Review of Challenges and Proposed Research Directions and Radar Sensor Solution for the Deployment of Self-driving Cars

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ABSTRACT

As the deployment of self-driving cars (SDC) is gearing up faster than it was initially conceived, there are still some challenges, questions, and concerns that need to be addressed before the technology can be fully implemented and rolled out. The existing literature lists few and some do not propose the direction or demonstration for tackling the listed problems. This proposed study gives a brief overview of identified potential challenges to the deployment of SDC and a guide on finding solutions to the challenges. This will aid researchers and developers on where to explore in order to facilitate the development, implementation, and deployment of SDC technology. It also demonstrates the coexistence of radar sensor and radar communication as a proposed solution in SDC implementation.

Keywords - **Challenges, Deployment, Implementation, Proposed solution, Radar, Review, Self-driving cars**

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I. INTRODUCTION

The implementation of self-driving cars (SDC) technology is becoming reality as many automobile and high technology companies (HTC) are rolling out the low-level test cases of the technology [1], [2]. SDC technology is invented to make the road safer, save lives, and reduce traffic congestions [2]. In the implementation of SDC, there are levels or phases of deployment based on car cruising automation mode and complexity of maneuvering [3]. At Level 1 (L1), some car operations such as steering and acceleration can be done automatically and most of the other functions are controlled by human driver. Also, for Level 2 SDC implementation, the human driver is still present and allows more functions- cruise control and lane centering [3] in addition to L1 operation to be done automatically while the driver is at alert and be ready to take control of the car at any time. In Level 3 (L3), the human driver is still present but may not monitor situation as in the other lower levels. There is driver assistance automation system (DAS) that understands safety-critical traffic and environmental conditions. Whereas, Level 4 (L4) operation is fully automation where there is no human driver present to control the car and monitor the situation. The cars are designed to perform safety-critical traffic and environmental control and monitoring autonomously. However, the operation of such level of car driving situation will be limited to secluded driving environments and scenarios. Level 5 (L5) SDC operation is also completely autonomous. SDC are required to perform far better than human driver in driving, traffic control, monitoring and making human judgment. The system is planned to be implemented into the general public roads and drive smartly alongside with unreasonable human drivers. As at the time of writing this report-2022, to the best of author’s knowledge, some companies like Tesla, Google’s Waymo, Nvidia, Uber, and Mcity are testing and achieving L1 to L4 SDC operations [4], [5], [6], [7], [8], [9]. As these companies are collaborating with stakeholders and government agencies on rolling out the test cases and getting prepared to fully commercialize SDC technology, there are various challenges facing the implementation and deployment strategy. There are also questions and concerns from the general public around the invention of SDC technology.

There are various write ups and white papers on some challenges in the deployment of SDC as the time of writing this article. The existing literature lists few and some do not propose the direction or demonstration for tackling the listed problems. This proposed study will provide a brief overview of identified potential challenges. It will also iterate some concerns and questions asked and propose directions on answering those questions. It also opensup areas where researchers and developers should be looking into in order to answer some questions and how to tackle the pending obstacles. This couldin turn help in the efficient SDC technology implementation,planning, and deployment. This proposed reviewed study also provides the concept of exploring the coexistence of radar sensing and communication capability with a demonstration. A typical representation of SDC driving environment is shown in Fig. 1.The remainder of this paper is organized as follows: Section II contains the list of identified challenges and proposed research direction. Section III contains a demonstration of radar system solutions. Section IV gives the conclusion.

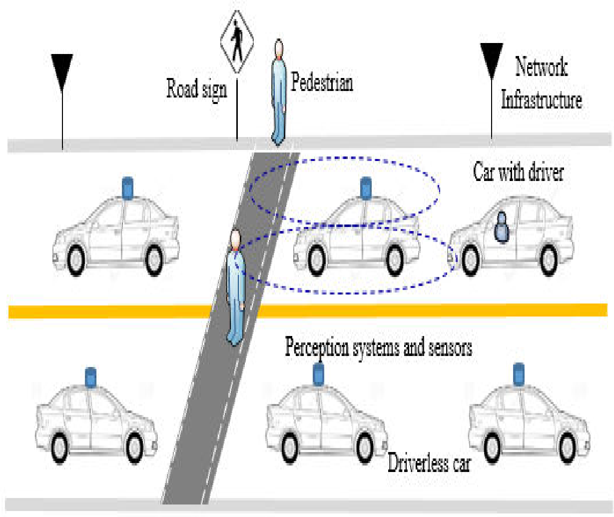

Fig.1.Representation of self-driving cars in two-way road

II. THE CHALLENGES AND RESEARCH DIRECTIONS

The study in [1] provides a review of motion planning for highway autonomous driving. The authors review [1] the main algorithms in motion planning, their features, and their applications to highway driving along with current and future challenges and open issues that can support the SDC deployment. Similarly, the article [2] surveys current federal policies and activities impacting technology developers, with special emphasis on privacy, cybersecurity, safety regulation, economy, energy and environment, and ethical issues. It is stated in the article [2] that safety is one of the most important public benefits of SDC technology. The study points out the bias that could occurs in the artificial intelligence (AI) decision making. However, how such bias could be tackled and engineering details about a specific bias are not provided.

Likewise, the study in [10] focuses on the review of challenges that come from decision making process which will guarantee safety operation of the SDC. The study gives review about the decision making in traffic efficiency, mobility rate and patterns, and safety related issue. In [11], the report states traffic, pedestrian, and weather conditions as the potential challenges that will impact the operation of SDC. It is also stated in the report [11] that the only way to ensure that every condition is tested before actual deployment is to set them up in a virtual world. The argument is, “will the virtual world be equivalent to heterogeneous dynamic world?”. Likewise, the report in [12] identifies five big challenges that SDC will need to overcome. The first problem [12] is that creating and maintaining up to date route maps for SDC could be difficult. For cars to be able to perform successful maneuvering, the cars need to know the route map to destination. The cars use this as reference and thereafter deploy the sensors for perception [12]. However, some automakers like Tesla is looking to building its own SDC prominently on imaging and sensor processing. The second challenge highlighted in [12] is that driving requires many complex social interactions just like [11] and this might be tough for SDC to understand and response to the frequent changing in the social interactions. For example, it is even hard for a human driver to know what decision a pedestrian at traffic intersection will make; either to enter the road when the pedestrian light is red and car lights are green in the traffic intersection or not. The report “[12] states that the fully SDC technology will ultimately need to be proficient at four key tasks: **1)** understanding the environment around them; **2)** understanding *why* the people they encounter on the road are behaving the way they are; **3)** deciding how to respond (it's tough to come up with a rule of thumb for four-way stop signs that works every single time); and **4)** communicating with other people”. Therefore, social and context awareness interaction data collected by SDC should be shared to further build reliable machine learning algorithms (MLA). Also, there are various social interaction classification algorithms and they can be employed in the SDC social interaction understanding[11], [13]. The third changeless identified in the report [12] just like [11] is the weather condition. No robot or human can predict the “mother nature” with 100 percent probability. The SDC ecosystem perception devices should be able to adapt to change in weather conditions when there is rain, fog, snow, icy road, bright sunlight, and darkness. One solution is to use radar and lidar sensors which seem to work well in bad weather conditions but the lidar sensors are more expensive. The fourth challenge reported in [12] is that there is a need to design regulations that the society or automakers know how SDC will operate. This could be more political than the technical and there could more hurdles to cross for regulators and stakeholders to agree on terms and regulations due to various interest, power, legal concern, diverse opinions, and so on. Also, the process could be more time consuming and fruitless. This proposed study suggests that the process should first start, and then, the involved parties will gradually come to terms for the benefit of everyone. Finally, the report in [12] states that cybersecurity will likely be an issue.

The report in[14] shows someother challenges such as building a safe, useful, and affordable car. The report [14] raised some concerns and questions suchas “what are the safety measures and systems in place to ensure the safety of deploying SDC?”. Another concern raised in the article[14] is that “doesthe society really need the SDC and are they generally useful to mankind. Will they cause more harm than good[14]?”. Also, considering the level of risk and liability involved, the automakers will want to add as much as possible hardware, software and technical support on the cars to ensure safety. This will likely make the price of these cars unaffordable to many intended users. This proposed study suggests that one way to answer some of the concerns in [14] is to practically deploy and test small scale deployment in controlled environments before going for mass deployment and implementations. Similarly, the challenges identified in [3]

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are road, weather, traffic conditions; accident liability, radar interference from multiple cars, performance of internal car system, driving and safety, navigation and guidance. These are part of challenges already discussed in [11], [12], [14].

Other potential problems and concerns not mentioned in white papers and in literature are as follow: The challenge of having a high computing and speed AI enabled central processor.When all inputs from SDC and perception systems are fussed together to the central processor, the processor should be able to process the data, execute instructions and make intelligent decision in less than a second with nearly 100% accuracy and with zero percent failure without advance notice. All the HTCare gearing up to engineer such central processors [2], [3], [4]. Another unmentioned potential challenge is the dynamic complex heterogeneous environments and surrounding. The environments and road traffic conditionsare changing at complex formation per time. The concern is how the system reacts to such changing environments.

Similarly, manufacturing and making a car worthy of autonomous driving is a big concern.To address this concern, some of the HTC are working with automakers and original equipment manufacturer (OEM) to make this possible[2], [3], [4]. Car mechanical system failure is also an issue. The SDC should be able to detect an intending failure before it happens and give advance warning and safely pull over.

Another challenge is the sensors and perception systems failure. Like the SDC mechanical failure, there should be advance warning with ability to safely pull over and trigger alarm to remote help and turning on emergency lights. Also, SDC should have multiple sensors to verify and validate the accuracy of information and data; and make advance warning.

Other potential challenges in SDC technology deployment are delayed process and response from decision making subsystem. This will depend on the efficiency of SDC AI decision making software and hardware. Reliability and quality of information gathered from the environments will also determine the performance of SDC technology. Likewise, reliability and quality of transmitting the information to and from appropriate unit is another challenge. Many other potential concerns are: “will users be confident enough to ride in the SDC, or pedestrians or other human drivers want to share road with the SDC?”. “What will happen to bad drivers that purposefully chase the SDC to ensure crash?”. Several of these questions would not be accurately addressed until there is actual deployment or multiples sources of test runs.

Meanwhile, as the deployment process is gearing up, this reviewed study is pointing out research and development areas for researchers, developers, HTC, and automakers. In addition, this proposed study suggests direction to look at; such as considering coexistence of radar sensor data and radar radio signal. The authors in [15] present the analysis review of coexistence of radar sensing and communication. This might address the problem of limited resources (like frequency), cost (hardware) and interferences from many radio signals from innumerable sources. Similarly, efficient AI and MLA that make accurate decisionsfrom accurate data will optimally increase the safety concern of SDC will be required. A demonstration of such SDC AIis showed in [16] where an efficient Vehicle-to-Everything (V2X) Communication algorithm is proposed.

The authors [17] give geometrical derivations using additional technical data like distance between the cameras and some other specific angles such as the cameras view of field angle. The study demonstrates how perception systems and sensors could improve the SDC operations. Similarly, in [18], the study describes how to develop and implement functionalities highly secure, trust, reliable and accurate sensors in the deployment of SDC. The authors [18] state that frequency (RF) sensors like radars and multitude of other types of radio RF sensors arrays (IoT based) are instrumental part of the general sensor configuration required for implementing a robust cyber-security strategy and enhancing privacy in addition to the other autonomous features. Also, the study in [13]presents an overview of the human-machine network architecture with a focus on three main issues that include architecture design, inference algorithms including security or privacy challenges, and application areas. The authors [13] also provide statistical modeling of human behavior to characterize human-machine interactions. The review of literature shows that this proposed study provides comprehensive challenges and paths to potential solutions. The identified potential challenges and potential solutions are summarized in table I.

Table 1: The Summary of Challenges and Proposed Solutions

No	Potential challenges and questions raised	Potential Solutions
1	Reliability and quality of transmitting the information to and from appropriate units in the SDC ecosystem	Proposed in [16]
2	Traffic, pedestrian, and weather conditions - [2], [11], [12]	Design virtual world equivalent to heterogeneous dynamic world [11]. Use radar and lidar sensors in bad weather conditions
3	Traffic, pedestrian, and weather conditions information sensed - [2], [11], [12]	SDC data should be shared to further build reliable MLA [12]
4	Political policy and regulations - [2,[12]	This proposed study suggests that government agencies, stakeholders, and automakers should start global forum to define and adopt policies for the benefit of all
5	Cybersecurity - [2,[12], concern oncybersecurity attacks on vehicle-to-everything (V2X) communication	This proposed study suggests that existing encryption algorithms in operation on life systems and new ones could be applied in SDC implementation
6	Difficulty in creating and maintaining up-to-date onboard digital route maps for SDC - [12]	Google and other companies plan to create digital maps for every city in all the countries of the world. Tesla plans to build its own SDC on imaging and sensor processing. [12]
7	SDC are likely to be expensive - [14]	Need to practically deploy and test small scale deployment in a controlled environments before going for mass deployment and implementations [14]
8	Does the society really need the SDC, Can the automakers produce nearly 100 percent safe SDC - [14]	Need to practically deploy and test small scale deployment in controlled environment before going for mass deployment and implementations [14]
9	Need for high computing and speed AI enabled central processor	Some HTC are engineering the processor, [2], [3], [4]
10	Dynamic complex heterogeneous environments and surrounding	Need to share real time data about dynamic environment
11	Manufacturing and making a car worthy of autonomous driving	Need to be answered
12	Car mechanical system failure	Design system with standby system, but this makes the SDC more expensive, make advance warning with ability to safely pull over
13	Sensors and perception systems failure	have multiple sensors to verify and validate the accuracy of information and data, and make advance warning with ability to safely pull over
14	Delayed process and response from decision making subsystems	Design and develop efficient and high-speed algorithms and processors
15	Reliability and quality of information gathered from the environment	having multiple sensors to verify and validate the accuracy of information and data
16	Accident liability, performance of internal car system	Need to be answered
17	Radar interference from multiple cars and sources	Need to be answered
18	Will users be confident enough to rider in the DDC, or pedestrians or other human drivers want to share road with the SDC	Need to be answered
19	What will happen to bad drivers that purposefully chase the SDC to ensure crash in L5 operation	Need to be answered, maybe adopt severe penalties policy for offenders
20	Incase of crash what is next or if the car goes wild or on rampage, where will the control coming from?	Need to be answered

III. RADAR SENSOR SOLUTION FOR SDC IMPLEMENTATION

Using radar sensing and communication, an object could be detected at distance or range, R (m) from a referenced point, using the reflected radar energy wave. A communication to such object or a device at that distance using radar radio signal will still be R. According to [19], assuming free space, R is given as:

$$40\log R = P_T + 2G_{dB} + 20\log \boldsymbol{\lambda} + \sigma_{dB} + E_{dB} + 240dBW/Hz - 10\log B - F - S/N - L_{TdB} - L_{RdB} - 33dB \quad (1)$$

Where LT = losses in the transmitter path, LR = losses in the receive path, E = integration efficiency factor, R = maximum distance in (m), PT = transmit power in dBW, G = antenna gain in dB, λ = wavelength of radar signal in (m), σ = RCS of target measured in dBsm, F = noise figure (dB),B= bandwidth in (Hz), S/N = signal-to-noise-ratio in(dB) required by receiver processing functions to detect the signal,
Most radars, in practice, operate between 400 MHz to 80 GHz which covers voice and data communication range.
Using the open source MATLAB automated driving tool box[20], a demonstration plot for radar detection is shown in Fig. 2. From the figure, areferenced car (RC)- (blue) moving with a speed of 50miles/hr., has the radar system (sensing at W-Band 75-76GHz and radio communication at S-band 2-4GHz); and the three other cars, orange, gold and brown moving with speed of43, 62, and 80 miles/hr. respectively. RC detects or senses the two cars and could communicate with them at that distance at good signal-to-noise ratio (SNR).

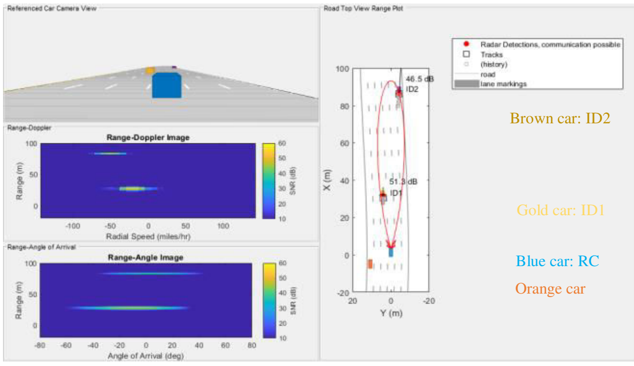

Fig. 2. Potential SDC Radar system detection plot

IV. CONCLUSION

This proposed study provides a brief overview of identified challenges in the deployment of SDC and proposes pathsto where researchers and SDC developers would need to explore and facilitate the deployment and implementation of SDC technology. The challenges reported in this proposed study are not all the exhaustive list of challenges and proposed solutions. There will be more emerging challenges as SDC makers start to roll out the cars.However, this is just to give a brief overview of challenges and how to move forward. When more new challenges come, the researchers and SDC developers will work on the optimization and tackle them.
Future studies will give comprehensive lists and explanations of existing and new challenges and provide more proposed solutions.

REFERENCES

[1] M. Revilloud , D. Gruyer and S. Glaser, "A Review of Motion Planning for Highway Autonomous," *IEEE Transactions on Intelligent Transportation Systems,* vol. 10.1109/TITS.2019.2913998, pp. 1-23, 2019.

[2] M. J. Hanna and S. C. Kimmel, "Current US Federal Policy Framework for Self-Driving Vehicles: Opportunities and Challenges," *IEEE Computer,* vol. 50, no. 12, pp. 32 - 40, 2017.

[3] "Challenges in designing a fully autonomous system for driverless cars," IToTWorld, 2019. [Online]. Available: https://iiot-world.com/artificial-intelligence/five-challenges-in-designing-a-fully-autonomous-system-for-driverless-cars/. [Accessed 11 November 2019].

[4] "Bring Level 4 Autonomous Driving Vehicles to Consumers," NIO, 5 Nov 2019. [Online]. Available: https://www.nio.com/news/nio-inc-announces-strategic-collaboration-mobileye-bring-level-4-autonomous-driving-vehicles. [Accessed 12 November 2019].

[5] "Future of Driving," Tesla, 2019. [Online]. Available: https://www.tesla.com/autopilot. [Accessed 11 November 2019].

[6] "We're building the World's Most Dxpereinced Driver," Gpoogle's Waymo, 2019. [Online]. Available: https://waymo.com/. [Accessed 11 November 2019].

[7] "SELF-DRIVING CARS," NVIDIA, 2019. [Online]. Available: https://www.nvidia.com/en-us/self-driving-cars/drive-labs/. [Accessed 11 November 2019].

[8] "Advanced Technologies Group," Uber, 2019. [Online]. Available: https://www.uber.com/us/en/atg/. [Accessed 11 November 2019].

[9] N. C. Moore, "Mcity demos: Self-driving cars can be even safer with connected technology," 23 June 2017. [Online]. Available: https://news.umich.edu/mcity-demos-self-driving-cars-can-be-even-safer-with-connected-technology/. [Accessed 28 November 2019].

[10] M.-D. Margarita and S. Francesc, "Autonomous vehicles: theoretical and practical challenges," *Transportation Research Procedia,* vol. 33, pp. 275-282, 2018.

[11] "Top 3 Challenges to Produce Level 5 Autonomous Vehicles," ANSYS, 2019. [Online]. Available: https://www.ansys.com/blog/challenges-level-5-autonomous-vehicles. [Accessed 11 November 2019].

[12] "5 big challenges that self-driving cars still have to overcome," VoX, 2019. [Online]. Available: https://www.vox.com/2016/4/21/11447838/self-driving-cars-challenges-obstacles . [Accessed 11 November 2019].

[13] A. Vempaty, B. Kailkhura and P. K. Varshney, "Human-Machine Inference Networks for Smart Decision Making: Opportunities and Challenges," in *IEEE*

International Conference on Acoustics, Speech and Signal Processing (ICASSP), Calgary, AB, Canada, 2018.

[14] "The three challenges keeping cars from being fully autonomous," MIT Technology Review, 2019. [Online]. Available: https://www.technologyreview.com/s/613399/the-three-challenges-keeping-cars-from-being-fully-autonomous/. [Accessed 11 November 2019].

[15] L. Zheng, M. Lops , Y. C. Eldar and X. Wang, "Radar and Communication Coexistence: An Overview: A Review of Recent Methods," *IEEE Signal Processing Magazine ,* vol. 36, no. 5, pp. 85 - 99, 2019.

[16] O. E. Olasupo, "An Efficient Vehicle-to-Everything (V2X) Communication Algorithm for the Deployment and Operation of Self-driving Cars," *International Journal Advanced Networking and Applications,* vol. 14, no. 1, pp. 5237-5249, 2022.

[17] A. Zaarane, I. Slimani, A. Hamdoun and I. Atouf, "Vehicle to vehicle distance measurement for self-driving systems," in *6th International Conference on Control, Decision and Information Technologies (CoDIT)*, Paris, France, France, 2019.

[18] H. G. Garakani, B. Moshiri and S. Safavi-Naeini, "Cyber Security Challenges in Autonomous Vehicle: Their Impact on RF Sensor and Wireless Technologies," in *International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM)*, Waterloo, ON, Canada, 2018.

[19] "Radar Measurement," Keysight, 11 June 2014. [Online]. Available: https://literature.cdn.keysight.com/litweb/pdf/5989-7575EN.pdf. [Accessed 29 November 2019].

[20] "Radar Signal Simulation and Processing for Automated Driving," MATLAB, 13 April 2019. [Online]. Available: https://www.mathworks.com/help/phased/examples/radar-signal-simulation-and-processing-for-automated-driving.html. [Accessed 29 November 2019].