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Machine Learning and Deep Neural Network – Artificial Intelligence Core for Lab and Real-World Test and Validation for ADAS and Autonomous Vehicles

AI for efficient and quality test and validation

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***Abstract*—Autonomous vehicles are now the future of automobile industry. Human drivers can be completely taken out of the loop through the implementation of safe and intelligent autonomous vehicles. Although we can say that HW and SW development continues to play a large role in the automotive industry, test and validation of these systems is a must. The ability to test these vehicles thoroughly and efficiently will ensure their proper and flawless operation. When a large number of people with heterogeneous knowledge and skills try to develop an autonomous vehicle together, it is important to use a sensible engineering process. State of the art techniques for such development include Waterfall, Agile & V-model, where test & validation (T&V) process is an integral part of such a development cycle. This paper will propose a new methodology using machine learning & deep neural network (AI-core) for lab & real-world T&V for ADAS (Advanced driver assistance system) and autonomous vehicles. The methodology will initially connect T&V of individual systems in each level of development and that of complete system efficiently, by using the proposed phase methodology, in which autonomous driving functions are grouped under categories, special T&V processes are carried on simulation as well as in HIL systems. The complete transition towards AI in the field of T&V will be a sequence of steps.**

Initially the AI-core is fed with available test scenarios, boundary conditions for the test cases and scenarios, and examples, the AI-core will conduct virtual tests on simulation environment using available test scenarios and further generates new test cases and scenarios for efficient and precise tests. These test cases and scenarios are meant to cover all available cases and concentrate on the area where bugs or failures occur. The complete surrounding environment in the simulation is also controlled by the AI-core which means that the system can attain endless/all-possible combinations of the surrounding environment which is necessary. Results of the tests are sorted and stored, critical and important tests are again repeated in the real-world environment using automated cars with other real subsystems to depict the surrounding environment, which are all controlled by the AI-core, and meanwhile the AI-core is always in the loop and learning from each and every executed test case and its results/outcomes. The main goal is to achieve efficient and high quality test and validation of systems for automated driving, which can save precious time in the development process. As a future scope of this methodology, we can step-up to make most parts of test and validation completely autonomous.

Keywords*—Machine Learning; Artificial Intelligence; AI-core; Autonomous Vehicles; ADAS systems; Test and Validation; Simulation; High quality; Efficient

I. INTRODUCTION

An autonomous car is a vehicle that is capable of sensing its environment and navigating without human input [1].

A. *Autonomous Vehicles and its History*

Autonomous vehicles or driverless cars specially can detect surrounding environment using a variety of techniques such as LiDAR, RADAR, odometry, GPS, and last but not the least - computer vision. According to SAE's automated vehicle classification [2], starting from level zero in which the vehicle has no control over the automobile (but it may provide warning to the driver), and all the way up to level five, which is complete autonomous driving which means that other than starting the autonomous system and setting up the required destination and related settings for navigation, and no human intervention or human input is required. The autonomous vehicle or driverless vehicle can drive to any location where it is legal and possible to drive. Advanced and sophisticated

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control systems, software and algorithms interpret all the sensory data and information to identify and detect appropriate and right navigation paths, as well as obstacles, other sub-systems and relevant signage information [3]. Autonomous or driver less vehicles have sophisticated control systems capable of taking in sensor data and analyzing the data to differentiate different objects in the surrounding environment and recognize vehicles, pedestrians and other obstacles in the surrounding environment which will be very helpful for later path planning to desired destination [4].

It has been known that some demonstrative systems in the direction of the autonomous and driverless vehicles dates back to 1920s and 1930s, Initial and one of the first self-driving vehicle and hence truly autonomous vehicle came in 1980s, with the University of Carnegie Mellon University's ALV project and their own Navlab project during 1984, Mercedes-Benz and University of Munich's project – Eureka Prometheus, and so on and so forth. Since then major organizations, research institutions, and companies have been working progressively in this field and direction and produced many working prototypes of autonomous automobiles. In August 2013, Daimler R&D with Karlsruhe Institute of Technology/FZI [13], made a Mercedes-Benz S-class vehicle with close-to-production stereo cameras and radars drive completely autonomous for about 100 km from Mannheim to Pforzheim, Germany, following the historic Bertha Benz Memorial Route [5].

B. *Testing and Validation of Autonomous Vehicles*

If one believes in pundits, full-scale fleets of autonomous vehicles are just around the corner. However, as the traditional automotive industry knows well, that there is a huge difference between building a few vehicles to run in reasonably benign conditions with professional safety drivers, and building a fleet of millions of vehicles that have to run in unconstrained real-world situations. Some say that successful and positive demonstration and a few hundred thousand km of driving experience and successful driving means that autonomous vehicle or driverless cars technology is essentially ready to be completely deployed at full scale. But, it is difficult to see and exactly know how such testing and validation would be enough to ensure correct safe operation and adequate safety. Indeed, at least some developers seem to be doing more in this direction, but the main question is how much more might be required, and how we can know that the resultant vehicles are sufficiently safe and secure to deploy in large scale in the real-world [6]. Vehicle-level testing won't be sufficient to ensure complete safety. It has long been known that it is infeasible to test systems thoroughly enough to ensure ultra-dependable system operation [6]. Of-course we pursue Model in the loop simulations and testing, Processor/controller in the loop, Software in the loop testing, Hardware in the loop testing [7], Integration level tests and finally full vehicle tests in a controlled testing grounds or sometimes in the real-world. The validation process follows each of the above mentioned steps until the final system i.e. the complete vehicle is validated and the system/vehicle functions as intended. The major drawback is that we still use age old testing technologies and methodologies to test these new age future autonomous vehicles and vehicles with ADAS systems.

C. *Machine learning*

Machine learning, in artificial intelligence (a subject which belongs to computer science and engineering), field/discipline concerned with an implementation of a computer algorithm and special software that can learn on its own. Expert systems and data mining software and programs are the most commonly used applications for improving and making the algorithms better through the use of machine learning and computer intelligence. Considering the most common approaches presently used, which are the use of artificial neural networks (large weighted decision paths) and genetic algorithms for solving a problem. So generally machine learning as we call it today is basically the subfield of computer science engineering that "gives computers the ability to learn without being explicitly programmed" (Arthur Samuel, 1959). Machine learning is where computers apply statistical learning techniques to automatically identify patterns in data. These techniques can be used to make highly accurate predictions which can be more accurate and more sensible in many cases, when we compare this to human predictions. We can say that the field of machine learning evolved from the study of pattern recognition problems and algorithms, we can also add in contribution of artificial intelligence with the field of computational learning theory, which can actually learn and predict within the given set of data, this kind of programming or model building from examples or sample data will overcome strict static program instructions. This kind of machine learning approach is used in many fields. Due to the shortcomings of classical programming approach for certain types of problems are not easy and sometimes unfeasible [4].

Machine learning field is very closely related as well as overlaps with the field of statistics mainly the field of computational statistics, which also concentrates on making predictions with the use of computers. The field of machine learning has strong ties to mathematical optimization and statistical methods, which delivers methods, application domains and theory or the field [4]. The field of machine learning is sometimes related with or closely compared to data mining, where the later stages/parts or sub-fields focuses mainly on exploratory data analysis which is also known as unsupervised learning. Machine learning methods can also be completely or partially be unsupervised learning, this can be used to learn and establish baseline behavioural profiles for different or various parts/entities and then later can be used to find out useful and meaningful anomalies. Machine learning is also used in the field of data analytics, here machine learning is used to derive and devise complex algorithms and models that get on their own to predictions, and in commercial use this particular kind of usage is called predictive analytics and is used in several commercial products. These kinds of analytical methods will make way for data scientists, researchers, engineers, and data analysts to "produce and give out reliable, repeatable decisions and results" and easily uncover "hidden insights" through learning from historical relationships and trends in the available data.

1) *Artificial intelligence*

Artificial intelligence is a form of intelligence which is exhibited by machines which might be to solve an existing high level problem which cannot be easily solved with classical

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programming. The ability of a computer or digital computer-controlled robotic system to perform tasks which are commonly associated with we humans or mainly intelligent beings like us [26]. The term used here is commonly and frequently applied to the project of developing sophisticated systems endowed with intellectual processes and most characteristics of humans, in which mainly are the ability to reason which is also known as reasoning power, find out or discover meanings for certain things in day to day life or in a specific problem, generalize some concepts, or also learn from past experiences. In the field of computer science, an ideal intelligent machine is actually a completely dynamic, flexible rational agent that can perceives its environment and also that can take actions that will maximize its chance of success at some goal [4]. Colloquially, the main term AI-the "artificial intelligence" is applied or used when a machine partially or completely mimics "cognitive" functions or skills or set of skills that we humans associate with other human minds, such as problem solving, learning and reasoning. One thing it could be is "Making computational models of human behaviour". Since we believe that humans are intelligent, therefore models of intelligent behaviour must be AI.

In the future as machines become more and more intelligent or increasingly capable, mental facilities once (in the past) thought to require intelligence are removed from the definition completely. For example we can consider optical character recognition which is now no longer perceived as an exemplar of AI, and hence has been excluded from the artificial intelligence, since they have become a routine technology. For instance imagine that you wanted to make a program that played the game of go. Instead of making the best possible go-playing program, you would make one that played go like people do, and learn the game like people do [26]. Capabilities currently classified as AI include self-driving cars, and interpreting complex data. Artificial intelligence research field is divided into multiple subfields, in which some will focus on specific problems or some will focus on specific approaches, we also have to note that some will concentrate on using particular tool or in the direction of satisfying particular and specific application.

Main goal of artificial intelligence research field includes learning, natural language processing, reasoning, trained perception, and ability to manipulate and move any object / move objects, and knowledge. Considering today’s artificial intelligence research field, the approaches includes machine learning (soft computing), traditional symbolic artificial intelligence, statistical methods, probabilistic approaches, logic approaches and so on and so forth [25].

2) Deep learning

Deep learning which is also known as deep machine learning, is a one of the sub branch of machine learning field which is partially based on structured algorithms which will try to create a model which is high level abstractions in the given data by using several multiple layers of non-linear and linear transformation functions, graph, deep graph, multiples of deep graph which can include multiple processing layers. Many inventors and computer science researchers have long dreamed of creating machines or computers that can think. This kind of desires dates back to at least the time of very ancient Greece civilization. The amazing mythical figures Pygmalion, Hephaestus and Daedalus, may all be completely interpreted as legendary inventors of that era, and Galatea, Talos, and Pandora possibly may all be regarded as artificial life [26]. Deep learning which we know now is part of a broader family or one of the last families of machine learning methods based on learning representations of available data [4]. An observation (e.g., an image, set of images, or even a video) can be represented in multiple ways such as a vector of intensity values per each pixel, or if we consider it in a more abstract way as a set of edges, boundaries, regions of particular shape and size etc. Some special representations are better or even than others methods at simplifying the basic learning task (e.g., natural speech recognition face recognition or facial expression recognition and so on and so forth). One of the main promises of deep learning techniques is replacing completely handcrafted features with better and efficient algorithms for semi-supervised or completely unsupervised feature learning and hierarchical feature extractions.

Deep learning is solution to more intuitive and complex problems which cannot be easily solved by classical computer programs or software. This kind of solution allows digital computers to learn from previous experience and also understand the world in terms of a unique hierarchy of concepts, with each of the concept defined in terms of its basic relation to simpler concepts. Now by gathering the knowledge or knowhow from previous experience avoids the need for human operators or users to formally specify and tell the system all kinds of knowledge that the computer needs. The hierarchy of different concepts allows the digital computer to learn complicated and highly complicated concepts by building them out of simpler ones [26]. If we now draw a graph, showing how these are exactly built on top of each other, you can observe that the graph is deep, with multiple layers and is very vast distribution. For this reason, we name this kind of approach to AI deep learning. Scientific research in the area of deep learning artificial intelligence will attempt to make efficient and better representations and create better models to learn these kinds of representations from a very large scale data which is completely not labelled at all. We can also see that some representations are inspired by advances in the neuro-science field and are very loosely based on interpretation of information processing (Note: Not data processing) and communication patterns in a natural nervous system, such as deep neural coding which will attempt to define relationships between various available stimuli and are completely associated with the neuro responses in the brain. Many deep learning and deep neural network architectures such as DNN (Deep neural network), CNN (Convolutional neural networks, Convolutional deep neural networks, deep belief networks, Artificial deep neural networks and recurrent neural networks have been continuously applied to the field of computer science, mainly in pattern recognition, computer vision, automatic speech recognition, audio recognition, natural language processing, bio-informatics and so on and so forth. Autonomous vehicles or so called driverless vehicles where they have been shown to produce a complete positive state of the art results on various different tasks. Deep learning techniques has been constantly used by automotive industry for developing vehicles with advanced driver assistance functions

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and recently this has been extended to autonomous vehicle development too [6].

II. Challenges in Autonomous Vehicles

Typical automotive safety arguments and discussions for the low-integrity devices can really hinge upon the ability of a human driver to exert control on the vehicle. For example, with an Advanced Driver Assistance Systems (ADAS), if a minor or major software fault or error causes a potentially dangerous situation of the driver and the surrounding environment, the driver might be expected to (or have to) over-ride whatever software function and recover to a safe state without causing much problem. Drivers are also expected to recover from significant vehicle mechanical failures such as tire blow-outs, engine failures and even problems with the steering columns and braking system. Simply in other words, in human-driven or normal vehicles that we have without any autonomy, the driver is completely responsible for taking the right corrective action while driving. And in some situations in which the vehicle driver does not have an ability to take control and provide corrective actions are said to lack controllability in this perspective, and hence the system must be designed to a higher Automotive Safety Integrity Level, or ASIL [8]. With a fully autonomous vehicle, the driver cannot be counted on to handle exceptional situations. But rather, the digital computer system must assume that role as the primary and main exception handler for faults, errors, malfunctions, and beyond-specified operating conditions.

Putting the computer in charge of exception handling seems likely to dramatically increase automation complexity compared to advanced driver assistance systems. The combinations of advanced driver assistance systems such as lane-keeping assistance and smart and automatic cruise control seem tantalizingly close to fully autonomous operation. However, a fully autonomous vehicle or truly driverless vehicle must have significant additional complexity to deal with all the possible ways that things might go wrong because basically there is no driver to grab the steering wheel and hit the brakes when something goes awry [6]. Automated driving is a huge paradigm shift from conventional vehicles, we have an incredible number of eventualities and unpredictable situations in the real-world, since we have ran differently from the conventional idea of an automobile, the paradigm shift is also a must in the field of testing and validation and hence and it is no longer a request but it is a basic need [9]. Now it is well noted to not just mass producing autonomous vehicles, but the critical part is to test and validate the vehicles in order to guarantee the must to have functionality and to comply with the safety standards.

A. Challenges in Testing and Validation

In the automotive industry, different phases in the development process of safety-critical control systems are often connected using the 'V' diagram, depicted in Figure 1 [10]. The 'V' diagram uses a 'top-down' approach to design and a 'bottom-up' approach to test and validation, although in practice the process does not strictly follow all phases in this sequence and goes through several iteration loops. The 'V' diagram is frequently applied to the development process of mechatronic vehicle systems [11]. However, the various development phases for ADASs and future autonomous vehicles (may) face some specific challenges [12].

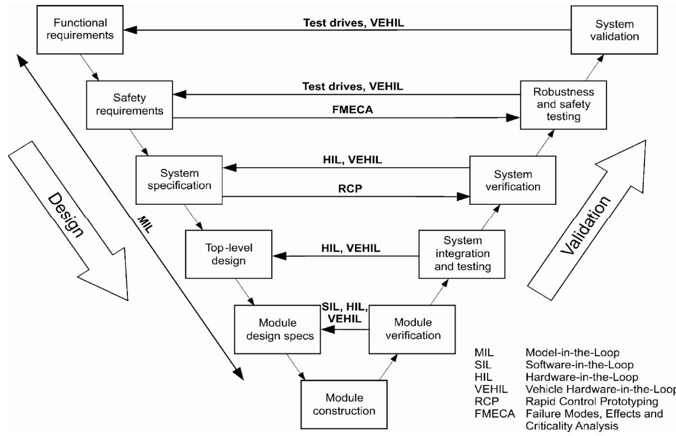

Fig. 1. [10] The 'V' diagram represents the sequential design, test and validation phases in the development of automotive safety critical systems, including the use of various test tools in these phases.

The main challenge with lab test and validation is the information exchange between different levels or stages of V-model. We can divide test and validation to be at two different levels/stages as depicted in Figure 2, one being the laboratory test and validation process which includes Model in the loop simulations and testing, Processor/controller in the loop testing, Software in the loop testing, Hardware in the loop testing [7], Integration level testing, and validation follows each of the above mentioned stages. As depicted in Figure 2, the other stage is real-vehicle/full-vehicle test and validation, which can take place in a controlled real-world testing ground or in actual real-world (can be in a public street with real-world traffic situations a very good example being Karlsruhe, Germany where vehicle systems will be tested in real-life traffic [13]).

As discussed in section I-B, in practice the process does not strictly follow all phases in this sequence and might even go through several iteration loops, hence resulting in challenges with laboratory and real-world test and validation. The feedback between most of the testing/validation stages and development stages is through human-to-human communication which faces its own drawbacks such as information loss, improper use of information, poor understanding capability and difference in competencies with the people involved in the communication.

Human-to-human communication takes place between the group who will pursue tests and the group who will have developed such a system. Such human-to-human communication includes filling forms with result of tests, or may even include sending emails briefly explaining test results. Such a communication would take serious amount of effort and time to integrate itself in a different stage/level of the V-model, and finally finding its way solving a problem, another issue with such communication is the loss of information and lack of understanding ability of the person who is acting as counterpart and receiving all the information. Presently there exist not many standards in providing feedback between different stages of the V-model.

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Real-world test and validation is one of the crucial stage where in the complete vehicle is tested and validated, sometimes even individual functions or features are focused in such tests. There are numerous challenges in real-world testing and validation. To start with, let us consider an example: let us assume that we have an autonomous vehicle to be tested in real-world. And let us say we obtain testing scenarios from the Euro NCAP [14], functionalities such as lane changing, pedestrian avoidance, lane keeping, and collision avoidance are being tested. The data from all the sensors [15] and sensor fusion data [15] has been logged and recorded. This logged data has to be extracted and subdivided into different scenarios (generally this process is termed as labelling) and fed-back to different laboratory testing stages of the V-model. Labelling [17][18] is a task conducted by humans, and hence the process is not efficient/accurate sometimes [18], and consumes a serious amount of time. The challenge is to facilitate efficient interaction within different testing and validation stages in the V-model. Feedback from real-world test and validation to laboratory test and validation is one of the challenges which is being concentrated here.

Another issue with test and validation is the development of the test cases and test scenarios for effective and efficient test and validation process. We humans can design and develop test cases and scenarios which we can think of, and even in case we have most of the required test scenarios designed to validate a function, accurate execution of these test scenarios in the simulation environment and/or in the real-world is a must. Huge amount of time and effort should be put in to generating test cases and scenarios, in carefully developing them, and deciding which test scenarios are valid, but this leaves human competences and abilities on its edges. The major challenge is to achieve as many valid test cases and scenarios which will not leave room for any errors or system failure at the end.

III. Objectives

In order to have efficient feedback and information flow between different stages of the V-model, and from real-world to laboratory test and validation, it is needed to find an efficient data mining/data sorting technique and a database system. The data here refers to the data logged from all the sensors of the vehicle under test (VUT) in real-world, including processed data such as sensor fusion in real-time, bus-data and calculations in real-time. The logged data also includes reaction of the VUT for the corresponding surrounding situation/environment. The advantage is that the data can be reused in laboratory tests and validation so that one can recreate real-world scenario in a simulation environment. Discussing about autonomous vehicles, we have an incredible number of eventualities and unpredictable situations in the real-world. Localizing the vehicle (localize is to bring in all the information of the surrounding to knowledge of the vehicle) in such real-world environment is not an easy task, and requires lot of sensors to achieve real-time and efficient localization, resulting in large amounts of data, but such huge amount of data [19] from different sensors is to be managed at a time (simultaneously) to facilitate localization of the vehicle (For instance, sensor fusion of Stereo-Camera [5], short-,medium- and long-range radar system, needs data from all the mentioned sensors at a time/ simultaneously). Such huge amount of data can also be termed as big-data [20]. Hence data mining is efficient to sort such huge amount of data, since we humans cannot cope up with it efficiently without data mining techniques anymore [19].

The database system supports in connecting different stages of the V-model. Efficient data mining/sorting system, will sort test scenarios within the recorded/logged data from real-world tests, this will reduce major human effort and time, but also will address to the problem of errors and inaccuracies in the process of labelling. Classification of recorded/logged data is a must, and is based on the individual functions and relevant functional-groups of an autonomous vehicle. The goal is to completely test and validate the functionality of an autonomous vehicle or vehicles with ADAS systems. Such an autonomous vehicle consists of individual functions (for example, emergency breaking, pedestrian recognition) or functions which work together to attain required functionality (for example, pedestrian recognition and avoidance, emergency breaking and cross traffic avoidance, here different functions work together to produce required functionality), hence justifying one approach of classification as mentioned above. The paper also discusses a control block which can be useful to reuse simple test scenarios to form numerous test scenario derivatives.

Secondly the aim of this methodology is to develop a new technology by implementing machine learning technics in the field of test and validation for autonomous vehicles and vehicles with advanced driver assistance system to achieve high quality, efficient and autonomous test and validation. Now the goal is to develop and program an AI-system (Artificial Intelligence system using machine learning techniques) which can take-in initial parameters, boundary conditions and few predefined test cases/scenarios, learn the basic goal of the respective test which is carried out, and also learn to further test the respective given function of the ego vehicle on the simulation environment. Here 'learn to further test' means to find out new test scenarios and test cases autonomously, efficiently and effectively conduct quality test and validation in the simulation environment as the first step and extend it to real-world test and validations in the next steps.

IV. Methodology

As discussed under section II-A, one of the challenges to efficiently connect the real-world test and validation with lab test and validation is the flow of information and data between different levels within the V-model. Here we propose phase methodology, in which the logged/recorded data from the real-world tests are fed into a trained machine learning system/deep neural network system which will classify different functionality or functional-groups of an autonomous vehicle or a vehicle with ADAS systems and starts deducing test scenarios from the available data.

A test scenario is a testing case- using scenarios to closely relate the real-world use case and eventually find the right condition to test the targeted function/system within the scenario [21]. Examples for test scenarios can include simple steering command, two lane changes, two lane changes + emergency brake, lane change right / left, overtaking, traffic

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jam and corridor [21]. This deduced test scenarios will be then sorted and saved in a database system. The test scenarios are then transformed to a generalized format (similar to OpenSCENARIO [21]: OpenSCENARIO is an open file format for the description of dynamic contents in driving simulation applications [21].) so that the methodology can be generalized and applicable to different OEMs, this will allow us to use the sorted data in different testing stages of the V-model. Such database will be a common database for the entire V-model.

For the second challenge we propose the methodology with the AI-core to generate test cases and test scenarios for effective and efficient T&V process, and accurate execution of these test scenarios in the simulation environment and/or in the real-world environment, which is a must. Hence, with the AI-core we can achieve maximum level of autonomous test and validation with very less human intervention.

A. *Concept of Realization*

As shown in the Figure 2 the data from the real-world testing is acquired and fed to the machine learning system, which is pre-trained to understand various functionalities, scenarios and surrounding environment. One method to differentiate between different testing scenarios is using the reaction of the VUT and the surrounding environment, the system will not only sort the test cases or scenarios, but will also transform the data in a general standard format and saves all needed data in the database. The data from the database is then fed appropriately to different laboratory testing stages in the V-model as shown in Figure 2. Feedback can be either direct or through a controlled block. In direct feedback the recorded/logged data is sorted and replayed in a testing stage, such as software in the loop and hardware in the loop simulation, a good example being, 'record and reply' in the software and hardware in the loop testing of a camera systems [22]. In controlled feedback, the sensor data and the scenarios can be altered with a parameter variation control block though which existing data and scenarios can be reused to form numerous test scenario derivatives.

In the second step, the machine learning system controls the surrounding parameters on the simulation environment will create specific test scenario for the ego vehicle/function under test. The driving input for the ego vehicle/function is also provided by the AI-core. The reaction is recorded and the ego vehicle/function is virtually tested under simulation environment, effectively generating valid new test cases and scenarios autonomously.

B. *Concrete Scenario*

Let us consider a classical example of laboratory testing on a software function using simulation environment. As shown in figure 2, the real-world tests are conducted, data from each and every sensor, sensor-fusion data from the ECU, bus-data and real-time calculations are logged/recorded, (such huge data can also be called as big-data [20]), and this recorded big-data contains numerous test scenarios and includes reaction of the VUT for the corresponding surrounding situation/environment. Since labelling test scenarios from such huge amount of data has its own challenges as explained earlier under section 2.1 and 3, machine learning system/deep neural network system comes in handy to sort the scenarios into different categories.

To sort the scenarios the machine learning/deep learning system should identify the surrounding environment including the actions of the surrounding dynamic objects such as other vehicles, pedestrians, animals, road conditions, weather conditions etc.., the system has to identify and detect the reaction of the ego vehicle for the corresponding situation. Now the surrounding environment and the resulting reaction of the ego vehicle can form one test scenario, and since there exists numerous such scenarios tailored within logged/recorded big-data, number of test scenarios can be derived. The derived test scenarios are sorted under different categories which are based on differences in requirements and descriptions (one approach is to have categories based on high level functions and functional-groups (as explained in section 3) of an autonomous vehicle or vehicle with ADAS system such as pedestrian avoidance, lane changing, assistive braking, emergency braking, collision avoidance, cross traffic avoidance etc.,), these sorted scenarios are then transformed to a standard general format (such as OpenSCENARIO [21]) and stored under database system. The sorted scenarios are then fed back to different stages of the V-model as depicted in the figure 2.

In this example the stored scenarios are fed into a simulation environment to recreate corresponding real-world scenario in the simulation environment, finally testing the ego software function under test. This happens without any control block in the feedback loop. Having the control block within the feedback loop provides the capability to vary the parameters to give wide flexibility for the testing stage to change the parameters as the testing is carried out, the possibility of varying the parameters to create slightly altered test scenario or completely new scenarios opens up a new dimension in test and validation stages conducted in laboratories and test benches, in other words, the system is now similar to closed loop system, which is advantageous over classical open-loop testing and validation [24]. Additionally since the test scenarios are in a standard format (example: OpenSCENARIO), it is a plausible solution to integrate such standard formatted data in each level of test and validation irrespective of the OEM.

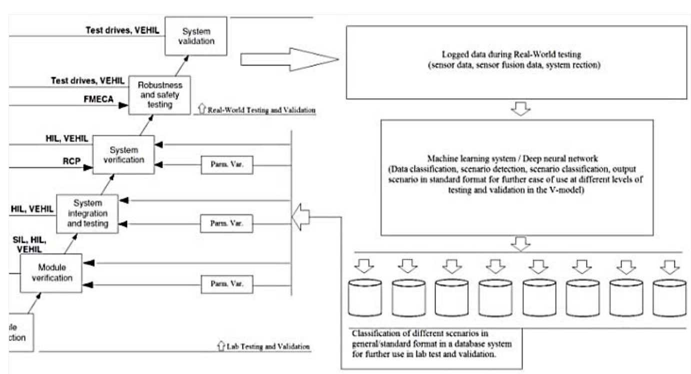

Fig. 2. Derived 'V' diagram representing the phase methodology for efficiently connecting the Lab test and validation to that in the real-world.

Additional advantage with such feedback methodology and parameter variation control block is that we have the ability to

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look into the future, since we have the complete data from the entire testing operation in the real-world, with which crucial tests can be repeated with different parameters and oversee what were the results earlier in the real-world and what is the present result of the ego software function or system under test.

It also gives us the opportunity to successfully anticipate specific outputs for certain inputs since the future is foreseen due to the recorded data. Hence with this example one can understand the basic use-case and functionality of the proposed methodology. The above methodology can be used at different stages of the V-model. Required, crucial and must-to-have test scenarios are noted and repeated/executed in the real-world environment with automated vehicles and automated surrounding environment, achieving the closed loop model with laboratory and real-world test and validation.

Now stepping to the second stage, initially the AI-core is fed with available test scenarios, boundary conditions for the test cases and scenarios, and many example scenarios, The AI-core will conduct virtual tests on the simulation environment using available test scenarios and further generates new test cases and scenarios for efficient and precise tests. As shown in Figure 3, the machine learning system controls the surrounding parameters on the simulation environment such as: other vehicles, lighting, pedestrians, traffic density, type of road, infrastructures, cyclists, construction sites on the road, accidents, fallen tree, environmental parameters such as sun, rain, fog, wind and dark driving condition in the night etc., further, the machine learning system will not only alter the above mentioned surrounding environmental parameters but also alters details and sub parameters, such as: color of the surrounding vehicles, visibility of the surrounding vehicles, reflections, shadows, height of the pedestrians, length of the bicycle, speed of other vehicles and mainly how each surrounding object will form a specific test scenario for the ego vehicle/function. The driving input for the ego vehicle/function is also provided by the AI-core.

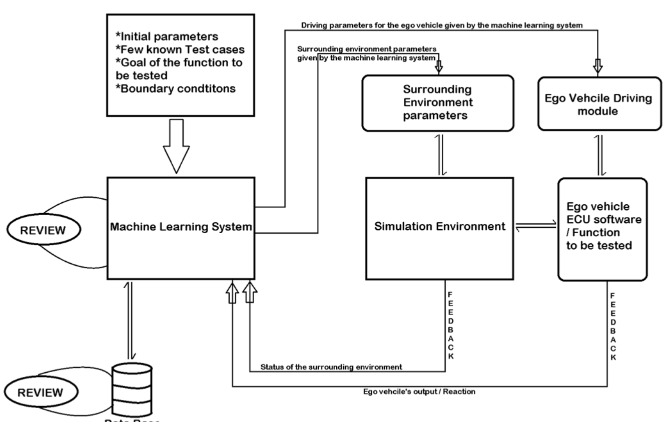

Fig. 3. Abstract level representation of AI-core (Machine learning system) controlling the deriving test scenarios and conducting tests in a simulation environment and validating certain aspects of the ego vehicle or ego function in test.

Now when we look at Figure 3, we can understand that the surrounding environment and the ego vehicle/function is completely controlled by the AI-core, hence the system will alter to set various parameters and test cases/scenarios (In fact in thousands or millions) therefore, effectively test the target function on the ego vehicle/software. The output/reaction of the ego car/vehicle is sorted and recorded in a database and can be reviewed later by an expert (initially or when needed). The system will then categorize the test scenarios into successful, critical, unknown and failed test cases/scenarios, which can then be reviewed by humans in the loop so that deviations from the specification can be found and corrected if necessary.

The critical and mandatory test cases/scenarios are then taken to the next level of testing, which is in the real-world environment with real-vehicles on a testing ground. The machine learning system has effectively generated and shortlisted the test cases/scenarios which we humans would have taken serious amount of time and effort or we humans may not have even thought about some scenarios which the AI-core would find. (It is important to keep in mind that the machine learning system is programmed and developed in such a way that it is working always to create test cases/scenarios within the boundary conditions to make the ego vehicle/function under test to fail).

The AI-core is not just limited to above mentioned functions. The future of this system is automating the real-world testing in steps to achieve fully automated and autonomous testing and validation. For example, initially we make the system to control few robots and pedestrian dummies at a testing/proving ground, but still keeping real drivers in the loop. In the later stages the machine learning system can be extended to control multiple vehicles and robots, together with controlling the ego vehicle to generate and have successful repeatable test scenarios at the end, which means to us, that we can conduct tests with real vehicles, effectively reaching boundary conditions (here the boundary conditions are referred to critical conditions at which the vehicle can be still controlled and crash can be avoided) but not having a single unwanted crash during the test. Since the machine learning system is quickly adaptable, the system will easily adapt and start testing irrespective of the manufacturer of the vehicle, the development methods or the functions involved.

V. SUMMARY AND OUTLOOK

This paper presents a methodology to connect test and validation of individual systems in each level of development and that of complete system by using the proposed phase methodology. The data is captured or logged from the real-world tests and then fed into trained machine learning/deep neural network system to derive and sort the test scenarios in a standard general format. The basic feedback loop of the control system is closed by means of a classical plant model and all additional input data is derived from sorted and standardized data from the database system, which is accessible at all stages of the V-model. A standard, such as upcoming OpenSCENARIO is a must, to standardize and generalize such a methodology. More scope is needed in the direction to adapt such standards in various levels of the V-model. This methodology introduces virtual testing and validation capabilities. Field tests and initial development phase of this methodology is in progress under projects such as Automated Testing Ground (ATG), with driving robots controlling the VUT.

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The AI-core is fed with available test scenarios, boundary conditions for the test cases and scenarios, and many examples. The AI-core will conduct virtual tests on the simulation environment using available test scenarios and further generates new test cases and scenarios for efficient and precise tests. We can understand that the surrounding environment and the ego vehicle/function are completely controlled by the AI-core, hence the system will alter to set various parameters and test cases/scenarios therefore, effectively testing the target function on the ego vehicle/software. The output/reaction of the ego car/vehicle is sorted and recorded in a database and can be reviewed later by an expert (initially or when needed). The AI-core (deep learning/machine learning system) is not just limited to above mentioned functions; the future of this system is automating the real-world testing in steps to achieve fully automated and autonomous testing and validation. Since the AI-core is quickly adaptable, the system will easily adapt and starts testing irrespective of the manufacturer of the vehicle, the development methods or the functions involved.

The trained AI-core, newly generated, sorted and standardized test data, test cases and test scenarios, databases and feedback methodology will obviously reduce human efforts, errors and delays, more over increases the overall efficiency in process. Such efficient, self-learning and generalized methodologies are needed to test these new age future autonomous vehicles and vehicles with ADAS systems. And with the second stage of the methodology, which will make test and validation an autonomous process in steps finally making the process intelligent, efficient and autonomous, finally making a way to achieve safe roads faster. A future research aspect is to extend this methodology for complete autonomous testing and validation for the future generation of ADAS and Autonomous vehicles with complete autonomously controlled environment in the real-world.

VI. Definitions/Abbreviations

ADAS: Advanced Driver Assistance System

LIDAR: Light Detection and Ranging

RADAR: RAdio Detection And Ranging

ASIL: Automotive Safety Integrity Level

HOV: High Occupancy Vehicle

LIDAR: Light Detection and Ranging

VUT: Vehicle under test

V-model: A software development model that includes requirements and design on the left side of a “V” with verification, testing and validation on the right side of the “V”

AI: Artificial Intelligence

ML: Machine Learning

DL: Deep Learning

DNN: Deep Neural Network

AI: Artificial Intelligence core inferring to a powerful computer running the AI software / Program

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