Autonomous Cars: Past, Present and Future - A Review of the Developments in the Last Century, the Present Scenario and the Expected Future of Autonomous Vehicle Technology

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Abstract: The field of autonomous automation is of interest to researchers, and much has been accomplished in this area, of which this paper presents a detailed chronology. This paper can help one understand the trends in autonomous vehicle technology for the past, present, and future. We see a drastic change in autonomous vehicle technology since 1920s, when the first radio controlled vehicles were designed. In the subsequent decades, we see fairly autonomous electric cars powered by embedded circuits in the roads. By 1960s, autonomous cars having similar electronic guide systems came into picture. 1980s saw vision guided autonomous vehicles, which was a major milestone in technology and till date we use similar or modified forms of vision and radio guided technologies. Various semi-autonomous features introduced in modern cars such as lane keeping, automatic braking and adaptive cruise control are based on such systems. Extensive network guided systems in conjunction with vision guided features is the future of autonomous vehicles. It is predicted that most companies will launch fully autonomous vehicles by the advent of next decade. The future of autonomous vehicles is an ambitious era of safe and comfortable transportation.

1 INTRODUCTION

Consumers all around the whole world are enthusiastic about the advent of autonomous cars for public. An autonomous car can operate without human control and does not require any human intervention. Campbell et al. stated that modern autonomous vehicles can sense their local environment, classify different kinds of objects that they detect, can interpret sensory information to identify appropriate navigation paths whilst obeying transportation rules. Considerable advancements have been made in giving an appropriate response to unanticipated circumstances where either a backlash can occur in the vehicular systems or some medium in the external environment may not behave as predicted by internal prototypes. To carry out successful autonomous navigation in such situations, combining a variety of technologies from different disciplines that span computer science, mechanical engineering, electronics engineering, electrical engineering, and control engineering, etc. is significant (Deshpande, 2014). The timeline of autonomous cars begins in 1926 with world's first radio controlled car- 'Linriccan Wonder'. Significant advances in autonomous car technology has been made after the advent of the vision guided Mercedes-Benz robotic Van in 1980, since when the main focus has been on vision guided systems using LIDAR, radar, GPS and computer vision. This developed into the autonomous technologies present in modern cars like adaptive cruise control, lane parking, steer assist etc. And, in the future, we will be part of a future where fully autonomous cars will be a reality, based on official forecasts by various automobile companies.

Transportation accidents is one of the major causes of death in the world. By 2020, this world could prevent 5 million human fatalities and 50 million serious injuries by introduction of newer and innovative methodologies and investments in road safety, from regional to international levels. The Commission for Global Road Safety believes that it is very crucial to stop this avoidable and horrendous rise in road injuries, and initiate year on year reductions (Campbell, 2010). Deshpande et al. gave a figure of nearly 3000 deaths because of road accidents daily, with more than half of the people not travelling in a car. Also, it has been reported by

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Deshpande et al. that if a paramount and efficacious action is not taken, transportation injuries are set to rise to 2.4 million per year, becoming the fifth leading cause of death in the world. So, number of traffic collisions will drastically decrease, due to an autonomous system's increased reliability and faster reaction time compared to humans. This would also reduce traffic congestion, and thus increase roadway capacity since autonomous vehicles would lead to a reduced need of safety gaps and better traffic flow management. Parking scarcity will become a historic phenomenon with the advent of autonomous cars, as cars could drop off passengers, and park at any suitable space, and then return back to pick up the passengers. Thus, there would be a reduction in parking space. Need of physical road signage will decrease, as autonomous cars will receive necessary information via network. There would be a reduction in the need of traffic police. Thus, autonomous cars can reduce government spending on things like traffic police. The need for vehicle insurance will also decrease, along with a decrease in the incidents of car theft. Efficient car sharing and goods transport systems (as in case of taxis and trucks respectively) can be implemented, with total elimination of redundant passengers. Not everyone is suitable driving, so, autonomous cars provide a relief from driving and navigation chores. Also, commute time will decrease, as autonomous vehicles can travel at higher speeds with minimum chances of error. The car's occupants will appreciate the smoother ride experience as compared to non-autonomous cars.

Autonomous cars provide excellent benefits, but, some challenges do exist. Although the notion has been rejected, but, it is believed that an advent of autonomous cars would lead to a decrease of driving-related jobs. Also, situations like inability of drivers to regain control of their cars due to inexperience of drivers, etc. is an important challenge. Lots of people love driving, and it would be difficult for them to forfeit control of their cars. Autonomous cars also pose challenges interacting with human-driven vehicles on the same route. Another challenge to autonomous cars is that who is to be held liable for damage- the car manufacturing company, the car's occupants/owner, or the government. Thus, implementation of a legal framework and establishment of government regulations for autonomous vehicles is a major problem. Software reliability is also a major issue. Also, there is a risk of a car's computer or communication system being potentially compromised. There is a risk of an increase in terrorist and criminal activities, for instance, cars could potentially be loaded with explosives by terrorist organizations and miscreants. They could also be used as getaway vehicles and various other criminal activities. Thus, autonomous cars have both pros and cons. This paper discusses the chronology of autonomous cars in a sequential manner, from historical antecedents to contemporary advancements to future predictions.

2 HISTORICAL ANTECEDENTS

Historical events helped shape modern semi-autonomous vehicles. The first step towards autonomous cars was the radio controlled car, called Linriccan Wonder. It was demonstrated by Houdina Radio Control in New York City. It was basically a 1926 Chandler that had transmitting antennae on its rear compartment and was operated by another car that sent out radio impulses while following it. These signals were caught by the transmitting antennae. The antennae sent the signals to circuit- breakers which operated small electric motors that directed the car's movements. It was one of the most primitive forms of autonomous vehicles. A modified form of Linriccan Wonder was used by the name "Phantom Auto" and demonstrated in December 1926 in Milwaukee, by Achen Motors. GM (General Motors) sponsored Norman Bel Geddes's exhibit Futurama at the World's Fair, 1939, which depicted embedded-circuit powered electric cars. The circuits were embedded in the roadway and controlled by radio, much like previous attempts for development of driverless cars. So, RCA Labs presented a significantly advanced model for autonomous cars.

RCA Labs built a miniature car in 1953. It was controlled and guided by wires that were laid in a pattern on a laboratory floor. Leland Hancock, a traffic engineer in Nebraska, and L. N. Ress, a state engineer took the idea of RCA Labs to a greater scale, by experimenting with the system in actual highway installations, which was done on a 121.92 meters long strip of highway just outside the town of Lincoln, Neb, in 1958. A series of detector circuits buried in the pavement were a series of lights along the edge of the road, which were able to send impulses to guide the car and determine the presence and velocity of any metallic vehicle on its surface. General Motors collaborated with it, and paired two standard models with equipment having special radio receivers and audible and visual warning devices that were able to simulate automatic steering, accelerating and brake control. Based on advanced models, in 1959, and throughout the 1960s, in Motorama (which was an auto show by GM), Firebird was showcased by

General Motors, which was a series of experimental cars which had an electronic guide system which could rush it over an automatic highway without driver’s involvement (Cranswick, 2013; Burgan, 1999; Temple, 2006). This led to Ohio State University's Communication and Control Systems Laboratory to launch a project to develop driverless cars which were activated by electronic devices imbedded in the roadway, in 1966. United Kingdom's Transport and Road Research Laboratory tested a driverless car, Citroen DS that interacted with magnetic cables that were embedded in the road, during the 1960s. It went through a test track at 130 km/h without deviation of speed or direction in any weather condition. It travelled in a far more effective way than by human control (Cardew, 1970; Pressnel, 1999).

The United States’ Bureau of Public Roads considered the construction of an experimental electronically controlled highway, in which, four states- Ohio, Massachusetts, New York and California - bade for the construction. The then governor, DiSalle pressed for such experiments for the future of automation. In the 1980s, a vision-guided driverless Mercedes-Benz robotic van, which was designed by Ernst Dickmanns and his team at the Bundeswehr University Munich, Germany, achieved a speed of 63 km/h on streets without traffic. Various national and international projects were launched with the progress in the field of autonomous vehicle technology. EUREKA conducted the Prometheus Project on autonomous vehicles from 1987 to 1995. Over 1 billion US dollars were invested in it (Xie, 1993; Flyte, 1995). DARPA, Defense Advanced Research Projects Agency of the U.S. Department of Defense is also responsible for the progress in the field of autonomous cars. Autonomous Land Vehicle (ALV) project in the United States made use of new technologies. These technologies were developed by the Carnegie Mellon University, the Environmental Research Institute of Michigan, University of Maryland, Martin Marietta and SRI International. The ALV project achieved the first road- following demonstration that used computer vision, LIDAR and autonomous control to direct a robotic vehicle at speeds of up to 31 km/h (Davis, 1987; Leighty, 1986; Lowrie, 1985; Chandran, 1987). HRL Laboratories (formerly Hughes Research Labs) demonstrated the first off-road map and sensor- based autonomous navigation on the ALV. The vehicle traveled over 610 m at 3.1 km/h on complex terrain with steep slopes, ravines, large rocks, vegetation and other natural obstacles (Resende, 2013). United States Congress passed the ISTEA Transportation Authorization bill, in 1991, which instructed US Department of transportation to demonstrate an automated vehicle and highway system. The Federal Highway Administration started with a series of Systems Analysis and then established the National Automated Highway System Consortium. The cost was shared by Federal Highway Administration, General Motors, UC-Berkeley etc. It was finally culminated in 1997 in San Diego, California, but later on dropped because of lack of funds (Bishop Jr, 1993). The newer autonomous vehicles became more and more efficient with time. The twin robot vehicles VaMP and Vita-2 of Daimler- Benz and Ernst Dickmanns of Bundeswehr University Munich, in 1991 drove more than 1,000 km on a Paris three-lane highway in standard heavy traffic at speeds up to 130 km/h, but semi- autonomously with human interventions. They demonstrated autonomous driving in free lanes, convoy driving, and lane changes with autonomous passing of other cars (Behringer, 1998). Vehicles highly autonomous, in some cases exhibited better speeds than human drivers. In 1995, Dickmanns’ autonomous S-Class Mercedes-Benz undertook a 1,590 km journey from Munich, in Germany to Copenhagen, in Denmark and back, using jolting computer vision and microprocessors with integral memory designed for parallel processing to react in real time. The robot achieved speeds exceeding 175 km/h on the German Autobahn, with a mean time between human interventions of 9.0 km, or 95% autonomous driving. It drove in traffic, executing various maneuvers to pass other cars (Wenger, 2005; Franke, 1997).

In 1995 itself, the Carnegie Mellon University’s Navlab project achieved 98.2% autonomous driving on a 5,000 km cross-country journey which was dubbed "No Hands Across America" or NHOA. The car was semi-autonomous by nature: it used neural networks to control the steering wheel, but throttle and brakes were human-controlled (Thorpe, 1991; Pomerleau, 1993). An advanced autonomous vehicle was exhibited by Alberto Broggi of the University of Parma. He launched the ARGO Project, which worked on making a modified Lancia Thema to follow painted lane marks on a normal highway, in 1996. The apotheosis of the project was a journey of 1,900 km over six days on the roads of northern Italy, with an average speed of 90 km/h. The car operated in fully automatic mode for 94% of its journey, with the longest automatic stretch being 55 km. The vehicle had two low-cost video cameras on board and used stereoscopic vision algorithms to understand its environment (Broggi, 2000). Some countries started using autonomous public transport systems by the dawn of the new millennium. In the early 2000s, the ParkShuttle, an autonomous public road transport system, became operational in the Netherlands (Shladover, 2007; Panatoya, 2003; Andréasson, 2001). US government also started working on autonomous vehicles, mostly for military usage. Demo I (US Army), Demo II (DARPA), and Demo III (US Army), were funded by the US Government (Hong, 2000). The ability of unmanned ground vehicles to navigate miles of difficult off-road terrain, avoiding obstacles such as rocks and trees was demonstrated by Demo III (2001). Real-Time Control System, which is a hierarchical control system was provided by the National Institute for Standards and Technology. Along with individual vehicles' control (e.g. throttle, steering, and brake), groups of vehicles had their movements automatically coordinated in response to high level goals (Bellutta, 2000; Shoemaker, 1998; Hong, 2002).

3 CONTEMPORARY PROGRESS

The modern automobile companies keep coming up with newer autonomous features in their recent models. Technological advancements seen every day in areas like information technology, communication, data analysis and storage etc. is not exclusive to these areas alone. The realm of autonomous cars is also progressing at a rapid rate these days. Segway Incorporated and General Motors jointly developed a 2 seat electric car, basically designed for urban environments and which could be driven normally or operated autonomously. Known as GM's EN-V (General Motor's Electric Networked Vehicle), it was first unveiled from 1st May through 31st October 2010 at the joint GM & SAIC pavilion at the Expo 2010 in Shanghai. EN-V was further divided into three different vehicle types: Jiao (Pride), Miao (Magic), and Xiao (Laugh). EN-V exhibits autonomous features such as self- parking/retrieval, vehicle platoons and collision avoidance. GM's EN-V became an important advancement towards paving the way in realizing a higher grade of vehicle connectivity, vehicle interfaces, motion control algorithms, and connected autonomous driving architecture (Eberle, 2011; Mudalige, 2010).

With the advances in autonomous technology, VIAC or VisLab Intercontinental Autonomous Challenge was one of the major competitions which led to improvements in the testing and analysis of autonomous vehicles and robotics. It was a 13,000 kilometers trip, nearly three months from Parma, Italy to Shanghai, China from July 20, 2010 to October 28, 2010. It involved four autonomous vehicles with negligible human intervention and high level of autonomy. This project was partially funded by ERC, European Research Council. It showed that in future it will be possible for goods to be transported between two continents with environmentally friendly vehicles with negligible human intervention. For the first time in history goods were packed in Parma and taken to Shanghai using autonomous vehicles (Bertozzi, 2011; Laugier, 2014; Broggi, 2010). Audi's autonomous TTS research car in September 2010 completed the 20 kilometers Pike's Peak mountain course in 27 minutes, very close to the human record of 17 minutes. It was a noteworthy achievement in that it set a benchmark, for the first time, as to how close driverless vehicles are to the best of human drivers. Audi TTS employed emerging software, algorithms, and electronics, basically, to aid driver's abilities, much like auto pilot feature of airplanes and jets (Funke, 2012; Kritayakirana, 2012; Okuda, 2014). Volkswagen's "Temporary Autopilot" (TAP) system can control the car semi-autonomously at speeds up to 130 kilometers per hour.

It was a milestone on the path towards accident free driving, according to Jürgen Leohold, head of Volkswagen Group Research. This system was initiated as a part of European Union's $40 million HAVEit (Highly Automated Vehicles for Intelligent Transport) project (Flemisch, 2011). It possesses various driver-assist functions like adaptive cruise control, and side monitoring for safer lane-changing, with a radar system, laser scanner and ultrasonic sensors. When in TAP mode, the car maintains a safe distance from the vehicle ahead, checks the lane markers to keep the car in the center, and automatically slows down when approaching a bend in the road. It aids in preventing accidents caused by inattentive drivers. The driver still maintains control and can override the car's actions at any point, however (Bartels, 2014).

The first cars licensed for autonomous driving on the streets and highways of the German state of Berlin are MadeInGermany and Spirit of Berlin, developed by the AutoNOMOs Labs. It was a project of Freie Universität, Berlin, and funded by the German Federal Ministry of Education and Research. The project had developing technology for driver assistance systems, innovative safety systems for cars and full autonomous vehicles in airports or mines as its major objectives. It has a very accurate GPS unit and three laser scanners at the front, and three at the rear of the vehicle detect any car or pedestrian all around the car. It can also detect traffic lights, intercity traffic and roundabouts (Reuschenbach, 2011; Dias, 2013). Karlsruhe Institute of Technology/ FZI (Forschungszentrum Informatik) and Daimler R&D made a Mercedes-Benz S-class vehicle which drove completely autonomously for 100 kilometers from Mannheim to Pforzheim, Germany. The vehicle followed the historic Bertha Benz memorial route. It used next generation radars and stereo cameras which aided in its autonomous automation. It aimed at reducing accidents, caused mainly by human error. Algorithms to link various aspects of automation and machine vision were used (Franke, 2013; Zeigler, 2014). Toyota developed its autonomous car basically for elimination of crashes which is one of the main causes for deaths caused by automation mishaps. Toyota used something it calls ITS (Intelligent Transport Systems) technology. The car system has been engineered in such a way that any system failure does not cause the car to crash. Lasers and radars have been used to have an effective know-how of the surroundings. The car is semi-autonomous, the driver can gain control of the car anytime he/she wishes. Toyota's advanced active safety research car is leading the automation industry into a new automated era (Guizzo, 2013). Nissan's 2014 Infiniti Q50 was releases in 2013, and was one of company's most effective autonomous cars. It uses cameras, radar and other next generation technology. The model delivers various features like lane-keeping, collision avoidance and cruise control. It was one of the first cars in the world in which the virtual steering column was used. The driver need not manually operate the accelerator, brakes or steering wheels. It charts a course towards the self-driving cars of tomorrow (Ulrich, 2013; Elżbieta, 2014).

One of VisLab's advanced autonomous car, BRAiVE, drove in downtown Parma on July 12th, 2013. It successfully navigated narrow rural roads, crosswalks, traffic lights, pedestrian areas, roundabouts and artificial hazards. It was a pioneer in the field of vehicular robotics, since it was totally autonomous (Wei, 2013; Broggi, 2013). Nissan Leaf all-electric car was installed with Nissan's autonomous car technology. "LEAF" is also formatted as a backronym for Leading, Environmentally friendly, Affordable, Family car. The car was showcased publicly in August 2013 in Nissan 360 test drive event held in California. Later in 2013, the Leaf drove on the Sagami Expressway in Kanagawa prefecture, Japan. Nissan has plans to launch several driverless cars by 2020. This demonstration acted as a prototype for Nissan's future driverless cars (Maddern, 2014). A Nissan Leaf fitted with a prototype Advanced Driver Assistance System was granted a license plate, because of which it was allowed to drive on public roads. This led to Nissan's goal of launching autonomous cars by 2020 one step forward. The Advanced Driver Assistance System is a next generation technology which will form a base for Nissan's future autonomous cars. It also uses sophisticated computer systems and drive by wire electronics. This car will be used by Nissan's engineers to evaluate how its autonomous driving software performs under real conditions, by using its time on the public highway to refine the car's software. This is being done to prepare the car for a fully-automated driving future.

Navia is a robotically driven electric shuttle which operates at a maximum speed of 20 kilometers per hour. Made by Induct Technology, France, it can accommodate 10 passengers. It uses four LIDAR units and stereoscopic optical cameras, and it does not require any road modifications. Its LIDAR unit and optical cameras help in generating a real-time three dimensional map of the surroundings. It is being successfully tested at various universities across Switzerland, England and Singapore (Zhang, 2014). Google plans to unveil hundred driverless car prototypes built inside Google's secret X lab, as officially said by the company on 27th May, 2014. Google proclaims it to be a manifestation of years of work that began by modifying existing vehicles. Google plans to release these models in the years to come. The field of autonomous automation keep on expanding day by day with newer advances for a future which is safer and more efficient (Headrick, 2014; Sunwoo, 2014).

4 PROSPECTIVE PREDICTIONS

Any technology enthusiast is curious about the future of cars and how will cars become more reliable, and faster. The governmental organizations are very optimistic about autonomous cars, of course they also have lots of challenges to face with the advent of autonomous cars. Autonomous cars provide advantages like high reliability, high speed, lesser governmental spending on traffic police, reduced need of vehicle insurance, reduction of redundant passengers, etc. with challenges like implementation of a legal framework for autonomous cars, and possible criminal and terrorist misuse among some. By late 2014, Volvo is set to feature ACC (Adaptive Cruise Control) in conjunction with power assisting steering (PAS, or simply steer assist). Steer assist helps the driver man-oeuvre by supplementing steering effort of the steering wheel. This would aid the vehicle to automatically follow other cars in queues. This is regarded as another dimension of autonomous driving (de Winter, 2014). The United States National Telecommunications and Information Administration, by the end of 2014 would set aside recommendations for broadband spectrum for autonomous cars. Other legal framework for an efficient execution of autonomous networks would be underway, according to Kim et al. Audi plans to release its autonomous cars for public by 2015. It will include features like autonomous acceleration, steering and braking the car in traffic jams and at low speeds. This will be basically for relieving the driver of prosaic driving tasks like driving in heavy traffic. By the mid of June 2015, various automobile companies like Nissan, Mercedes, Toyota, Bosch etc. will introduce various self-driving features like autonomous steering, braking, lane guidance, throttle, gear shifting, and unoccupied self-parking after passengers exit for public use. Also, Mobileye plans to release its hands-free cars by 2016. This car is expected to be fully autonomous.

By the beginning of 2017, the United States National Highway Traffic Safety Administration is expected to authorize the adoption of Vehicle- to-Vehicle technology on all new vehicles, whether autonomous or not. This would aid in reducing accidents and vehicle mishaps, and would be aided with collision avoidance system and other autonomous technologies (Biswas, 2006). Tesla plans 90% autonomous cars for public which is expected to have an 'autopilot' feature which would make the '90% autonomous' travel possible. Google plans to release its 'Self driving cars' for public by 2018. These cars would perform all safety functions for the entire trip, with the driver not expected to control the vehicle at any time, though the driver would be free to do so. It shall also include parking functions, and unoccupied cars shall also be used for transportation and miscellaneous functions. By 2018, Nissan is set to bring an autonomous maneuvering feature, in addition to standard ACC (adaptive cruise control) and lane keeping. Fully autonomous cars shall be available by 2019/2020. The era of cars autonomous to a certain appreciable degree would begin. In order to bring benefits to its consumers, Volvo is set to bring an autonomous car which would involve pioneering technology necessitating considerable driver support systems, which would aim at avoiding any kind of crashes and loss of life. Volvo aims to launch a safety vision which would state that no one be killed or seriously injured in the upcoming safe autonomous car, in 2020. By mid of 2020, most of the major cars companies like Audi, GM, Daimler, Mercedes-Benz, Nissan, BMW, and Renault expect to sell vehicles that are somewhat autonomous, if not fully. Most of the cars would be equipped with features like ACC, lane keeping, automatic parking etc. (Schumacher, 1996). Companies like Ford expect autonomous vehicles with various functions such as driver assist, ACC, automatic parking etc. by 2025. Also, it is predicted that most cars would be autonomous and would be operated completely independent from a human control by 2035. The future of autonomous cars is not distant (Garza, 2011).

5 CONCLUSIONS

This paper discusses basic chronology leading to the development of autonomous cars. Autonomous vehicles developed from the basic robotic cars to much efficient and practical vision guided vehicles. The development of Mercedes- Benz vision guided autonomous van by Ernst Dickmanns and his team gave a paradigm shift to the approach followed in autonomous cars. Also, contemporary developments in autonomous cars reflect the vivid future autonomous cars behold. Official future predictions about autonomous cars point out that most automobile companies will launch cars with semi and fully autonomous features by 2020. Most cars are expected to be fully autonomous by 2035, according to official predictions as cited earlier. This paper reviewed the historical antecedents, contemporary advancements and developments, and predictable future of semi and fully autonomous cars for public use.

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