A Survey of Self-driving Urban Vehicles Development

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Abstract. The purpose of this paper is to conduct a literature survey on the research of self-driving car which operating in an urban environment. The chosen literature is the literature published since the 2007 DARPA Urban Challenge (DUC) competition and fulfills the criteria of autonomous vehicle level 3 or higher based on the Society of Automotive Engineers (SAE). In addition to using sources from scientific publications, this survey also carried out through websites of companies that develop self-driving car as well as through news published on various media. This is because not all commercial companies publish the results of their research through scientific papers. The results of this survey are a comparison of the main technologies used in the existing self-driving car systems, as well as comparing the advantages and disadvantages of each of these technologies. The conclusion can help researchers find the latest information about self-driving car technology and find a direction of research in the field of self-driving car.

1. Introduction

A self driving car or autonomous vehicle is a vehicle system that can travel to predetermined destinations without human intervention of the driver [1-3]. To accomplish this task, self-driving car must be able to detect environmental conditions, create a global path to the destination (in the form of waypoints) and take into account environmental conditions to get to the waypoint to avoid the obstacles that surround them (build local path) [4]. Self-driving car can be useful in reducing the risk of accidents due to human error, reducing congestion, freeing drivers from the burden of driving long distances, minimizing the need for parking and many more benefits [5-6].

Over the last three decades, the number of studies in the field of autonomous vehicle has increased [7]. This is the result of advances in sensor and computing technology which has reduced the size and price of the equipment needed. Survey studies of various autonomous vehicles have also been carried out. Badue et al. conduct research surveys on self-driving cars published since the DARPA Urban Challenge (DUC) competition, which is equipped with an automation system that can be categorized by Society of Automotive Engineers (SAE) as level 3 or higher. The discussion of the paper is divided into perceptual system architecture and decision-making systems. The article also describes the typical architecture of an autonomous car system and discusses the architecture of the Universidade Federal do Espírito Santo (UFES) autonomous car system. The article also discusses the main research on autonomous cars [8]. Zhao et al. reviewed important technologies of autonomous cars. In the paper, four major autonomous car technologies were examined and discussed. The four main technologies are car navigation systems, lane planning, environmental perception and car control. The survey was conducted in major research institutes and groups from different countries. In addition, Zhao et al. presented predicts the development trend of the autonomous car [9]. Bimbrwaw presented the trends of self-driving car technology in the past, present and future. Various semi-autonomous features have been introduced in modern cars, such as systems that keep the vehicle online, automatic braking and adaptive roaming control. It is estimated that most companies will launch fully autonomous vehicles in the next decade [10]. Paden reviewed the current state of the urban planning and travel planning algorithm. The
algorithms studied are discussed about their effectiveness. The comparison presented in Paden article should provide a better understanding of the advantages and disadvantages of autonomous vehicle trajectory planning algorithms [11]. Marina and Sandu presented the latest state-of-the-art study by Deep Reinforcement Learning (DRL). The author presented the current jobs related to DRL. Marina and Sandu also compared the strengths and weaknesses of using the DRL concept. Research on the simulation of DRL algorithms for autonomous cars is also presented [12]. While Katrakazas et al. reviewed existing approaches and compare the methods used to path planning on autonomous vehicles. The path planning consists of (1) finding a path, (2) finding the safest maneuver, and (3) determining the most feasible path. The method developed by researchers at each of these three levels shows different levels of complexity and accuracy of performance. This article presents a critical evaluation of each methods, in terms of advantages and disadvantages [13]. Although many articles have conducted surveys of autonomous car research, no research has compared the advantages and disadvantages of each technology of these autonomous vehicle system.

The purpose of this research it to conduct a literature survey on self-driving car research. The literature chosen is the literature published since the DUC competition and fulfills the requirements as a level 3 or more autonomous vehicle based on SAE. In addition to using sources from scientific publications, this survey is also carried out through the company's website that develops autonomous vehicles and through information published in various media. This is because not all commercial companies publish the results of their research in scientific articles. This article will present a comparison of the technologies used in autonomous car systems, and will discuss the advantages and disadvantages of the technologies used in these autonomous vehicles.

2. Methods
This study uses the literature survey method. The selected literature is literature that discusses autonomous vehicle systems that can be categorized as SAE level 3 or more and published since the DARPA Urban Challenge competition. However, not all commercial companies inform the progress of their research regarding autonomous vehicles in scientific publications. So we also use company sites or news from various media that discuss research on autonomous cars. The discussion will be emphasized on leading research on autonomous cars, discussing the technology used and comparing each of the advantages and disadvantages of each of the main technologies of the autonomous car.

3. Results and Discussion
3.1. Self-driving Car Researchs from DARPA Urban Challenge 2007
One of the major milestones in the technology of self-driving car in an urban environments was the DUC in 2007. The competition purpose was to test the ability of vehicles to drive between checkpoints while respecting the California traffic code. This required exhibiting behaviour, such as maintaining the lane, intersections priority, parking, queuing, merging and passing or overtaking. Six teams completed the event which showed that fully autonomous urban driving was possible [14].

The first winner of DUC was the Tartan Racing team from Carnegie Mellon University with an autonomous vehicle called "Boss". Tartan Racing team successfully completed the DUC challenge in 4 hours 10 minutes. The CMU Boss vehicle used variational techniques for making a local trajectories in structured environments and a lattice graphs in a 4-dimensional configuration space (including position, velocity and orientation) together with Anytime D* to find a obstacle-free paths in car parks. However, in the navigation strategy, Boss made two mistakes in determining that he needed to turn U, so the Boss had to travel an additional 3.2 km which was not needed [15].

The second winner of DUC was the Stanford Racing team from Stanford University with an autonomous vehicle called "Junior". Junior successfully completed the DUC challenge in 4 hours 29 minutes. The Stanford team used a search strategy called Hybrid A* which, during the research, lazily built a tree of motion primitives by recursively applying a finite set of maneuvers. The search was guided by a carefully crafted heuristic and the sparsity of the tree was ensured by keeping only one node in a given region of the configuration space. The robot was able to demonstrate the merging, the management of the intersections, the navigation in the parking lots, the change of lane and the autonomous half-turns [16].
The third winner of DUC was the VictorTango team from Virginia Tech with an autonomous vehicle called "Odin". Odin successfully completed the DUC challenge in 4 hours 36 minutes. The VictorTango team built a graph discretization of the possible maneuvers and searches the graph with the A* algorithm. During the competition, Odin was able to drive several hours without human intervention, negotiating intersections of stop signs, merging into and across traffic, passing through the parking lot and maintaining the speed of the road [17].

The team that successfully completed the DUC in the fourth position was MIT team with an autonomous vehicle called "Talos". MIT used a variant of the RRT algorithm called RRT closed-loop with biased sampling [18-19]. A key innovative aspect of the MIT system, compared to many other teams, was that autonomous decisions have been made based on locally sensed perception data, in preference to pre-specified map data where possible. Another innovative aspect was the use of a powerful and general purpose RRT-based planning and control algorithm that meets the requirements of lane driving, three-point turns, parking and maneuvering across fields of obstacles with a single unified approach [20].

The other two teams that successfully completed the DUC challenge were The Ben Franklin Racing Team from the University of Pennsylvania with an autonomous vehicle named "Little Ben" [21] and a Cornell team from Cornell University with an autonomous vehicle named "SkyNet" [22]. It was noted several incidents of collisions between vehicles on this DUC. Among them was a collision between Talos and SkyNet [23].

3.2. Self-driving Car Researchs from Google
Google is the most famous in the autonomous domain. Autonomous car technology research by Google began in 2005 [9]. In 2008, Google AV with Pribot from Levandowski was able to deliver pizzas across the California Bay Bridge to San Francisco-Oakland [24]. In 2009, Google's autonomous vehicle project was led by Sebastian Thrun, who also led the Stanford University team and winning the 2005 DARPA Grand Challenge with his "Stanley" car [25].

Google's autonomous car has become an independent company called Waymo. Waymo's autonomous car uses a RADAR to detect distant objects and their speed, a LIDAR to create a detailed map of the world around the car, and high-resolution cameras to acquire visual information, such as the red or green traffic signal [26]. The Google’s autonomous car first driving license was issued in Nevada, USA in May 2012. By the end of 2014, the eight-car Google’s autonomous project was tested over 700,000 kilometers covered an urban road, a highway, a mountain road, a various roads, and no proactive accidents occurred.

3.3. Self-driving Car Researchs from Vislab
In July 2013, an autonomous car developed by the Artificial Vision and Intelligent Systems Laboratory (VisLab) of the Parma University, Italy, drove around the old district of the city of Parma without any human participation. The autonomous car successfully passed the roundabout, the single two-lane, recognized the pedestrians crossing the road, recognized the traffic lights, and so on. In 2010, a driverless van made the longest journey approximately 13,000 kilometers within three mouths, which began in Italy and ended in China.

In 2013, a driverless test program called PROUD-Car Test was organized by Vislab. It can be seen that a car with no one in the driver's seat can move successfully on a mixed traffic route (rural, highway and urban) open to public traffic. In 2014, a new driverless vehicle called Deeva was designed with a similar appearance to that of a normal vehicle.

3.4. Self-driving Car Researchs from Tesla
In 2015, Tesla Autopilot introduced: freeway driving, in ramp to off-ramp and Tesla summon released. In 2016, all Tesla models built with appropriate hardware for SAE level 5 capabilities: steering and acceleration/ deceleration, monitor environment, fallback performance, capability in all driving modes. Tesla plans 90% autonomous cars for public which is expected to have an ‘autopilot’ feature which would make the ‘90% autonomous’ travel possible.
3.5. Self-driving Car Research from NuTonomy

One autonomous vehicle that has been socialized to the public is an autonomous economy. Taxi cars NuTonomy operates in a 6 km area on Singapore’s One-North technology business district. NuTonomy car provides three main buttons, namely "Manual", "Pause" and "Autonomous".

The Singapore’s One-North technology business district has a challenging complexity for autonomous cars. There are many pedestrians and although traffic tends to be stable but sometimes there are dangerous traffic situations. All of them provide opportunities for autonomous cars to learn about environmental conditions.

Navigation priority from nuTonomy uses three priority sequences. The first priority is "do not hit pedestrians", the second priority is "do not hit other vehicles", the third priority is "do not hit objects". Things that are not prioritized are like "not crossing the center line", or "giving a comfortable trip". NuTonomy car will try to follow all traffic rules at all times, but are allowed to violate less important rules.

This autonomous car uses the RRT* path planning algorithm to evaluate many potential path alternatives based on data from other cameras and sensors [27]. The decision-making algorithm will evaluate each of these pathways and choose the path that best matches the priority of the rules above. Most autonomous car companies use machine learning [28]. Machine learning algorithms have been used successfully for many autonomous cars. Indeed, NuTonomy uses machine learning algorithms to interpret sensor data, but not in decision making. This is so that the reason for making choices made by the machine can be known. If using machine learning as a decision maker, it is feared that it cannot be believed what decision-making behavior will be carried out because machine learning is like a black box. The ability to explain what an autonomous car will do will greatly help the trust of users and the government in giving permission to operate autonomous cars nuTonomy.

3.6. Self-driving Car Researchs use Deep Reinforcement Learning

While the traditional approach of planning and control is the current mainstream in autonomous vehicle system, learning-based approaches [29] have emerged and have attracted increased interest from researchers. In practice, these optimization-based approaches work quite well in practice [11, 13].

Kendall [30] demonstrates the first application of deep reinforcement learning for self-driving car. From randomly initialized parameters, the model can learn the path strategy using a single input monocular images. The general reward setting is the distance traveled by a vehicle without the human driver taking control.

4. Conclusion

This paper has discussed a survey of current research on autonomous vehicles. The surveys discussed included the development of autonomous vehicle research since the DARPA Urban Challenge competition until now, the development of navigation system technology, system path planning and control. For each discussion, a comparison of the strengths and weaknesses has also been presented.

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