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Research Article

Integrating Controller Area Network (CAN) with Cloud-Based Data Storage Solutions for Improved Vehicle Diagnostics using AI

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ARTICLE INFO **ABSTRACT**

Machine learning and AI algorithms are gaining popular use and acceptance in virtually all sectors. The leading drivers of this evolution are computing and data storage advancements, hence an increasingly interconnected world. While this is applauded, massive information tracking and diagnostics are less embedded in vehicle engineering.
Cars are increasingly well-connected and with the advent of car sharing and autonomous vehicles, all of them will need to be autonomous and fully safe. Cars sold in this last decade are equipped with multiple embedded electronic control devices, nowadays increasingly interconnected via Controller Area Networks (CAN). At the same time, all new vehicles are connected, not only cellularly but also via storage systems that are attached to clouds. These systems have evolved to be platform agnostic, can accept a high arrival rate of data, and become low-latency storage systems in clusters spread over several continents. They deliver geo-localized near real-time storage that can be used to monitor one car within a several-kilometer radius.
Such systems can store in real-time (limited minutes latency) data that collectively spans 40 million kilometers covering the 20,000 cars being sold every day. These cloud-attached storage systems are not only capable of storing vast amounts of data in real-time but they are also used as data platforms whereby AI can constantly monitor vast sets of cars.

Keywords: Integrating Controller Area Network , Industry 4.0, Internet of Things (IoT), Artificial Intelligence (AI), Machine Learning (ML), Smart Manufacturing (SM), Computer Science, Data Science,Vehicle, Vehicle Reliability

1. Introduction

This approach recurrently integrates the Controller Area Network (CAN) and different cloud-based storage solutions for vehicle diagnostics, as an enhancement to existing Over-The-Air (OTA) updates, complemented with CAN-capable AI to mitigate automotive cybersecurity issues related to more complex vehicular functions implemented with Software-Defined Systems (SDS).

With different popular cloud-based storage solutions, this work presents an exact approach to Cloud-CAN integration using regular dongles.

The study also reacts with a straightforward and versatile architectural framework that employs the Internet of Cars Blockchain (ICB) model to protect data exchange parallel to network communication protection during predictive, contextual vehicle failure detection.

This work also presents a vehicle failure prediction model showcasing effectiveness by computing an inaccuracy of less than 5% and designating intelligence to small automotive controllers. The CAN sensor's values are determined inside the automotive controller.

Feature engineering produces useful transformations for the development of precise model diagnostics. The presented
model platform can produce flexible diagnostic models, capable of working with trending vehicle sources. Such a model can reduce the complexity and computation requirements and is competitively advantageous. In

addition to the limited complexities during development, the overall architecture has the potential to process data over the cloud.

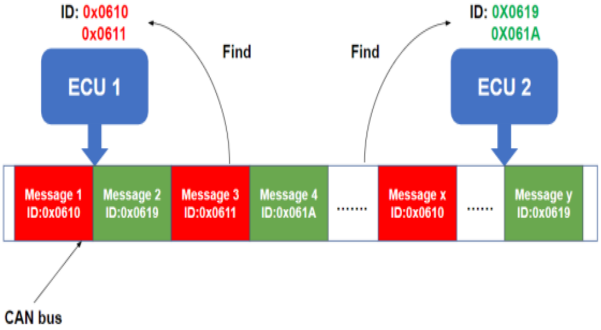

Fig 1: ECU mapper schematic diagram

1.1.Background and Rationale

Data storage and analytics capacity, known as artificial intelligence (AI) or machine learning (ML) models, is growing alongside the increase in the data generated by Electronic Control Units (ECUs) within modern vehicles. To provide significant benefits, the growing capacity for AI within vehicles must connect with the considerable capacity of the cloud, creating what is known as cloud-AI solutions. Hardware implementing cloud-AI solutions requires AI acceleration hardware, cloud access points, a vehicle, and ECUs. This paper investigates the extent to which automotive ECUs meet four critical capabilities to participate in a cloud-AI solution. Neither the Controller Area Network (CAN) nor higher-level bus solutions are presently fit for cloud-based data storage analytics because filtering options, data rates, and buffer sizes offer inadequate support for the large amounts of data expected in the cloud AI era. These limitations affect all potential bus bridge solutions and are shared by all recent automotive Ethernet solutions. With the limitations detailed in this paper, AI software and hardware within vehicles may not be performing the necessary amount of data storage analytics as anticipated due to inadequate bus support at present.

1.2.Research Objectives

The primary objective of this research is to provide a technological solution that can effectively provide real-time vehicle diagnostic data using cloud-based CAN data storage systems and fast AI data analytics techniques. The following are the specific objectives that we will focus on delivering the main objective:

1) Develop a comprehensive procedure to integrate cloud-based data storage networks with Controller Area Network (CAN) systems to provide real-time fault diagnosis for commercial vehicles.
2) Design effective software to parse and store the real-time CAN data on chosen cloud storage solutions quickly.
3) Develop a cloud-based vehicle diagnostic software that makes use of machine learning models enabling effective fault prediction on the stored vehicle data in real-time.
4) Implement a web-based real-time dashboard for diagnostic data visualization at all levels of a commercial vehicle system.

We believe that contributing to these specific objectives will assist the automobile industry's progression towards more automated fault diagnostic systems, allowing them to reduce overhead costs while also improving vehicle safety.

1.3. Scope and Limitations

This work focuses on the design of CAN-to-cloud data acquisition and storage techniques, and the development of a vehicle-health monitoring system offered by CAN, by storing the data on a cloud. The cloud-server storage of data and analytical software can analyze the vehicle's state more securely and robustly. The aim is to develop a practical model of how the existing free and paid cloud services can be integrated with different in-vehicle or on-board devices and sensors to plan, design, and increase vehicle-device serviceability more economically and securely. In the present scenario, all the vehicles are incorporated with an on-board diagnostic II (OBD-II) where an equipped scanning tool digitally reads the specific vehicle information.Using an on-board OBD-II, the vehicle information such as vehicle pins and the automotive circuit data are recorded to find and diagnose the different problems for each of the vehicles. The OBD-II port gives real-time data regarding the vehicle. The existing OBD-II tools and systems are based on various types of technology such as OBD test tools, hardware original equipment manufacturers, computer-based analysis tools, and communication networks for the vehicle. The collected data is used to identify any faults and risks, which occur inside the vehicle and can degrade the vehicle's performance. The information records the vehicle-based protocols such as SAE J1850 VPW, ISO 9141, ISO 9141 KWP2000, and ISO 14230 CAN protocols. Our work on integrating a vehicle-based diagnostics system with cloud computing will pave a path to designing a unified diagnostics system using AI, integrating with IoT technology for long-term service and effective, cheap vehicle device maintenance.

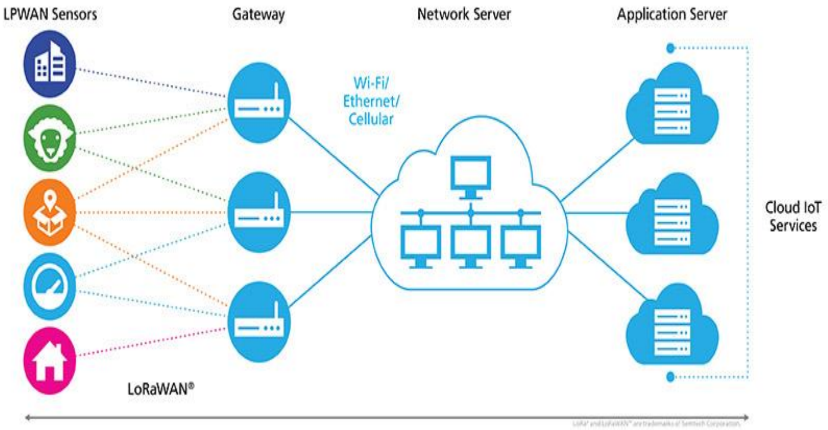

Fig 2: LoRAWAN architecture Data

2. Controller Area Network (CAN) Technology

With the advent of Controller Area Network (CAN) technology, engineers started to design and connect more and more microcontrollers to automotive and other complex systems. Now, instead of adding wires one by one, the automotive wiring harness is reduced significantly, resulting in a more straightforward electronics system structure for vehicle dynamics and safety control. Since CAN was engineered initially in response to the industry challenges of reduced wiring harnesses and reduced electronics costs, we could foresee the success story of harnessing transportation electronics over the past 30 years. During this period, significant development of CAN technologies was achieved, and various offshoots of CAN technologies were spawned, such as J1939 for trucks, the lower-level device monitoring plans for off-highway vehicles, and CAN in cyber-physical systems networks as a classical microcontroller electronics and actuation system bus. The CAN technology growth created a set of well-defined, ISO-approved CAN communication protocols as networked electronic building blocks.

The industry's success fuels the demand for more, newer, and better electronic features in vehicles, ranging from improved methods to manage environmental protection and fuel economy, active and passive safety systems, increased onboard vehicle communication connectivity for consumer electronics devices, etc. Also, direct messages between vehicles and cloud devices enhance vehicle environment awareness, leading to significant changes to the road and new cost/benefit analyses for new innovative vehicle electronics systems. As the computer power increases, onboard Artificial Intelligence (AI) methods, algorithms, and ever-increasing levels of vehicle electronic features proliferate to the point even the releases of software updates require new vehicle business models. Ephemeral functions can be programmed in, increasing the potential sources of functional failures requiring frequent vehicle repairs or reducing payment for extended warranties. This places a new communication requirement on networks to provide the ability to fix repairs remotely. At the same time, as connected vehicles form large networks, terabytes of vehicle operational data are logged in vehicles daily, and efficient ways to offload local vehicle operational data to the cloud are important. The network technologies required to address this requirement are still heavy, they add significant weight, and their systems are complex when one considers these network technologies strictly from a vehicle perspective.

2.1.Overview of CAN

To fully understand the conditions of the onboard diagnostics, the vehicle subsystems need a way to communicate with a central hub. This hub will not only collect but will also perform actions based on the collected data. One of these major hubs in the vehicle domain is the Controller Area Network (CAN) bus. The data from the various car subsystems is collected, processed, and used in the vehicle's safety and operation systems. However, data collection additionally happens in an external device, which is the AutoDIM. The open-source AutoDIM allows anybody to collect, process, and analyze the data. During the trips, the actual system of the AutoDIM is a CAN bus data collector that collects, processes the data, logs the data, and collects follow-up data based on pre-configured rules. The implementation of the AutoDIM is based on car hacking and has been built upon the AUDI CAN bus that was used in the Intelligent Vehicles 2012 competition.The need to automatically assess the state of vehicle subsystems is not new. The sudden and likely irreversible increase in the complexity of vehicle subsystems and the amount of data collected from the subsystems has led to a strain on current state assessment systems. This strain is primarily attributed to the need for increased safety and the introduction of smarter features in the car. The car as a complex system has become a life-critical application. In a fairly recent newsletter regarding electric vehicles, the severity of state assessment is clear. The newsletter regards the possible implications an electric vehicle has when considered as a "quiet" car. The nature of the vehicle being quiet is related to the fact that it cannot generate or distribute sound and it is silent during operation. Because the vehicle is silent, pedestrians have a harder time judging its presence. Based on this perception, especially visually impaired pedestrians will have a possibly increased probability of not reacting to the car. This could lead to situations that cause harm. With the silent behavior of electric vehicles, intersection accidents are believed to increase without a corresponding increase in countermeasures.

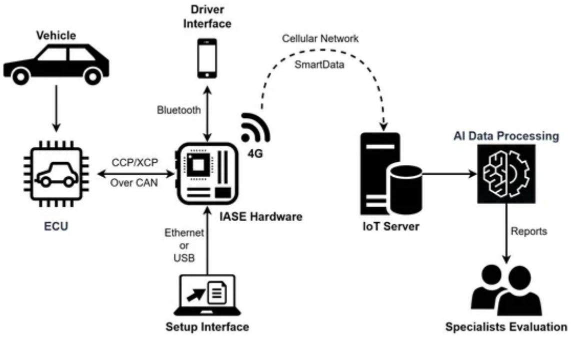

Fig 3: IASE Data Flow Overview.

2.2.CAN in the Automotive Industry

CAN was developed by Robert Bosch GmbH in 1983 to address the automotive industry's need for a serial communication protocol between microcontrollers. "Controller Area Network" (CAN) adopts a multi-master configuration, which means that each network node can correctly initiate communication on the bus without any dominance conflict.The CAN bus is based on a pair of twisted cables: DATA+ and DATA-. The data transmission speed is defined as a unit with bit/s, cell, and is typically chosen from the range 10 kbit/s-1 Mbit/s. The underlying physical layer is a two-wire, 'multi-drop' communications interface, which is terminated at each end of the network by a unique differential 120 Ω resistor across the lines. The electrical bandwidth of the standard on which the physical layer relies allows a 250 kbps data transmission rate with a 500 m cable length. Nevertheless, in the automotive industry, speeds of typically 125 kbps are used for wired networks because of EMI/RFI considerations and poor-quality cables. With advanced technology, e.g., connectors, cables, and driver-integrated circuits, baud rates of 1 Mbps are feasible.To arbitrate between simultaneously transmitted messages, the medium access control sublayer synchronizes transmission time slots, allocates these slots to different driver requests (all complemented with an ID number) and guarantees that collisions are detected. When it comes to implementing the CAN functionality, microcontrollers typically feature a CAN controller with integrated Message Buffer Memory (MBM) to ease the process.The standard ISO 11898-1 chapter 11 outlines the characteristics of the protocol (for example, arbitration, framing) built on this MAC sublayer, the process of segmentation, reassembly, error detection, signaling and handling, and many performance measures. These features come together with frame format description and well-defined time frames, while a protocol controller specification and behavior complete the standard.The message comes with the architecture of the protocol stack, which belongs to the application layer and is installed on different software drivers. The CAN protocol then handles application calls, invoking the lower-level service primitives.

2.3. Advantages and Challenges

The significant advantages of the recent CAN-cloud integration are that it substantially improves vehicle diagnostics capabilities, and enables large-scale vehicle health data analytics by advanced artificial intelligence models for intelligent transportation systems. Such an integration is a significant step for robust and scalable smart and autonomous vehicles. The CAN requires the physical security and privacy of the confidential data that it is transferring. All vehicle sensor data is inherently security-sensitive. But adding a cloud to a vehicle CAN worsen the situation by exposing the private data (at least part of it) to a distant server, and by making the data vulnerable to remote adversaries.The Controller Area Network (CAN) is a robust serial communication bus standard commonly used in vehicle and mobile embedded systems. The main CAN security and privacy methods focus on the lower layers to protect the integrity and confidentiality of the communication data. Probing any other vehicle signal may also reveal something about the current trip. Consequently, one major data security and privacy function of a future vehicle cloud system is to hide/reduce the leakage of secret data. Furthermore, even a vehicle itself may send private CAN messages to protect itself from passive attacks. Every vehicle potentially has confidential (such as revving the engine and spinning the wheels) and location-based data. Combining this data with information from the CAN Cloud will provide a rich detailed trip dataset that will help establish confidential information. Digitally portraying the route that a vehicle takes by geocoding every GPS coordinate into a trip-on-road segment can increase privacy.

3. Cloud-Based Data Storage Solutions

The data generated by the different electrical control units onboard Commercial Off Shelf (COTS) vehicles is both fast and large. Since the internal onboard vehicle network (the CAN network in our case) cannot provide Internet access, offloading the onboard vehicle data (both streaming data and archival data) to the Cloud is a big challenge.With the recent advancements in the field of Big Data and Data Science, cloud-based data storage architectures have now become a great practical way to achieve off-board storage and large-scale vehicle data processing. A simple map structure that links the real-time vehicle data with the Cloud is established using the V-Cloud aggregator. Through the Map Data structure, the real-time data arrival and arrival status are exposed. The data is formatted specially so that it can be sent to the Cloud Platform through a communication channel.In V-Cloud, the cloud-based storage tier is built on top of the data storage solutions of each OEM's big data architecture and contains all data and services needed for vehicle diagnostics, real-time fleet management, and vehicle HMI. Auto manufacturers with traditional Big Data architectures often need to modify back-end storage layers to work with centralized vehicle networks, which is time-consuming and expensive. With cloud-based storage solutions such as Hyper File Cloud or Google Cloud Engine, these problems are solved.First of all, the cloud is light, and the vehicle network does not need to have advanced database management capabilities, such as reasonably expensive storage products. The data link to the cloud can guarantee the supervision of the data management boundary and prevent unauthorized access. It is also easier for collaborators who share data resources with auto manufacturers to access data regardless of their specific back-end storage systems.The release of CLA (Cloud Library API) is a notable milestone on V-Cloud to prove the architectural flexibility of integrating auto vehicle data with off-board cloud storage. The main reason is that, in the short term, the communication or dispatcher software can provide instructions and converge on the right path to deliver real-time data. CLA is based on the V-Cloud Speed Demon (V-Cloud SD) framework. It inherits a simple GPS equipment that realizes the start and end of the queue. SD provides a complete multi-layered end-to-end, professionally managed wireless data-offloading construction stack.CLA is used for integrating vehicle data with Global Model Vehicle Telemetry. It is easy to make sensory data readily available to relevant stakeholders (such as insurers, third-party fleet operators, etc.) and gives them an important competitive advantage. For a $30 bundle (minimum prepaid data if you are running in the U.S., it is $250 when outside the U.S.), the user can easily access their real-time vehicular data.

3.1.Importance in Automotive Industry

The importance of integrating Controller Area Network (CAN) with cloud-based data storage solutions for improved vehicle diagnostics using AI created a significant need as it addresses the best possible way to use vehicle-generated CAN communication messages. Extracting, filtering, storing, and utilizing the data for further processing and analysis with the use of Artificial Intelligence in wireless protocols and their differences are well documented. However, the importance, benefits, PHP functionalities, and capabilities of using cloud-based data storage and managing for performing diagnostics on logged CAN messages, especially in an automotive context, have not been widely investigated. For example, IoT and Big Data were used to process automobile traffic flow, energy consumption, and vehicle repair and replacement prediction; extract traffic accident information; study and formulate decision tree models at uncontrolled intersections; and create the systems of vehicle fault prediction and repair and so on.As a result, performing advanced analytics, database management, and instrument cluster designs utilizing cloud-based storage solutions such as Amazon Web Service, Microsoft Azure, Google Cloud, and IBM Watson IoT realize the benefit of embedding CAN communication functions inside the vehicle. As a result, it becomes a great accomplishment regardless of the vehicle's make and model. Besides, many vehicle makes and models make use of multiple microcontrollers connected by a general-purpose serial communication-based protocol which can be part of the CAN bus. The CAN protocol is utilized to establish vision, radar, and sensor networks within the vehicle and to transmit sensor and vehicle state messages between microcontrollers. These systems play important roles in the operations of autonomous systems such as advanced driver support systems, semi-autonomous operation systems, and advanced assistance systems on the vehicle, environment, and vehicle-sharing services. For this reason, it is expedient to connect the CAN bus to an automotive gateway using a segmented topology where the external network is IPv4 and establish routers, NATs, and firewalls.

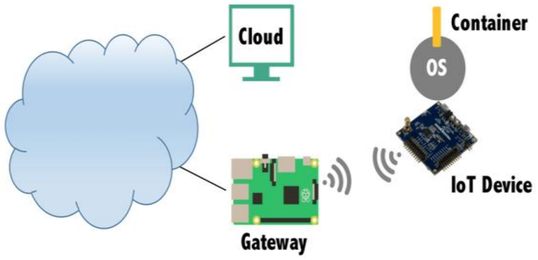

Fig 4: Gateway connecting cloud diagram

3.2.Types of Cloud-Based Solutions

For vehicle diagnostic applications, there are several data storage solutions available that integrate cloud-based services. These assist on-premise diagnostic tools in the analysis of more complex and voluminous data, and they may also provide additional layers of security to safeguard sensitive vehicle-related data. One distinctive feature of cloud-based diagnostic tools is that they are designed to update information in real-time. Sharing the diagnostic data with the vehicle owner, automotive service centers, technical departments, and other stakeholders is also simplified. The known types of software solutions helping to integrate the CAN interface with a variety of cloud-based storage tools and their key features are discussed in this section. Some of the tools are hardware-based, and others are software-based. They vary in the different stages of the data they help to collect, process, and analyze and also the uses they serve. These are summarized in Table 1, along with their source URLs and associated types of subscription plans. To ensure better compatibility with newer applications, we have included all of the solutions created by companies that have earned GitHub badges as verified contributors.The primary targets of these diagnostic solutions are automotive fleet management and other telematics applications, but some of their features are also helpful in general vehicle diagnostics. Some of the data stored in the vehicle after diagnosis may include information related to diagnostic trouble codes (DTCs), pending fault codes, monitor status, fuel system status, calculated fuel used, and engine load. The diagnostic reports may also capture instantaneous fuel economy, distance traveled while MIL is activated, stored freeze frames, freeze frame data, fuel pressure levels, and the vehicle-to-wheel-based speed ratio. These smart solutions may also help to save costs on unnecessary mechanic visits. According to the National Research Council (NRC) 2007, the diagnostic capabilities of some software tools are limited. These require regular updates, and this, in turn, requires that these updates should be possible to access quickly and cost-effectively. Ensuring that the customers maintain their off-lease or out-of-warranty vehicles under the manufacturer's programs is considered crucial in this study. This is because the manufacturer can reduce warranty costs. They may do this by reducing the time taken to diagnose and repair the out-of-warranty vehicles; from the owner's perspective, it also leads to reduced time and costs of vehicle repairs.

.3.3.Security and Privacy Considerations

The growing list of essential services provided by connected vehicles and the associated software systems makes cybersecurity a crucial element. Consequently, it is essential to integrate robust security technology into the architecture of cloud-based vehicle platforms. Although encryption is the standard approach used to secure stored at-rest or in-transit data, security is no longer guaranteed if an untrusted entity can execute arbitrary read and write commands over CAN. Equally important is the ability to embed security mechanisms within the CAN bus itself to authenticate or secure the transmission of vehicle data, particularly if the payload is destined for the cloud.Using redactable or searchable encryption would enable the remote server administrator to still perform diagnostic or data processing functions on the encrypted data. This feature alone of a secure cloud storage system remains an open and interesting privacy-enabling investigative question. The main role of the cloud server is to manage the encryption and decryption keys. These keys could be blacklisted by some remote key management service should they be extracted from a compromised vehicle. While running on the cloud, the server is engaged in an authorization policy revision and/or encryption and decryption key management on two dimensions. First, the policies could be revoked, modified, or renewed, and every cloud service provider operation will need to be associated with an active policy. Measures exist that disconnect a link between a breached surface and all other segments. Another approach for cloud server management is a system image integrity check and tamper-proofing that is critical and demands robust system design principles to preserve the integrity, confidentiality, and security of vehicle diagnostics. Ensuring data integrity is more critical for over-the-air software updates.

4.Integration of CAN with Cloud-Based Data Storage

Developments in cloud technology are helping to make data storage cheap, while the expanding capabilities of Artificial Intelligence (AI) are improving diagnostic accuracy. The advantages have prompted research to support the use of cloud technology in connection with onboard data sources for Intelligent Transportation Systems (ITS). Integration of cloud technology with data platforms, including big data and available APIs, together with efficient access to this platform from vehicles, is a key requirement that should be fulfilled to achieve success. The emergence of Ethernet with high technology advances has enabled the use of cloud storage services for many broadband-based systems. However, the high system cost makes these systems infeasible for commercial vehicles.However, a majority of the vehicles still rely on CAN as the onboard data networking protocol to handle the transmitting-receiving of electrical signals among the ECUs. The deficient bandwidth and low design flexibility make the use of cloud technology not practical for traditional CAN architecture. To address these discrepancies, we propose a Software-Defined Controller Area Network (SD-CAN) framework integrated with The Gateway Control Module (GCM). In this innovative framework, FlexCAN, as a hardware controller, provides a transceiver to transmit determined messages to the GCM so that the vehicle data is allowed to travel securely to the cloud through an industrial LTE communication module. Having the SD-CAN framework deployed, we can further provide algorithm guidelines for exploiting overcloud vehicle data application services. The developed CAN-cloud flexible integration model can then integrate vehicle data in the cloud for online machine learning through the data processing tool. The contributions of this paper are twofold as follows: (1) the extended application of the SD-CAN for the cloud reservoir purposes, enabling fine-grained applications requiring different data granularities from real-time CAN-bus limits; (2) A novel overcloud concept is proposed to utilize the SD-CAN exchange data for the benefit of vehicle AI analytics. We demonstrate with a series of on-road vehicle experiments, the SD-CAN framework response in the following scenarios.

4.1. Benefits of Integration

Collaboration and information flow. By connecting subscriber devices to centralized, cascading information exchange hubs, cloud data storage solutions provide an environment that is conducive to collaboration. This "many-to-all" communication model, provided on high-performance servers, gives optimal information exchange in which all subscribed clients can communicate their measurement data as a single source to the AI algorithms. Up to now, such interaction was only possible in very complex and logically symmetrical two-input networks with application-specific customer data. Additionally, HVAC can only share and receive data from several input sources through a single channel. This arrangement further stresses the processing of quality information that does not compromise the performance of the system.Speed and distance. While some data center storage solutions communicate with each subscriber over the internet, others are organized within a single complex, discrete, proprietary, widespread, and high-speed local area network.Large data storage engines connect various subscriber databases, servicing and transporting angular, linear, and translational position sensors, sound level monitors, earth-to-hingle heat sensors, and general telecommunications connections. Directional properties - meaning input signal connections, data communication and conditioning, and MAC data mangling - are within typically narrow sectors. Like gateway devices and universal digital media dictionaries, all of these sensors utilize cost-effective receiver ASICs to form application-specific deep packet interfaces for their subscriber data. Control of this real-time data is further managed within a customizable interlock capability, service and service request arbitration, and a core set of buffering capabilities that are aligned to be tailored to ensure integrity and correctness in reconversion.Indeed, high-speed switches and amplifiers are developed with selective data media redirection to keep data channel access open, infrastructure performance high, and unidirectional capacities low. Here, the cloud delivers application-specific "canopies" of two-tiered choices: a very wide area network datacenter with state-of-the-art photonic, electrical, optical, and gigabit speed network to server storage connections; centralized backbone switches that combine servers into decentralized hubs; dense distribution points that provide control over event transfers and pertinent signal communication points; and network data transmission capable of passing both voice chips and sophisticated session-enable hubs. With few exceptions, music media access techniques and related memory storage methods deliver unique content bias, speeds, communication patterns, and scalable structures. Caching and mediations, as well as data-centric capabilities, drive heterogeneous databases with interrelated resources and added diverse profiles.Scalability and priorities. Signal data handling mode efficiency threatens to put the stem capacity of the data center storage facility into the cold and empty echo arena in which engineers consider four or five successive bus cycles as the length of a full-fidelity control store.

4.2. Technical Challenges and Solutions

Existing cloud storage solutions, such as Dropbox, Google Drive, and AWS S3, do not have built-in support for CAN data collection or analysis. The onboard computer of the vehicle, i.e., the Electronic Control Unit (ECU), or any additional piece of hardware required to interface with the CAN bus to collect CAN data, also requires some local storage. Data collected from the vehicle is typically stored on the onboard computer on an SD card or similar high-capacity storage solution. Data stored on this local storage presents a technical challenge; it must be pushed to a cloud storage solution and processed.

No cloud storage solutions have a built-in mechanism for handling CAN data, and very few file synchronization applications or cloud storage tools can push an indefinite number of files to cloud storage and sync indefinitely. Tools are currently available that can transfer and synchronize a limited number of files. To solve the CAN data collection and data analysis problem, an appropriate communication protocol through APIs is needed to allow the management of the CAN data over the cloud.

Thus, there is a technical necessity for software and hardware solutions to develop a mechanism to upload data to the cloud.The software and hardware can be easily interfaced with the car's ECU. At the user's request, the car ECU will collect the CAN data and store it in an unreadable format using the Embedded File System (EFS), which is a file manager for users to access file systems on the local storage onboard computer. It uses the CPU and flash storage on the hardware module to work with data. The EFS stores the data with HTTP or some other communication protocol and pushes the stored data to a cloud platform. In case cloud storage is required, it uses cloud computing techniques to automatically cycle the data to other machines on the internet.

The EFS can monitor the cloud storage and keep a tally of how much space the user has used on the cloud, alerting when the amount nears its limit, and ensuring data is properly backed up. The EFS remains as an interface between the hardware and Internet data gateway modules with virtual control by the user.

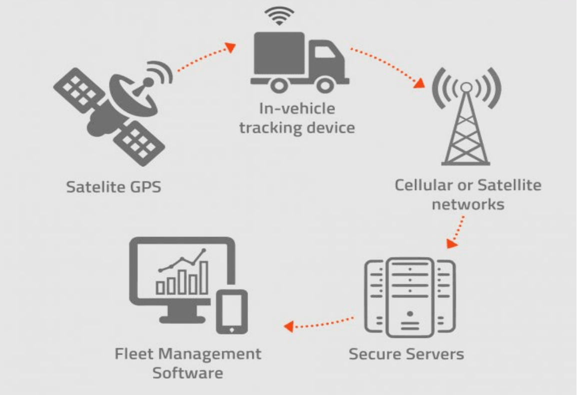

Fig 5: Typical fleet telematics setup

4. Artificial Intelligence in Vehicle Diagnostics

As an advanced field of computer science, AI includes both machine learning (ML) and deep learning (DL). ML is a current gold standard in AI, as it uses proven tools to enable computers to learn from data so that decisions can be made without the need for explicit programming. In the automotive and transportation industries, AI/ML is currently being used for applications ranging from vehicle safety and autonomy to vehicle health management (VHM). Specifically, AI/ML is being used for traffic modeling, predictive diagnostics, predictive maintenance, predictive energy management, driver pattern recognition, real-time data-driven traffic sign recognition, Internet of Things (IoT) connectivity, connectivity through a variety of wireless communication formats, and more. There are various AI and ML methods and tools that can be applied in automotive and transportation applications. Model-based AI is based on deterministic logic, i.e., rules and algorithms, and pattern recognition AI is based on probabilistic logic, i.e., associations and statistical analysis. From supervised to unsupervised learning to recognition that needs manually labeled datasets, and white-, gray-, and black-box systems, it is recognized that every model has limitations. That being said, supervised learning is currently known to be the most accurate method for solving complex problems, while unsupervised learning is good for clustering problems. In particular, ensemble learning has been extended to stacked generalization. What is map_reduce programming, for example, is used in Apache Hadoop, which is an open-source software framework for distributed storage and the use of large data sets across clustered servers. Instead, Apache Spark is an open-source general-purpose cluster computing system. As deep networks, the family of neural networks is considered to have multiple hidden layers. Deep networks are trained with a large labeled dataset. Specifically, deep learning is a kind of machine learning that has networks capable of understanding patterns that exist in streaming data. Fundamentally, deep learning uses a simulated brain that operates like a complex version of the human brain.

5.1.AI Techniques for Diagnostics

There are a plethora of AI techniques available for dialogue management, and many of these would be very suitable for handling the flow of information in an advanced Automotive Diagnostic Support System (ADSS). A selection of AI techniques that are suitable for use in an ADSS are classification, planning, and reasoning. A simplified version of the mobile robotics classification framework may be used to select the best strategy from the pool of possible solutions for diagnosing and troubleshooting (maintenance) problems in the vehicle subsystems. Planning techniques are used to adapt the standard diagnostic and troubleshooting tasks to account for the inconsistency of input information and to emulate the interactive troubleshooting process during real maintenance tasks in the ADSS. Techniques of epistemic logic and commonsense reasoning, such as unification, and working with incomplete and uncertain information, are used for generating and reasoning about possible troubleshooting hypotheses and to account also for the user's preferences to guide him/her throughout the troubleshooting process.

5.2.Applications in Automotive Industry

Integrating Controller Area Network (CAN) with cloud-based data storage solutions for improved vehicle diagnostics using AI.

A network of distributed computers interconnected by communications and control devices, such as a transportation system (i.e., a bus, a railway system, or the streets of a city) connected by traffic lights regulating the mobility of vehicles and pedestrians, and the various electronic control units (ECUs) present in modern vehicles interconnected using wired connections (often presented using a bus concept) are good examples of distributed intelligence applications. The scheme has today a robust kernel constituted by ECUs distributed by the vehicle connected using a Controller Area Network (CAN) as specified by ISO 11898. Most modern automotive vehicles count on several ECUs, being that some of which take care of logistics related to passenger comfort and others related to driving assistance, constituting Group Sense and Act Orchestration acting on four areas: Diagnostic, Drive, Environmental Control, and Comfort, each one demanding access to a large information foundation to work coherently.Recently, the operation of a cloud computing data repository has also been adopted for automotive applications. Uninterrupted growth of the capability of these solutions has been increasing over the years with possibilities to support more specific telematic services, i.e., supplementary diagnosis and/or management of the main activity of automotive vehicles. This chapter aims to demonstrate the evolution of the support embedded in ECUs from a few years ago to the present and the potential derived from an association with a cloud-based data store software package to improve vehicular diagnosis through the intensive use of artificial intelligence techniques, from Knowledge Discovery and Data Mining to predictive and semantic analysis including visual dimensioning.

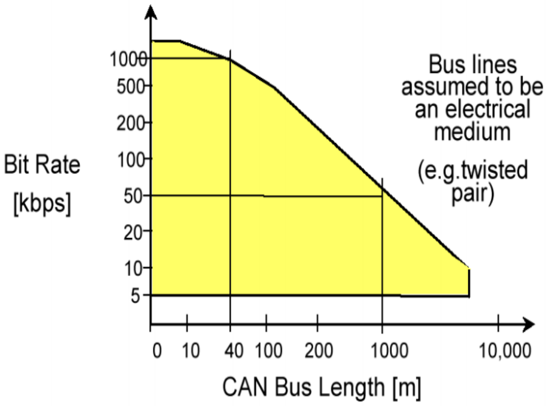

Fig 5: Bit Rate Transmission Distances

5. Case and Studies

There are patents in the domain that integrate data collectors with a cloud system to store data. However, as of now, none of the patents available in the domain utilize the controller area network data from the sensors of a vehicle, or from an ECU, specifically to store data in a cloud-based storage system. Furthermore, none of the available patents utilize artificial intelligence mechanisms that can point out specific key data areas or provide references to the accurate data to provide a diagnostic application together with the cloud storage solution. It is necessary to have a prototype of an end-to-end system with the capabilities to store the data in a cloud system and perform diagnostics on it based on the data stored in it. This system will handle vehicle data, such as controlled area network (CAN), from various types of sensors. Based on the behavior of the data, a faulty sensor on the vehicle or a faulty controller area network is reported.The prototype should be designed and have the flexibility to read vehicle data, post that data to the cloud system and write INSITE-type software applications that are used for diagnostics. Researchers working on these types of systems designed REST-based API calls which allow for a single point of contact to validate all public methods. The prototype is designed to post the collected data from the controller area network or the ECU sensors to the cloud system. Researchers also worked on methods for posting entity data to the cloud, retrieving entity data from the cloud, deleting entity data from the cloud, and retrieving collections of entity data. With the vehicle data being posted to the cloud system, there should be an ability to run diagnostics on it. INSITE software allows running diagnostics on engine data. The prototype should read vehicle CAN data, convert it to J1939 data, and upload the J1939 data to the cloud system for storage. The vehicle data is collected for each vehicle and the timestamp of the vehicle data when that data was collected is uploaded to the cloud system. The vehicle team at a dealership can access the vehicle data at the time of each fault code. The vehicle team can access the vehicle data at the time of the event to determine the root cause of the issue. With the vehicle data being posted to the cloud system, there should be an ability to run diagnostics on it.Researchers wrote a cloud-based application that would allow querying the vehicle data. For instance, a user of the application did a fault code lookup and it returned the vehicle data on the day that the fault code appeared. The vehicle data detected a threshold warning of the data being over 100. The vehicle data also provides Vehicle Identification Numbers (VINs) whose data are over 100 for check engine events. This application may be further developed to query any vehicle parameters to perform precise monitoring.

6.1. Real-world Implementations

The following presents a variety of designs from the literature, which implement external database services for vehicle CAN bus-enabled solutions. The basis of each design is the statement of service for data streaming, real-time storage, SQL retrieval and/or cloud storage, and operations using an external database. Each design focused on different objectives and aspects of state-of-the-art challenges and requirements. Here we discuss the most recent and significant real-world implementations dealing with vehicular data from different vehicle components. We summarize the coding languages, listed from the most used to the least used in the following CRANtastic environment, specific purposes, the external database used, and several concluding remarks.Implementations dealt with separate vehicle components in which CAN message monitoring was handled separately in a distributed manner. Many communication ways were used but mainly Wi-Fi, timestamped data, and external database push and pull technologies. DriveRecorder was used as a tool for data acquisition of LTC (Learn to Control) messages which were stored in a database. The database was updated and recorded every tenth of a second, recording the sensor's values as part of the CAN messages. JSON data structures were produced which were later stored in a separate database. The information from each CAN message was batch-processed and pushed to the cloud using OPEN DATA solutions, part of Alibaba Cloud. The presented work was data-specific, handling only 3 parameters, namely, recording the two driving motors' torques and one of the two wheels. Both the hardware and software had proven DR to be a quite useful tool for extracting CAN traffic. The real-world implementation indicates that this technique should expand to the broader CAN traffic and deal mostly with big data.

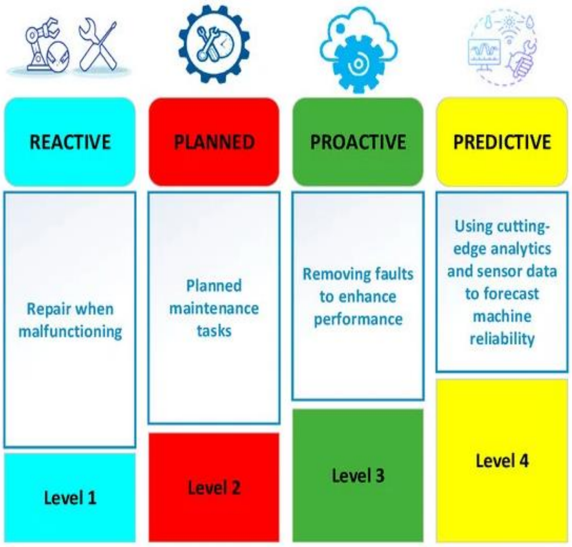

Fig 6:Diverse levels of system maintenance

6.2.Results and Performance Metrics

With the parameters optimized and trained, several deep-learning models were used to analyze both raw async and sync frames from the CAN network. The results are shown in Table 2, where it is clear that greater accuracy (as determined using precision) was achieved for synchronizations. Training is done to identify the sync frames more accurately as they carry the most valuable information of a message in a CAN bus network. Further, three other performance metrics, which are true positive rate, false positive rate, and training and validation loss, were plotted and analyzed to provide insights regarding the performance of the models. From the ROC curve plot for the best model, YOLO (You Only Look Once) yet, as shown in Figure 4, the AUC (area under the curve) was also calculated and it was observed that YOLO (You Only Look Once) resulted in the greatest accuracy, followed by Faster-, Retina-, and SSD-net.To examine the best overall model, which was selected according to training performance, 4 datasets were created with different balance preservation methods. It was observed that the best model resulted in the least false positives, the highest percentage recall, and the greatest precision for Dataset 2, the unbalanced, which had the largest number of only async frames. This shows that the three most challenging performance metrics, which are true positive rate, false positive rate, and accuracy, could be used to fine-tune a selected model to obtain the greatest accuracy. With this, the user could consider applying deep learning models on the final dataset, Dataset 2, to carry out finer-grained analyses that could be applied as part of smarter vehicle technologies to accurately identify vehicle malfunctions.

6. Future Directions and Emerging Trends

Numerous future directions could potentially further improve the impact of using cloud-based data storage solutions with CAN for vehicle diagnostics. Just as there have been parallel efforts waged in the fields of cyber and physical security, linking these advances with cloud-based solutions and CAN could greatly enhance vehicle safety, reliability, and comfort. Assembling onboard data with probe vehicle data could obtain statistical data from which more accurate models could be generated. There is also ongoing research using real-time analytics to predict potential fault conditions. CAN is ideally suited to offload some of the most time-consuming processing from such systems given that the data is already being aggregated and parsed at the time of generation. Emerging trends include migration to the cloud for at least some engine control firmware or software that could relieve the extra processing necessity of injecting the fault states post-data storage. Advances in local 5G could also open the door to faster-than-local processing and further reduce the latency for fault generation that we presented here. These trends are to be exploited and implemented by very large publicly traded fleets. These firms will embrace these analytics and demand increased resolution cloud storage to optimize the value of their investments. Current trends in urban mobility aim for a more equitable, faster, and cleaner movement of people and goods. At the same time, increasing vehicular density in small areas has caused problems, such as congestion, noise, and pollution, with major costs for human health, the economy, and the environment of urban areas. Therefore, the long-term impact of this work is a vehicle diagnostics enhancement that will ease congestion while providing benefits both today and in the future by offering a cleaner and more efficient urban environment.

7. Conclusion and Recommendations

In this work, we have demonstrated the concept of a transparent interface developed for CAN signals, which when integrated with a cloud, can allow automotive companies the ability to monitor and analyze the fault codes generated in vehicles during their lifecycle. The transparent interface efficiently allows automotive engineers (or mechanics) to enable the diagnostic threshold for the vehicles during their R&D. This interface simultaneously can be used to transfer relevant information to the cloud which can in turn feed a supervised machine-learning algorithm in the Cloud. Such an algorithm with relevant vehicle information can be extremely efficient and can score new vehicle-generated fault codes efficiently. Therefore, vehicle's Over the Air (OTA) protocols can use the score for updating the vehicle's Electronic Control Unit (ECU) settings. Such settings could result in a better performance of the vehicle without interacting with the dealers or the driver. It could also be used for predictive maintenance by scheduling the next service appointment.Overall, it could allow companies to enrich future models by tracing back the data signals at the time of fault occurrence and by updating the algorithms within the ECUs to make necessary changes for ensuring better products that pass the tests with lesser chances of false positives after the product launch. In the proposed architecture, we advocate the data generated and stored is linked to the vehicle identification number. This unique vehicle identification through the ECU associations allows the expert engineer to further go back and look at the data signals close to the faulty event. Often, diagnosis, causing an event and actual evidence are three different timestamps. The ability to correlate all these together can significantly enhance and enable companies to develop better products.

8. Conclusion

In a relatively short amount of time, many of the systems included in vehicles have gone from nearly completely isolated systems to very connected and fascinating networks of systems. Such connectivity has led to the opportunity for not just more efficient vehicles, but in some cases, completely new products and services made possible by essentially these vehicle systems. Moreover, many firms are changing from being product-focused firms to product-offering-based firms. While the future outlined in this paper provides some exciting possibilities for many organizations, it also suggests that some complexity will be added by having to be more aware not just of the artifacts produced by the engineering process, but also of the performance of such artifacts in the field.In conclusion, this paper outlines a novel framework for expanding existing Vehicle Cloud services for vehicle diagnostics of loss of internal data communications targeting the potential uses for the extensive information available from CAN data. However, still, much work needs to be done based on the presented work. First, validation can be done only on a few real-world vehicle data and integrating vehicle data storage on a cloud-based platform, however, its performance analysis can be done only on a simulated environment. Data privacy issues need to be solved for any application. Secondly, the end-to-end architecture of the Vehicle Cloud should be scalable enough to handle the exponential increase in data. Thirdly, end-users must be educated on using the data to the fullest for vehicle diagnostics independent of the vehicle manufacturer. This third point echoes a common problem of data analysis projects. Even simple data analysis projects require that the end-users of the results are well educated on not only how to obtain and interpret the results.

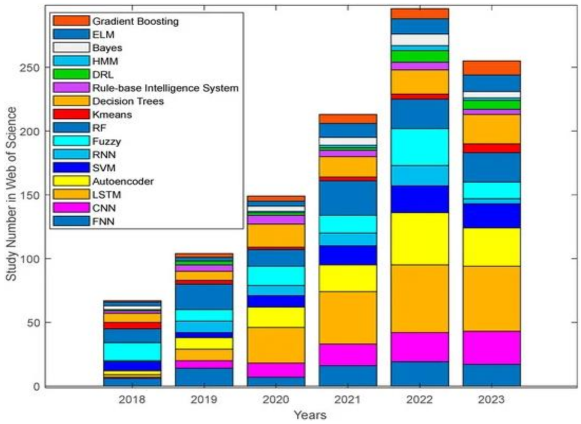

Fig 7: The number of AI methods in Web

9.1 Future Trends

The automotive industry is dynamic and continuously evolving to newer standards and requirements. With the continuous growth and increase of on-board vehicle systems, the demands and relevancies of future vehicles in terms of seamless communications, flexibility and reconfigurability, and energy and environmental considerations are also being impacted significantly. Accordingly, paradigm shifts are happening in automotive electronic systems and are leading to emerging next-generation automotive electronic technological trends. Hence, the automotive industry needs to track these trends early so that they can capitalize on the strengths of each draw synergies to enhance value sourcing, and finally secure a competitive advantage in the marketplace.

It is noticed that, apart from technical development, automotive business models are also evolving rapidly. These business models have witnessed a transformation from a product-centric approach to solutions-centric and services-centric approaches. This has been made possible by the changes vehicles have experienced from isolated mechanisms to interconnected computing platforms. Hence, in the smart connected world of modern automotive vehicles, automotive companies are embracing technologies and software platforms in smart ecosystems such as SensorFleet, which incorporate AI, IoT, and Big Data, to be the forerunners.

The emerging trends in electronic systems relate to the increasing primary requirement to be environmentally friendly, reconfigurable, and self-healing, with dependable and secure systems. Also, the shift from domain-centered 'vertical' stacks to virtualized horizontal layered platform types following technically standard rules as per the Automotive Software Architecture (AUTOSAR) standards and virtualization standards with strict safety domains, e.g. ISO26262, need to be considered. Furthermore, the advent of new networks for the future is opening up new deployment scenarios. The targeted automotive networks move from fault tolerance to fault avoidance in data streaming, making ad-hoc wireless deployment practical. Major research is ongoing to exploit the possibilities of edge computing, which implies moving the task parallelism to the vehicle edge, which may be essential for validating a dedicated vehicle motion application.

Consequently, low-level programming abstractions for secure and dependable computation have become the latest interest in leading OS platforms. The data-streaming nature of the future is also interesting for real-time analysis of driving population's behavior in city intelligence—a recently promising approach—and an under-considered source of reliability estimates and dependence. Practical random access via and timely side effects of vehicle firmware updates while driving will further increase the roots of trust and confidence in modern vehicles and hence make AI smarter.

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