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Artificially Intelligent Self-Driving Vehicle Technologies, Benefits and Challenges

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***Abstract*— Because of the availability of ubiquitous, convenient and an on-demand network access to a shared pool of configurable computing resources, the integration of Internet of Things (IoT) and Artificial Intelligence (AI) in different areas of our daily activities is becoming inevitable. AI is revolutionizing healthcare, transportation, education, industry and other aspects of our lives. This paper focuses on the transportation sector particularly on autonomous or self-driving vehicles (AV). It covers application areas of AI, technologies and infrastructures used by AV, Private Companies which are in the race of AV development and their achievement through time, Benefits of AV, Challenges of AV and Mitigating the Challenges of AV.**

***Key words*—Artificial Intelligence, Autonomous Vehicles, Autonomous Cars, Self-Driving Vehicles, Self-Driving Cars, Cybersecurity, Internet of Things, IoT, NVidia, NXP, AI, AV,**

I. INTRODUCTION

The availability of ubiquitous, convenient and an on-demand network access to a shared pool of configurable computing resources [1], the growth of storage capacity and a decrease in the cost level, as well as the simplicity of data transfer via the internet, have promoted the use of affordable sensors and became a base for the rise of Internet of Things (IoT) and for Artificial Intelligence to be researched in different fields of specialization.

Numerous computer scientists have defined Artificial Intelligence in their own understanding. Before we define AI, it is important to first define intelligence. Intelligence is defined differently from the perspective of different professions. But it can be described as a general mental ability for reasoning, that involves the ability to reason, plan, solve complex problems, think abstractly, comprehend comple x ideas, learn quickly, learn from experience, which reflects a broader and deeper capability for comprehending ou r surroundings "catching on," "making sense"of things or "figuring out" what to do on differ ent situations based on prior knowledge and experiences [2, 3].

Researchers and practitioners from different field of studies such as mathematics, psychology, engineering, economics, and political science began to discuss the possibility of creating an artificial brain in the 1940s and 50s, as a result the field of artificial intelligence research was founded as an academic discipline in 1956[4]. At present, AI is the branch of computer science that refers to a set of computer science techniques that enable systems to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, language translation, and decision making using machine learning and deep learning based on algorithms and powerful data analysis capability that enables computers to learn and adapt independently [5].

In AI, there are three basic things that enables it to function, these are:

a) Ability to interact with the real world to perceive, understand, and act [6].

b) Reasoning and planning to observe the inputs and plan for action based on what the system believes about its environment, as opposed to just what the system has explicitly represented [7].

c) Learning and adaptation, to produces changes within the system so that it performs more effectively within its environment and making adjustments in order to be more attuned to its environment over a period of time [8].

AI is revolutionizing transportation, healthcare, education, public safety and security, industry, and other aspects of our daily life [9]. AI and robotics will also be beneficial for the industries struggling to attract younger workers, such as agriculture, food processing, factories and fulfillment centers [10].

The impact of AI and robotics is expected to grow in the coming years, and it will take over tasks that are now performed only by people [11]. AI may also be the cause of possibilities to create more destructive military systems and more advanced criminal activities that endanger the society [12].

II. APPLICATION AREAS OF AI

Although there are different instances of AI, its research and practice share common technologies, such as machine and deep learning, which vary considerably in the sectors of the economy and society, among many few are transportation, healthcare, education, energy, public safety and security, employment and workplace, and entertainment[13]. This paper focuses on transportation.

Transportation

Transportation researchers and practitioners are encouraged to meet the goals of providing safe, efficient, and reliable transportation while minimizing the impact on the environment and communities such as pollution and greenhouse gases emission increased interest among them, to explore the feasibility of applying AI paradigms to address some of the aforementioned goals [14].

Integrating technology using sensors in automobiles started before 2000 for the internal state of the vehicle, such as its speed, acceleration, and wheel position [15]. In 2001, Global Positioning System (GPS) was introduced to personal vehicles with in-car navigation devices which was the largest international market for the GPS, accounted for 34 percent ($3.6 billion) and since then became a fundamental part of the transportation infrastructure[16,17]. GPS assists drivers and also provides information to technology companies and cities administrations about transportation patterns [18].

The adoption of smartphones with GPS technology further increased connectivity and the amount of location data shared by individuals [19]. Current vehicles are also equipped with a wide range of sensors that had a number of functionalities which combined real-time sensing with perception and decision-making such as Airbag Control, Anti-lock Braking Systems, Electronic Stability Control, and Traction Control Systems [20].

As shown in table 1, the integration of sensors and GPS in personal vehicles brought the introduction of automated capabilities into commercial cars gradually since 2003 and this leads to self-driving or autonomous vehicles [21].

Table 1:
Integration of Sensors since 2003

Context	Automated Functionality	Release Date
Parking	Intelligent Parking Assist System	2003
Parking	Summon	2016
Arterial & Highway	Lane departure system	2004
Arterial & Highway	Adaptive cruise control	2005
Highway	Blind spot monitoring	2007
Highway	Lane changing	2015

According to the Society of Automotive Engineers (SAE) J3016-201806 document, motor vehicle driving automation systems that perform part or all of the dynamic driving task (DDT) on a sustained basis are classified into six SAE Levels [22-24].

Level 0 – No Driving Automation

All aspects of the dynamic driving task will be performed by the human driver. All conventional vehicles are categorized under this level.

Level 1 – Driver Assistance

In this level, a driver assistance system will execute either steering or acceleration/deceleration system by using information about the driving environment and with the expectation that the human driver performs all remaining aspects of the dynamic driving task.

Level 2 – Partial Driving Automation

A driver assistance system will execute either steering or acceleration/deceleration system by using information about the driving environment with the expectation that the driver completes the object and event detection and response subtask and supervises the automation system.

Level 3 – Conditional Driving Automation

In this level an automated driving system (ADS) will execute all aspects of the dynamic driving task with the expectation that the human driver will be ready to respond to a request to intervene.

Level 4 – High Driving Automation

In this level an automated driving system (ADS) will execute all aspects of the dynamic driving task even if a human driver does not respond appropriately to a request to intervene.

Level 5 – Full Driving Automation

In this level, sustained and unconditional performance will be done by the ADS of the entire DDT without any expectation that a user will respond to a request to intervene.

As explained above the levels of automation can be categorized into two groups, with the driver performing part or all of the DDT (Levels 0, 1, and 2) and the ADS performing the entire DDT while engaged (Levels 3, 4, and 5).[4]

Self-driving/Autonomous Vehicles

Since the 1930s, science fiction writers dreamed of a future with self-driving cars, but the idea of autonomous vehicles first gained public exposure in the 1939 ‘Futurama’ World’s exhibit fair at New York City sponsored by General Motors, which envisioned "abundant sunshine, fresh air and fine green parkways upon which cars would drive themselves"[25,26]. Starting then researchers are exploring this areas. Research into self-driving technology can be divided into three phases [27]:

1. 1980 – 2003: During this period, University research centers worked on two visions of vehicle automation. The first were automated highways systems where relatively "dumb" vehicles relied on highway infrastructure to guide them and other groups worked on self-driving cars that did not require special roads.
2. 2003 – 2007: The U.S. Defense Advanced Research Projects Agency (DARPA) held three "Grand Challenges" that markedly accelerated advancements in self-driving technology. The first two were held in rural environments, while the third took place in an urban environment. Each of these encouraged University research teams to develop the technology.
3. 2007 onwards: Private companies have advanced the research of AVs, among many few are discussed in section IV.

III. Technologies and Infrastructure

A self-driving vehicle needs to collect information through its equipment and based on that information it executes the decision. Vehicle equipment includes physical and digital infrastructure, any of which may be public or private [28].

Generally the technologies that enable the self-driving vehicles can be categorized as High processing power computers, Sensors and sensor-processing technologies, Software and control systems, High-definition mapping, and Connectivity as shown in fig. 1[29].

High Processing Power Computer (Processors)

The high processing power computer is considered as the AI autonomous brain that performs deep learning, computer vision and parallel computing algorithms [30]. There are many autonomous brains available on the market and under research among these few are:

Tegra Xavier: Is a 64-bit ARM high-performance system on a chip for autonomous machines designed by Nvidia and introduced in 2018. It is incorporated into a number of Nvidia's computers including the Jetson Xavier, Drive Xavier, and the Drive Pegasus. The design targets and architecture started back in Fabricated on TSMC 12 nm process, the chip itself comprises an eight-core CPU cluster, GPU with additional inference optimizations, deep learning accelerator, vision accelerator, and a set of multimedia accelerators providing additional support for machine learning (stereo, LDC, optical flow)[31,32].

Nvidia Drive PX2: Designed by Nvidia with the capability of understanding the environment around the vehicle in real-time, precisely locating itself on high definition map, and planning a safe path. This autonomous brain combines facilities for deep learning, sensor fusion and surrounding vision [32].

The NXP BlueBox: is a development platform series designed by NXP Semiconductors N.V. that provides the required performance, functional safety and automotive reliability for self-driving cars. The latest addition to the series, the BLBX2-xx family, incorporates the S32V234 automotive vision and sensor fusion processor, the LS2084A embedded computer processor and the S32R27 radar microcontroller [33].

Nuvo-6108GC-IGN: It is designed by Neosys Technology to fuel emerging GPU-accelerated applications, such as AI, Virtual Reality(VR), autonomous driving and CUDA

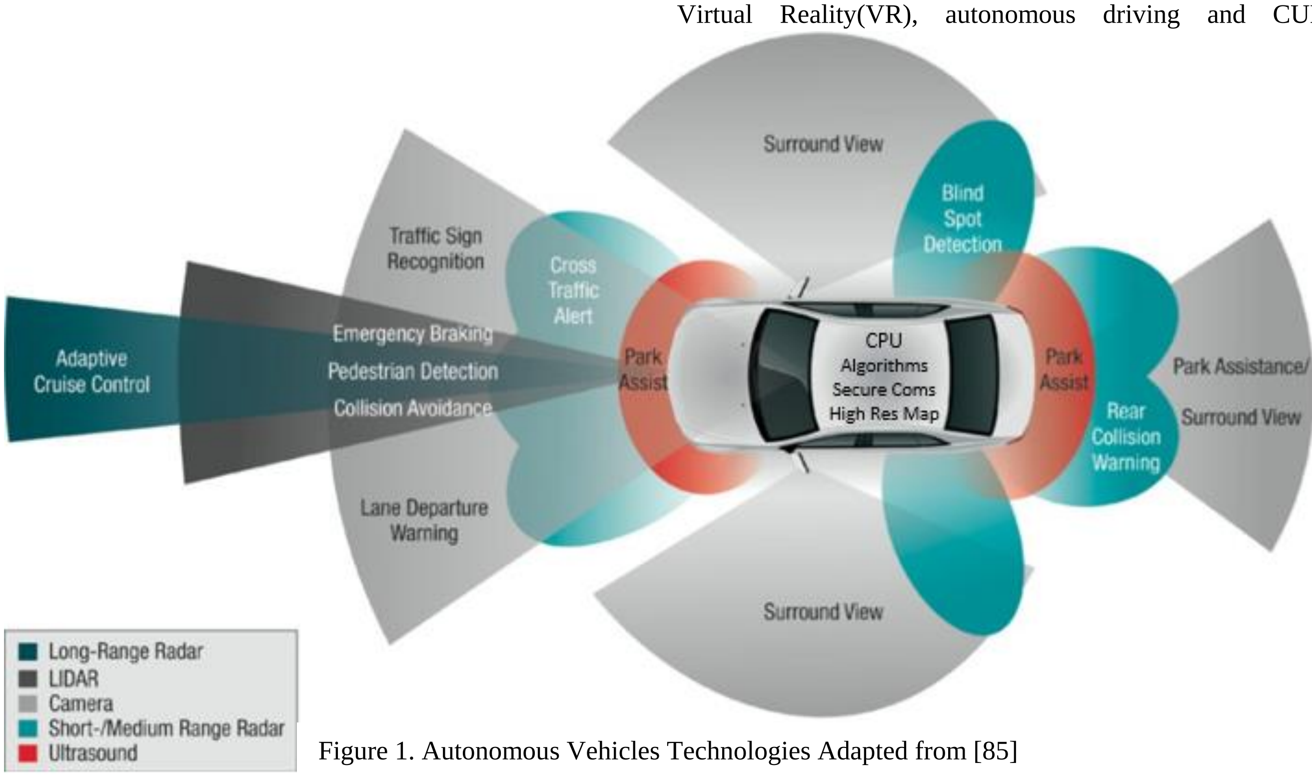

Figure 1. Autonomous Vehicles Technologies Adapted from [85]

computing by accommodating 250W NVIDIA GPU. Nuvo-6108GC-IGN in-vehicle GPU computer supports, Xeon E3 v5 or 6th-Gen Core i7/ i5 CPU with up to 32 GB ECC/ non-ECC DDR4 memory. It incorporates general computer I/O like Gigabit Ethernet, USB3.0, serial port, x16 PCIe port for GPU installation and also x8 PCIe slots to install additional high performance expansion card with high bandwidths for data collections/ analytics and communication [34].

Radar, LiDAR and Ultrasound Technologies

In order for an autonomous vehicle to see things, it relies on multiple electronic sensors. The most popular sensors used include radar, LiDAR, camera and ultrasound to sense the vehicle's surroundings [36].

Radar: This technology has been used for decades to calculate the velocity, range, and angle of objects on land, sea, and in the air particularly for military applications [37]. Now on the road, radar is playing a key role in Advanced Driver Assistance Systems (ADAS) in the self-driving vehicles. It is useful in two ADAS technologies: automatic emergency braking system (AEBS) and adaptive cruise control (ACC). These applications use long-range radar (LRR) systems with ranges of 80 m to 200 m or greater. Current LRR systems operate in the 77 GHz frequency band (76 – 81 GHz). This frequency has several advantages for automotive use, in which the wide bandwidth available improves accuracy and object resolution; with a wavelength of 3.9 mm, the antenna can be small; and atmospheric absorption limits interference with other systems [38].

LiDAR (Light detection And Ranging): It is one of the sensor technologies in self-driving vehicles which provides high-resolution, three-dimensional information about the surrounding environment. It can simultaneously locate the position of people and objects around the vehicle and assess the speed and route at which they are moving. Using that information, an on-board computer system can determine the safest way for a self-driving vehicle to drive to its destination [39].

Ultrasound: It uses much lower frequency sound waves, but above the audible range to sense the surroundings. Though it has much shorter range detection, about 6 meters, it serves as a redundant system to detect nearby vehicles. This is critical when a self-driving car attempts to make a lane change on the freeway. Some cars can use multiple ultrasound sensors to create a 360-degree view as a driving aid in semi-automatic vehicles [40].

IV. PRIVATE COMPANIES AND AUTONOMOUS VEHICLES

Many companies have carried out trials or are engaged in continuous on-road testing of highly automated vehicle prototypes whose capacities are evolving rapidly due to improved sensor-processing technologies, adaptive algorithms, high-definition mapping and in some cases, the deployment of vehicle-to-vehicle and infrastructure-to-vehicle communication technologies[29,30]. Among many few of them will be discussed.

General Motors (GM)

In 2016, GM acquired Cruise Automation, a San Francisco-based start-up focusing on self-driving technology and GM's real-world autonomous car research has extended to another city, with Cruise Automation's self-driving Bolt Electric Vehicles (EV) now tackling the streets of Scottsdale, Arizona. The electric cars, which have been retrofitted with various sensors, laser scanners, and other onboard smarts to replace a human driver, had previously been plying the tarmac in San Francisco, California.

In 2017, GM released its third-generation, which is based on the Chevrolet Bolt EV and equipped with all of the necessary hardware for real-time navigation without relying on a human driver but was not ready for self-drive.

In 2018, GM has revealed its self-driving car, the Cruise AV, which the automaker says is the first production-ready autonomous vehicle. The fourth generation of GM's Cruise AV driverless car, is even more of a departure from what we currently find on the automaker's dealership forecourts. That's because it has no steering wheel and no pedals: indeed, no manual driving controls whatsoever. Instead, most features are controlled by a touchscreen in the center of the dashboard. That's where occupants will be able to interact with the autonomous systems [41-43].

Google

Google initiated its self-driving car project in 2009 and made its project public in 2010.

In 2014, Google unveiled its own reference vehicle, a two-door fully autonomous car. A year later, this prototype made the first ever fully self-driving trip in normal traffic on public roads and logging over 140,000 miles, this is the first in robotics research at the time.

In 2016, Google's self-driving car program became Waymo, a stand-alone company operating alongside Google and other technology companies under the umbrella of Alphabet Inc. Till 2018, Waymo's fleet of self-driving vehicles has logged over 8 million miles in autonomous mode on public roads and in 2016 alone, Waymo's systems logged over a billion miles of simulated driving, a feat made possible by Waymo's in-house simulator and the power of Google's massive data centers [44-49].

TESLA

In October 2014, Tesla Motors announced its first version of AutoPilot on Model S. Its system is capable of lane control with autonomous steering, braking and speed limit adjustment based on signals and image processing. The system provided autonomous parking and was able to receive software updates to improve skills over time.

In March 2015, Tesla Motors released its autopilot technology through a software update for the cars equipped with the systems that allow autonomous driving and has been testing the autopilot system on the highway between San Francisco and Seattle with a driver but letting the car to drive almost unassisted. In mid-October 2015, Tesla Motors released version 7 of their software in the U.S. that included Autopilot capability.

On January 9, 2016, Tesla introduced version 7.1 as an over-the-air update, adding a new "summon" feature that allows cars to self-park at parking locations without the driver in the car.

In September 2016, Tesla updated its software to version 8.0, bringing with it the most "significant over-the-air overhaul of the Tesla touchscreen and introduces the biggest user interface revamp since the launch of Model S," Recently Feb 10,2019 Tesla released software update to add a few new features to its vehicles including blind spot warning and auto-folding mirrors[50-56].

BMW

BMW started working on autonomous vehicles in 2004 since then it achieved different success to bring the technology on the road of different cities. In 2006, the first self-driving track trainer (BMW 3 Series) laps Hockenheim while following the racing line. In 2011, it introduced highly automated test cars on the A9 motorway in Germany. In 2014 at the Customer Electronic Show (CES), BMW unveiled a self-driving, which can break, steer and accelerate without any intervention from the driver. In 2015 at the CES, BMW introduced 360° collision prevention and remote valet parking assistant integrated in the BMW i3. In 2016 at the CE, it showed the integration of Automated Gesture Control Parking in the BMW i3.

In March 2017, BMW announced its tie-up with non-life insurance company Allianz; the automobile manufacturer and insurance company plan to jointly investigate causalities and responsibilities when accidents occur.

In February 2018, BMW released a prototype of a Level 5 fully automated self-driving car and also announced that it will market automated self-driving cars called "iNEXT" by 2021 [57-61].

Audi

Audi is a member of the Volkswagen Group and has its roots at Ingolstadt, Bavaria, Germany [62]. It is one of the companies that is in the race of autonomous vehicle reality. In 2005, Audi and Stanford University were fastest to complete a 150-mile course, winning that year's DARPA Grand Challenge for automated vehicles [63]. In 2009, an Audi TTS sets the world speed record for automated vehicles with a speed of 210 km/h (130.5 mph). In 2013, Audi was the first carmaker to test piloted driving under real conditions in Nevada, and the first OEM to receive a Nevada autonomous driving license. In 2014, the U.S. states California and Florida follow; Audi was also the first company to gain California permit for testing. At Hockenheimring speedway, the Audi RS 7 piloted driving concept completed a lap at racing speed without a driver present [64]. In 2015, Audi was the first company to allow non-engineers in the driver's seat of a car equipped with "Highway Pilot" technology on a 566-mile test drive from Silicon Valley, California to CES in Las Vegas, Nevada [65]. In 2016, Audi brought Level 2 automation to the road with "Traffic Jam Assist" feature [66].

In 2017 at CES, Audi announced a partnership with NVIDIA to use artificial intelligence to deliver highly automated vehicles starting in 2020[67] and showcased deep learning advancements with an Audi Q7 piloted driving concept vehicle, in the same year at the Audi Summit in Barcelona, Audi presented its Audi AI technology as well as the debut of the Audi A8, a brand exhibition that showcased new concepts for piloted driving [68].

Now, the Audi A8 is equipped with a long-range radar, a front camera, four mid-range radars, several 360-degree cameras, up to 12 ultrasound sensors, and the world's first-ever laser scanner. It is capable of creating a three-dimensional map of its immediate surrounds and "look" up to 328 feet ahead [69].

In 2020-2021, Audi will introduce a Level 4 "Highway Pilot" feature technology similar to what has been demonstrated in the concept vehicle "Jack", that offers hands-free driving at posted limited access highway speeds in which the vehicle can execute lane changes and pass cars independently [68].

V. BENEFITS OF AUTONOMOUS VEHICLES

Autonomous, or self-driving, vehicle technology may be the most significant innovation in transportation since the mass introduction of automobiles in the early 20th century.

There are numerous potential benefits to be expected from the adoption of autonomous vehicles that include:

1. **Make Transportation Safer**: Fatal crashes were resulted from drunk, distracted, or tired human drivers; these

factors are involved in 29 percent, 10 percent, and 2.5 percent, respectively. Since autonomous vehicles are not involved in those human factors they have the potential to significantly mitigate these public safety crisis [70].

2. **Reduce Transportation-Related Pollution:** **t**ransportation is one of the top sources of global warming emissions [72], Optimists assume that autonomous vehicles will reduce pollution because they will be all electric and mostly shared, but many users will probably choose personal autonomous vehicles [73]. Policy must give strong incentives to companies that operate trips that are shared among the maximum number of passengers and it should discourage self-driving cars with no or single-occupancy rides from operating [74].
3. **Reduce Congestion:** investment in mass transit is vital to improve the efficiency of transportation networks, especially in congested urban areas. Taxis, ride-hailing services, private bus lines, and public transit systems may broadly adapt autonomous vehicle could lead to significant reduction in congestion and a greater reduction in the cost associated with it [20].
4. **Improve Access to Transportation:** AVs may help to improve service by providing innovative first- and last-mile solutions either through a fleet of shared AVs or through low-capacity autonomous shuttles that provide access to the fixed-route system [75]. It can also be deployed with special consideration for disadvantaged populations including for people who are unable to drive themselves, such as the young, the elderly, and the mobility impaired [71].
5. **Improve use of Urban Infrastructure:** even if most of the urban infrastructure are not fully ready for autonomous vehicles, if autonomous vehicles are for shared rides it could reduce the need for parking and expansion of roads. Policy must ensure that any repurposing or expansion of public roads and spaces need to consider the transition to AV and integrate the requirements of AV to the infrastructure [76].

VI. CHALLENGES OF AUTONOMOUS VEHICLES

Despite the great promise of autonomous vehicles, there are several challenges that must be addressed before they became commonplace. The different challenges that may encounter are related to:

1. **Heavy Weather**: like human drivers autonomous vehicles are encountering limitations when they operate in bad weather such as snow, heavy rain, fog, or other severe weather conditions because of the trouble "seeing" in some low-visibility situations and adapting quickly to loss of traction[73]. In addition to bad weather, operating during night time especially in areas with dim light may also affect the image quality of the object in the surroundings [78].
2. **System Reliability and Cybersecurity:** the connectivity of autonomous vehicles to each other, to infrastructure, or to the Internet makes it vulnerable to cyber-attack and as an effect, autonomous driving functions can be exposed to tampering [79]. In 2016, the team of researchers of the Chinese company, Keen Security demonstrated that vulnerability of autonomous vehicles can be exploited by malicious hackers for serious attacks [80].Moreover, like mobile phones, robots and any other consumer devices, autonomous vehicles' software require upgrades that may need to be backward-compatible with earlier models of vehicles and sensor systems [81].

As autonomous vehicle manufacturing companies are increasing and the number of vehicle models using diverse platforms became inevitable. Upgrading of autonomous driving features, software and other system will have to be performed on the diverse platforms [20], which will make software reliability and security a concern especially if third party software applications are used [82].

3. **Job losses**: researchers predicts that Artificial Intelligence will outperform humans in many activities in 2023, such as translating languages by 2024, writing high-school essays by 2026, driving a truck by 2027, working in retail by 2031 writing a bestselling book by 2049, and working as a surgeon by 2053[83]. A 2014 study carried out by Stanford University shows that autonomous cars could account for between 70% and 90% of taxis on the roads by 2060[80], which leads to a drastic job losses.
4. **High Cost Autonomous Vehicles:** new technologies tend to be expensive before reaching the mass marketing stage. In addition, if system failures happened it could be fatal to both passengers and other road users, all critical components of autonomous vehicles need to meet high manufacturing, installation, repair, testing and maintenance standards, these will make it relatively expensive to afford by common people [73].
5. **Ethical and legal situation**: Autonomous vehicles are supposed to identify obstacles automatically and form appropriate emergency strategies constantly to ensure driving safety and improve traffic efficiency. However, not all collisions will be avoidable, and AVs are required to make difficult decisions involving ethical and legal factors under emergency situations [84]. Rigorous testing and regulatory oversight of vehicle programming are essential to ensure that self-driving vehicles protect both their occupants and those outside the vehicle. Therefore, public policy related to self-driving vehicles must improve safety for everyone in the environment that a self-driving car is operating [71]. Since many nations are not yet ready with the law governing autonomous

vehicles, if it involves in accident it will be difficult to handle the case.

VII. Mitigating the Challenges

It may not be possible to avoid the challenges that may encounter due to autonomous vehicles, in this sections few recommendations to mitigate them are presented.

High resolution sensors like cameras and LiDAR with a special processing algorithm may assist to overcome the challenges that the autonomous vehicles are facing due to bad weather. This requires combined effort of autonomous vehicle manufacturers and researchers for the solution.

System reliability and cybersecurity are few of the most important factors that affects the safety of autonomous vehicle passengers if compromised by any means. To minimize the damage every manufacturer needs to consider the fail-safe principle to all the processes that the autonomous vehicle will undergo starting from the design stage.

Job losses because of the autonomous vehicles may be compensated by other jobs that will be created because of the existence of these vehicles, entrepreneurs and different agencies need to work together to discover future jobs that are not yet existed.

Any decision that will be taken by an autonomous vehicles may affects either the passenger or road users. To handle the legal issue that involve autonomous vehicles, it will be advantageous to have an international body in consensus of nations that deals with such situation.

VIII. Conclusion

Artificial intelligence is revolutionizing, healthcare, education, public safety and security, industry and other aspects of our daily life especially transportation through autonomous vehicles. Despite the great promise of autonomous vehicles, there are several challenges that must be addressed before they became commonplace. In this paper from the basic components of artificial intelligence to the mitigation of challenges of autonomous vehicles were discussed. This will help the autonomous vehicle researchers, entrepreneurs and others to propose solutions for concerns that are mentioned in this paper.

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