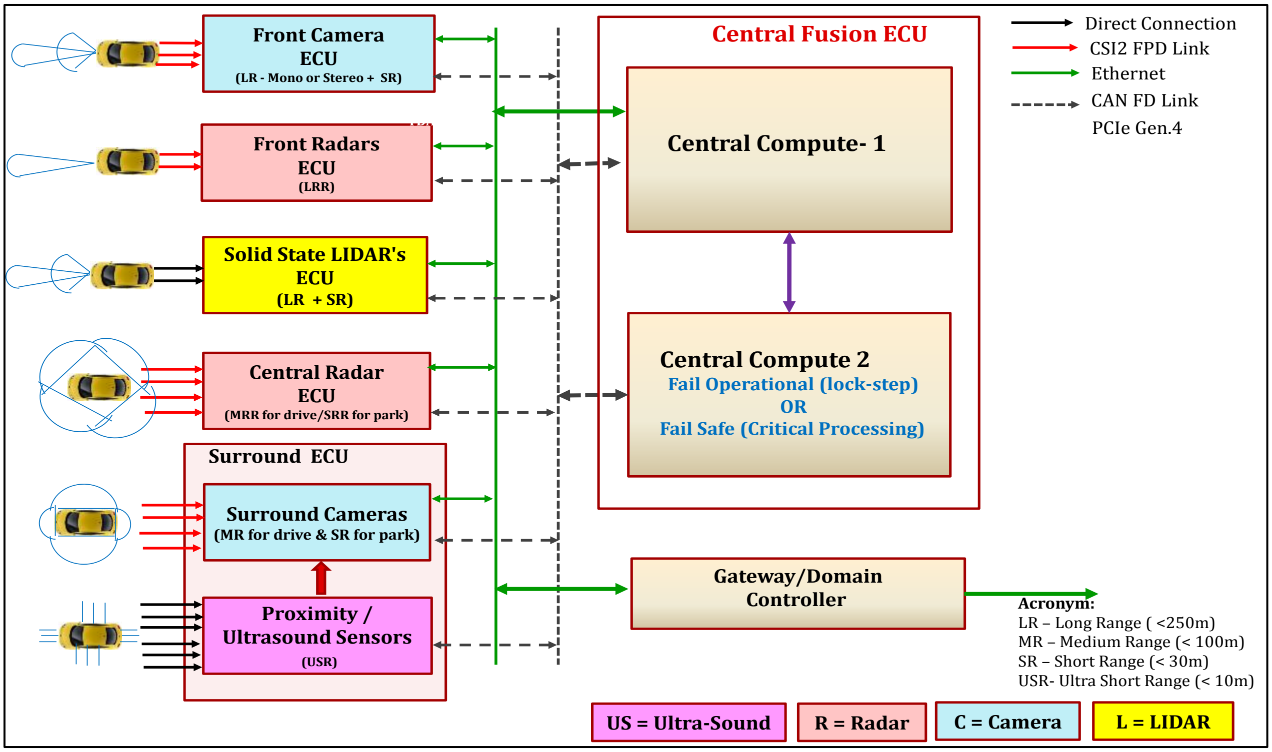

Figure 3: ADAS/AD Domain: Example Topology-I

Example Topology-II

This topology is built from the ground up keeping automated driving functions with aim to optimize overall performance and cost as shown in figure 4. In this topology, pre-fusion ECU (also known as satellite ECU) is used for doing perception in front as well as surround across cameras, radars and lidars. The overall fused information from front and surround is passed to Central Fusion ECU to compose final fusion. The bandwidth requirement within ADAS/AD Domain is ranges from low to high in this topology, based on granularity of fusion process. The central fusion provides fail safe (and/or fail operational) compute using two chips providing redundancy and ASIL-D MCU [8]. Central fusion also performs localization, driving policy, motion planning and control of actuators (steering, break and throttle) similar to topology-I.). The calculated control commands to actuators are sent to Chassis domain via central Gateway using domain controller. The advantage of this topology is flexibility to do multiple fusion topologies from low-level (raw-data) to mid-level (feature-level) to high level (object-level) fusion providing performance boost [4].

There are many variations feasible in this example topology-II, with few listed as below.

1. The Surround ECU typically uses surround Camera and ultrasounds. This can additionally integrate mirror cameras (CMS) to reduce cost [7].
2. The surround Lidar: This is not shown in this diagram. In this case up-to 4-6 lidars are mounted across car to do lidar based perceptions in surround ECU.

The table-II shows the typical system partitioning for example topology-II with ECU, sensors and functions.

Table-II System Partitioning for Example Topology-II

No	ECU	#of Sensors	Functionality
1	Pre-fusion Front ECU	Upto 3 Front Cameras	Camera Perception (Objects, depth, free space,…)
		Up to 2 Front radars	Radar Perception (Objects, depth, velocity,…)
		Up to 2 Front Lidars	Lidar Perception (Objects, depth, free space,…)
2	Pre-Fusion Surround ECU	Up to 4-6 Radars with 360 degree coverage	Radar Perception (Objects, depth, velocity,…)
		Up to 4-8 Cameras & Up to 12 Ultrasounds with 360 degree coverage	Camera & Ultrasound Perception (Objects, depth, frees pace,…)
3	Central Fusion ECU	V2X, HDMaps, GPS, IMU	Fail Safe /operational compute for following functions 1) Map based & SLAM Localizations 2) Object fusion 3) Driving Policy 4) Motion Planning (Highway, Parking,…) 5) Control
4	Domain Gateway	Nil	Interface & Protocol conversion

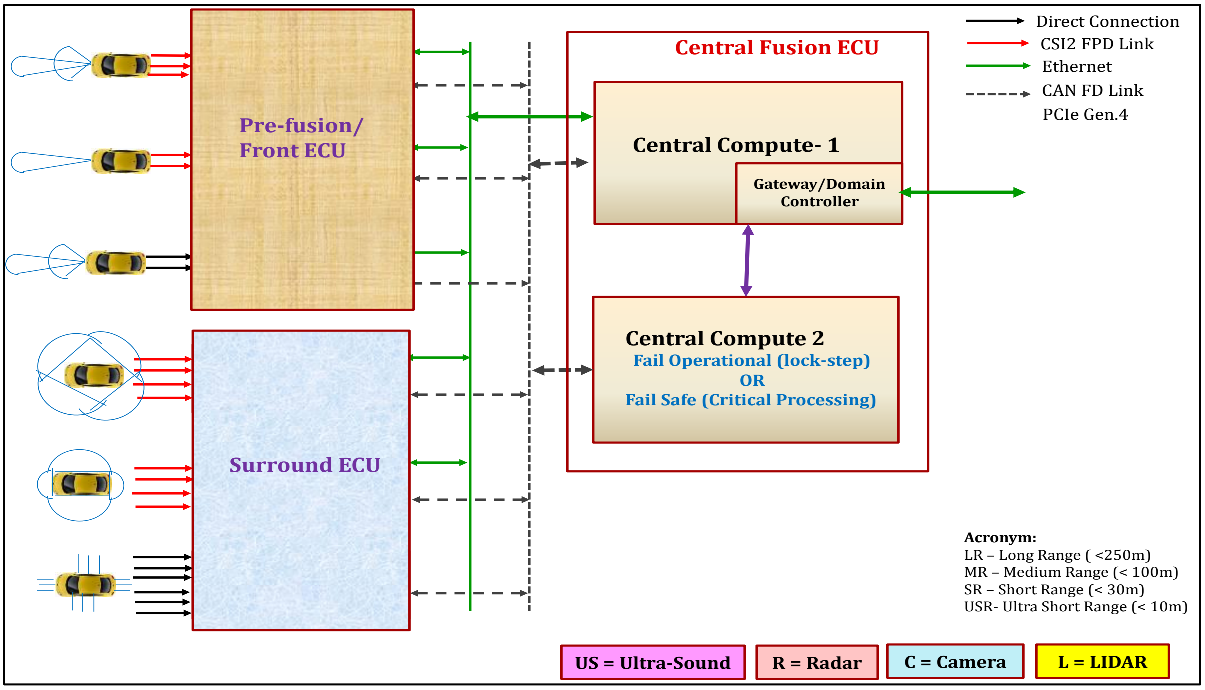

Figure 4: ADAS/AD Domain: Example Topology-II

Topologies Comparison and Tradeoffs

There are many variations of topologies feasible and all have different system level parameters e.g. partitioning, #of ECU, cost etc. The table-III summarized these tradeoffs parameters using example topology I and II discussed in this paper.

No	Topic	Example Topology -I	Example Topology -II
1	Functional Partitioning	Different ECU for each perception modality followed with central fusion ECU	Satellite ECU for Front and surround followed with central fusion ECU
2	#of ECU	7	3
3	Intra domain Bandwidth	Low (Mainly exchanging object data for high level fusion)	Low-High (Based on high level-Object fusion or mid level - feature fusion)
4	Functional Safety	High	High-Medium
5	incremental development with legacy ECUs	Yes	No
6	System Cost	High	Low
7	Ease of Software development	Medium	High

Table-III: Tradeoffs for Example Topology-I vs II

As shown in table-III, every topology has its own pros and cons. The selection of actual topology depends on the parameters that given TIER1/OEM is interested in optimizing e.g. Number of ECUs, intra domain connection bandwidth, functional safety [8], incremental development with legacy ECUs, cost and ease of software development. One more aspect is ease & ability to validate entire automated function in virtual environment [9] and real car while selecting given topology.

Conclusion

This paper presents overall vehicle E/E topology with emphasis on ADAS/AD domain. There are multiple options available for topologies within ADAS/AD Domain to achieve desired goals of automated functions. To explain various system tradeoff parameters, two extreme ends of topologies are selected. The paper explains details of two selected example topologies including system partitioning within the ADAS/AD domain. The paper gives comparison of the example topologies with multiple parameters. The selection of actual topology depends on the parameters that given TIER1/OEM is interested in optimizing e.g. Number of ECUs, connectivity, functional safety, legacy support, cost and ease of software development.

References

[1] Ralph Moritz, Tamara Ulrich and Lothar Thiele, "Evolutionary Exploration of E/E-Architectures in Automotive Design", Springer book, Operations Research Proceedings, 2011, 361-366,.

[2] SAE J3016, "Taxonomy and Definitions for terms related to on-road automated motor vehicles"

[3] Mihir Mody, Niraj Nandan, Shashank Dabral, Hetul Sanghvi, et.al, "Image Signal Processing for Front Camera based Automated Driver Assistance System", IEEE International Conference on Consumer Electronics, (ICCE) , Berline, 2015

[4] Shyam Jagannathan, Mihir Mody, Jason Jones, Pramod Swami and Deepak Poddar, "Multi-sensor fusion for Automated Driving : Selecting Model and Optimizing on Embedded Platform", AVM track, Electronic Imaging, 2018

[5] Mihir Mody, Pramod Swami, Kedar Chitnis, Shyam Jagannathan, et.al, "High Performance Front Camera ADAS Applications on TI's

TDA3X Platform”, IEEE22nd International Conference on High Performance Computing, HiPC, 2015

[6] Prashanth Viswanath, Kedar Chitnis, Pramod Swami, Mihir Mody, et. al, “A Diverse Low Cost High Performance Platform for Advanced Driver Assistance System (ADAS) Applications “,Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, CVPR, 2016

[7] Mihir Mody, Piyali Goswami, Rajat Sagar*, Gregory Shurtz, et. al. “Fully-Integrated Surround Vision and Mirror Replacement SoC for ADAS/Automated Driving”, IEEE, Hot Chips 29 Symposium (HCS), HC29, 2017

[8] Kedar Chitnis, Mihir Mody, M G Biju, Sivaraj R, et. al, “Enabling Functional Safety ASIL Compliance For Autonomous Driving Software Systems”, AVM track, Electronic Imaging, 2017

[9] Prashanth Viswanath, Mihir Mody, Soyeb Nagori, Jason Jones and Hrushikesh Garud ,”Virtual Simulation Platforms for Automated Driving: Key Care-abouts and Usage Model”, AVM track, Electronic Imaging, 2018

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