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A review of common practices and challenges in autonomous driving

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Abstract. Autonomous driving technologies have garnered significant attention in recent years, promising transformative impacts on transportation systems. The landscape of transportation is undergoing a profound transformation with a focus on achieving autonomy in vehicles, ranging from advanced driver assistance systems (ADAS) to the ambitious goal of fully autonomous vehicles. This article delves into the complexity of autonomous driving, exploring both the advancements driving this paradigm shift and the intricate challenges impeding its seamless integration into daily life. The journey toward autonomy involves breakthroughs in sensor technology, artificial intelligence, and connectivity, with a crucial emphasis on sensor fusion for precise navigation. The review highlights key advancements in machine learning, computer vision, and sensor technologies that underpin autonomous driving systems, offering insights into their current capabilities and limitations. The synthesis of this review aims to provide a holistic understanding of the current state of autonomous driving, facilitating informed discussions among researchers, practitioners, and the broader public. By shedding light on both achievements and challenges, this paper contributes to the ongoing discourse on the future of autonomous driving and informs the development of strategies to address the complexities inherent in achieving widespread adoption of this transformative technology.

Keywords: *autonomous driving, self-driving vehicles, artificial intelligence, sensor fusion, deep learning.*

1. Introduction

The landscape of transportation is undergoing a transformative shift, marked by the relentless pursuit of autonomy in vehicles. From cutting-edge advanced driver assistance systems (ADAS) to the ambitious vision of fully autonomous vehicles, delivery robots, the automotive industry is at the forefront of technological innovation. In this article, we delve into the intricate tapestry of autonomous driving, examining both the common practices that propel this paradigm shift and the multifaceted challenges that cast a shadow on its seamless integration into our daily lives.

The journey towards autonomous driving has been characterized by a convergence of breakthroughs in sensor technology, artificial intelligence and deep learning algorithms, connectivity, and mapping. Vehicles equipped with an array of sensors, including cameras, LiDAR, radar, and ultrasonic sensors, engage in the intricate dance of sensor fusion. This practice involves the meticulous integration of data from diverse sensors, creating a composite and nuanced understanding of the vehicle's surroundings. Sensor fusion is the linchpin of perception for autonomous driving, allowing to navigate the complex and dynamic environment with high precision and error tolerance.

However, according to Muhammad et al. significant improvements in sensor fusion technologies and hardware manufacturing still demand further attention in research and academia before full industry deployment as it serves the key role in reducing road accidents and saving human lives [1]. For instance, only in Kazakhstan approximately 15 thousand people were injured because of over 10 thousand road incidents occurring in the preceding year [2]. There has been a notable 21% increase in deaths counts. Further analysis suggests that over 86% of accidents are caused by drivers.

Machine learning and artificial intelligence technologies empower deep neural networks to learn from vast datasets, adapt to diverse driving conditions, and make split-second decisions. This can hopefully dramatically reduce the number of road accidents and subsequent deaths. According to the National High-way Traffic Safety Administration (NHTSA), over 94% of incidents are usually caused by human errors [3]. The advent of deep learning, the widespread deployment of Automated Driving Systems (ADSs) is projected to reduce not only the number of accidents, but also atmospheric emissions, stress, increase traffic efficiency and overall social wellbeing by nearly $800 billion in monetary value by 2050 [4].

Despite these notable strides, the road to fully autonomous driving is fraught with challenges that demand meticulous consideration. Safety concerns loom large, requiring the industry to address unpredictable variables such as adverse weather conditions, erratic human drivers, and unexpected obstacles. Striking a balance between achieving technological reliability that matches or surpasses human drivers in all situations and ensuring the utmost safety is a formidable challenge.

The regulatory and legal landscape presents another intricate puzzle. The accelerated pace of technological development has outpaced the establishment of comprehensive frameworks governing autonomous driving. Questions of liability in the event of accidents, data privacy, and the standardization of testing procedures demand urgent attention to facilitate the widespread adoption of autonomous vehicles. Harmonizing these regulations on a global scale emerges as a pressing necessity.

Ethical dilemmas cast a philosophical shadow on the path to autonomy. Autonomous vehicles are confronted with situations where moral decisions must be made, such as choosing between minimizing harm to the vehicle occupants and avoiding harm to pedestrians. Resolving these ethical conundrums requires a delicate balance between societal values, legal considerations, and technological capabilities.

In an era where vehicles are increasingly connected and reliant on software, cybersecurity risks add an additional layer of complexity. Autonomous vehicles, with their extensive network connectivity, become susceptible to hacking, potentially leading to severe consequences. Establishing robust cybersecurity measures to protect vehicle systems from unauthorized access and manipulation is an ongoing challenge that requires constant vigilance.

As we navigate through the intricate landscape of autonomous driving, it becomes evident that this technological frontier is not merely a convergence of hardware and software but a holistic reimagining of transportation. The promise of safer, more efficient, and accessible mobility beckons, but not without overcoming the intricate web of challenges that intertwine with progress. Researchers, engineers, policymakers, and society at large are integral players in this transformative narrative, shaping the future of autonomous driving.

1.1. Autonomous driving prospects and social challenges

The widespread adoption of ADSs is imminent. According to Moreno et al. the availability of vehicles results in increased financial and biodiversity burden to cities [5]. Moreover, recent COVID-19 events have sped up Artificial Intelligence (AI) adoption and subsequently greater enhancements of Deep Learning (DL) algorithms. This has led to the re-emergence of an old concept of smart cities or rebranded as the «15-Minute City», closely discussed by Moreno et al. in his work. He mentions that this concept has been depicted as the Sustainable Development Goal 11 of United Nations. And one of the subgoals revolves around removing or, at least, replacing non-green vehicles from cities with their electric counterparts. Consequently, this leads to autonomous driving as new opportunities arise.

Yurtsever and his team foresees the following potential impacts on society [6]:

1) ADSs will help mitigate traffic accidents, improve traffic efficiency, and reduce emissions by stabilizing the city ecosystem.

2) A new opportunity shall arise revolving around Mobility as a Service (MaaS), which already has a noticeable impact on logistics.

However, Maas can also play a major role in other areas of human life, not limited to logistics. Potentially, with an increased growth of elderly people, ADSs technology can help them improve their quality of life and productivity. Not to mention a steady shift towards MaaS consumption by masses as opposed to vehicle-ownership. According to Yurtsever's et al. research, vehicle ownership is projected to become 50:50 by 2030.

As ADSs become more advanced and intricate, they gain the ability to operate in indeterministic environments. With its fast-paced evolution, there is a need to monitor and classify the level of automation. According to the Society of Automotive Engineers (SAE) there are 5 levels of driving automation. The taxonomy mentions level zero as no automation at all. It's up to the driver to handle every aspect of driving. Level one depicts primitive driver assistance, whereas level two includes partial automation. These systems usually have emergency braking and collision avoidance mechanisms integrated into vehicles to support the drivers in emergency situations. SAE note that the difficulties start arising from level three and upward.

The challenge of level three automation lies in conditional automation: in cases when the driver needs to take over the control during an emergency. In addition, level three automation is limited to certain operational domains. For example, highways. During an investigation, it has been proven that the control takeover from automated mode to manual mode usually results in traffic accident risks. Thus, this is yet to be solved.

Level four automation adds on a whole new complexity layer on top of existing technology. It includes automatic departure, parking, and routing. Level five automation steps up the game by making the vehicle operate seamlessly on any road network, any weather condition or indeterministic situations. Nonetheless, both levels of automation require special domain infrastructure to operate well. At the current state of urban roads, the environmental variables are still highly indeterminate, which are difficult to predict accurately.

For example, Tesla's ADS failed to differentiate a white truck colliding with the vehicle and killing the driver [8]. Therefrom arise the ethics dilemma: who's responsible, and how the system should normally behave? Should it prioritize the driver's wellbeing or the pedestrians. These questions need careful consideration.

2. System components and architectures

This chapter describes the software and hardware used by the ADS researchers, developers and engineers and their intrinsic details. We explore the intricacies of deep learning-based decision-making architectures and their components. ADS are designed to operate independently by processing streams of incoming data from different on-board sensors. These can include cameras, radars, global positioning systems (GPS), light detection and rangings (LiDARs), ultrasonic sensors and many more.

Various components of ADS architectures are usually based on AI and Deep Learning technologies but are not limited to these. Sometimes a classical approach is taken that involves non-learning-based components. Nonetheless, these systems still have a common architecture at its core: perception, localization, high-level planning, low-level planning (behavior arbitration) and motion controllers. The system may consist of an end-to-end learning approach where the sensory input data is mapped to motion controllers or of an action pipeline-based approach where decisions are computed in a pipeline-based fashion [9].

2.1. Key technologies

The ADS systems involve multiple components such as computer systems, robotics, mechanical engineering, machine and deep learning, communication, systems engineering and many more resulting in a complex autonomous device of its own. The actual computing system usually includes a set of similar technologies to benefit from its advantages and overcome the disadvantages of the devices on-board. For example, the ADS system usually includes a variety of sensors: cameras, radar, LiDAR, ultrasonic sensors, and GPS.

Cameras play a pivotal role in the sensor suite of autonomous vehicles, contributing to their ability to perceive and interpret the surrounding environment. Cameras are primarily employed for environmental perception, capturing visual information from the vehicle's surroundings. They act as the «eyes» of the autonomous system, providing a real-time feed of the road, traffic, pedestrians, and other relevant objects. The cameras give a straightforward 2D view of the surroundings, making it useful for object classification and lane detection. Lane markings, road edges, and other lane-related information are extracted from the camera feed. Additionally, cameras contribute to tracking the vehicle's position within the lane and adjusting its trajectory accordingly. However, cameras also face challenges such as adverse weather conditions, low-light situations, and potential occlusions. To mitigate these challenges, sensor fusion and redundancy strategies are often employed, combining camera data with information from other sensors to enhance overall reliability and safety in autonomous driving systems.

Whereas cameras capture visual information in the form of images or video frames using visible or infrared light, radars use radio waves to detect objects and measure their distance, speed, and angle. They provide long-range detection and are less affected by environmental conditions but typically have lower resolution. The generated data size of radars is small: around 10-100 KB per second [10].

Like radars, LiDARs emit laser beams to measure the time it takes for the light to reflect off objects, providing precise distance and 3D mapping. They have long-range detection and high resolution in three dimensions, providing detailed spatial information. The performance is also notably good. LiDARs are widely used in object detection, distance estimation and edge detection of still objects. The sensor is less effected by weather conditions than camera, but the competitive cost is high, which restricts its wide adoption in ADS.

2.2. Critical ADS tasks

The utilization of machine learning, particularly deep neural networks, is a cornerstone in autonomous driving. The entire task of navigating through a city can be subdivided into six major components: road detection, lane detection, vehicle detection, pedestrian detection, collision avoidance and traffic sign detection.

Road detection aims at recognizing road boundaries and other areas where autonomous vehicles are allowed to drive. A common practice is to use convolutional neural networks (CNNs) for such tasks. There are also other works presenting an end-to-end model called RBNet for road detection in a single network [1]. Lane detection, like road detection, is responsible for keeping within the vehicle lane on roads, thus, ensuring vehicle safety and minimizing risk of collision.

Vehicle and pedestrian detection are vital part of ADS system. It must recognize other vehicles and objects, and estimate their sizes, shapes, and relative speed to navigate around the city. Pedestrian-vehicle accidents are a common issue. The ADS need to learn to differentiate humans from other objects, track all possible pedestrians to avoid collision. Wang et al. proposed a new system with pedestrian body parts semantic detection using DNNs and contextual information to build accurate location [11].

2.3. ADS architectures

A robust architecture is directly responsible for ADS system performance. It defines how the entire system is controlled and managed. A good system architecture can help autonomous vehicles computer and analyze voluminous amounts of data more efficiently and produce better predictions. There are many approaches to how to design these systems.

One popular approach is an ego-only system. This system carries all the necessary technology on board and is independent of other ADS vehicles, always making driving decisions in a single self-sufficient manner. Whereas connected ADS may or may not depend on each other, which is decided by the infrastructure and situation on the road, and the need to exchange the information when such arises.

Another approach is a modular system [12]. It is structured as a pipeline linking together different components of sensory input. The typical pipeline looks like feeding data streams from sensors into object detection and locations modules. The produced information is then used for scenery prediction and navigation; decision-making is generated and fed to the control module. The advantage of such a system is in its modularity, but so is its disadvantage: the error is propagated along the entire pipeline with small errors resulting in major system failures.

The third approach was mentioned earlier: end-to-end driving. This approach revolves around the model trying to imitate an expert human driver. This approach is not fully end-to-end though, as it needs an additional step to generate the driving actions. But the question here is should the ADS system drive like a human or not? The end-to-end driving approach is an emerging promising technology. It learns to interact with the environment through repeated failures, but lacks safety-measures and interpretability, making it unpopular.

3. Challenges and corner cases

The pursuit of autonomous driving technology leads to groundbreaking advancements and rapid adoption, equally, a spectrum of intricate challenges and corner cases. As engineers and researchers push the boundaries of innovation, they grapple with scenarios that transcend the ordinary, demanding solutions that can navigate the unpredictable intricacies of real-world environments.

In recent years, the number of news or road accidents involving ADS systems that led to fatalities has increased. Early adoption of self-driving vehicles had led to five cases of ADS failures: four of which are attributed to Tesla and one to Uber [13]. The first two cases happened in 2016. The autopilot failed to recognize the truck in both cases, taking it for open space the second time. On the third incident the ADS system failed to recognize the highway divider in 2018. And in 2019 the autopilot crashed unable to recognize the semitrailer. With regards to Uber, the ADS system failed to recognize pedestrians walking.

There are many challenges that researchers and engineers must overcome to make automated driving safe. One such challenge is how to handle irrational or unpredictable human behavior. Human drivers remain a formidable challenge for autonomous systems. From unpredictable decision-making at intersections to sudden lane changes, interpreting and predicting human actions present complex challenges that require nuanced solutions. Handling the idiosyncrasies of human behavior in diverse cultural and driving contexts adds an additional layer of complexity.

Another challenge is adverse weather conditions. More particularly, poor illumination and changing appearance. The main drawback of using cameras has to do with lighting conditions. It is inherently difficult to deal with low-light conditions. For example, snow may drastically change the appearance of city streets or roads, hiding the key features of scenes such as road lanes. To solve this issue, a sensor fusion strategy is employed as described above. Although, these strategies are not robust. Driving in direct sunlight may cause problems to ADS vision systems anyway as it is also susceptible to direct sun glare. Paul et al. proposed a combination of HDR algorithms to improve autopilot's performance [14].

There is also an ongoing debate on how to handle failure detection and diagnostics. How to define sensor failure? What constitutes failure? There is no pre-defined standard. Moreover, there is no reliable study or standard on how to detect sensor failures. Even if the sensors are working properly, how should the sensor data failure be detected in real time scenarios? The sensors may be working correctly, but the generated data may not reflect the actual scenario. An example may be sensor blocking or occlusion. The last type of failure is algorithmic. Hazardous weather conditions may directly affect algorithm's performance. Sometimes utilizing priorly collected information is important. Therefore, developing robust algorithms still proves to be a challenge.

Autonomous driving systems also pose a new challenge to their developers: cyberattack protection. With a wide adoption of autonomous cars cybersecurity becomes an important part of ADS. There is no absolute security, but basic protection from spoof attacks, denial of service makes it vital for human safety. The data streams must be checked before proceeding further to sensor fusion. For instance, an occluded roadblock detected by radars may be corrected by the camera data and vice versa.

Lastly, the final issue is to manage ADS energy consumption, effectiveness, and costs. Finding the balance between the three proves to be a real challenge.

4. Conclusions

The journey toward autonomy is defined by breakthroughs in sensor technology, artificial intelligence, deep learning algorithms, connectivity, and mapping. Sensor fusion, a linchpin of perception in autonomous driving, intricately weaves data from an array of sensors to create a nuanced understanding of the vehicle's surroundings. However, the journey is not without its tribulations.

Safety concerns loom large, necessitating meticulous attention to unpredictable variables such as adverse weather conditions, erratic human drivers, and unexpected obstacles. The regulatory and legal landscape poses a puzzle, demanding swift attention to establish comprehensive frameworks governing autonomous driving. Ethical dilemmas cast philosophical shadows, requiring a delicate balance between societal values, legal considerations, and technological capabilities.

The imminent widespread adoption of Automated Driving Systems (ADSs) holds promises and social challenges. The advent of smart cities, propelled by AI adoption and enhanced Deep Learning algorithms, envisions a shift towards sustainable, efficient urban living. The rise of Mobility as a Service (MaaS) emerges as a transformative force, potentially improving the quality of life for the entire population and reshaping the landscape of vehicle ownership.

The diverse architectures of ADSs, from ego-only systems to modular pipelines and end-to-end driving approaches, offer insights into the myriad ways researchers and engineers approach the design and functionality of autonomous systems. Each architecture comes with its advantages and challenges, emphasizing the need for ongoing innovation and refinement.

References

[1] Muhammad, K., Ullah, A., Lloret, J., Del Ser, J., & de Albuquerque, V.H.C. (2020). Deep learning for safe autonomous driving: Current challenges and future directions. *IEEE Transactions on Intelligent Transportation Systems, 22(7), 4316-4336*. https://doi.org/10.1109/TITS.2020.3032227

[2] Goverments Report. (2022). The number of road accidents in Kazakhstan increased by 8.9%. *Retrieved from*: https://www.gov.kz/memleket/entities/pravstat/press/news/details/444039?lang=ru

[3] Singh, S. (2015). Critical reasons for crashes investigated in the national motor vehicle crash causation survey. Washington, DC, USA, Tech. Rep. DOT HS 812 115. *Retrieved from*: https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115

[4] Montgomery, W.D., Mudge, R., Groshen. E.L., Helper. S., MacDuffie, J.P. & Carson, C. (2018). America's workforce and the self-driving future: Realizing productivity gains and spurring economic growth. *Securing America's Future Energy, Washington, DC, USA. Retrieved from*: https://avworkforce.secureenergy.org/wp-content/uploads/2018/06/Americas-Workforce-and-the-Self-Driving-Future_Realizing-Productivity-Gains-and-Spurring-Economic-Growth.pdf

[5] Moreno, C., Allam, Z., Chabaud, D., Gall, C. & Pratlong, F. (2021). Introducing the «15-Minute City»: Sustainability, resilience and place identity in future post-pandemic cities. *Smart Cities, 4(1), 93-111*. https://doi.org/10.3390/smartcities4010006

[6] Yurtsever, E., Lambert, J., Carballo, A. & Takeda, K. (2020). A survey of autonomous driving: Common practices and emerging technologies. *IEEE access, (8), 58443-58469*. https://doi.org/10.1109/ACCESS.2020.2983149

[7] Standatrs. (2016). Taxonomy and definitions for terms related to driving automation systems for on-road motor vehicles. *Retrieved from*: https://www.sae.org/standards/content/j3016_201401/

[8] McFarland, M. (2019). Who's Responsible When an Autonomous Car Crashes? *Retrieved from*: https://money.cnn.com/2016/07/07/technology/tesla-liability-risk/index.html

[9] Grigorescu, S., Trasnea, B., Cocias, T. & Macesanu, G. (2020). A survey of deep learning techniques for autonomous driving. *Journal of Field Robotics, 37(3), 362-386*. https://doi.org/10.1002/rob.21918

[10] Liu, L., Lu, S., Zhong, R., Wu, B., Yao, Y., Zhang, Q. & Shi, W. (2020). Computing systems for autonomous driving: State of the art and challenges. *IEEE Internet of Things Journal, 8(8), 6469-6486*. https://doi.org/10.1109/JIOT.2020.3043716

[11] Wang, S., Cheng, J., Liu, H., Wang, F. & Zhou, H. (2018). Pedestrian detection via body part semantic and contextual information with DNN. *IEEE Transactions on Multimedia, 20(11), 3148-3159*. https://doi.org/10.1109/TMM.2018.2829602

[12] Chen, C., Seff, A., Kornhauser, A. & Xiao, J. (2015). DeepDriving: Learning affordance for direct perception in autonomous driving. *IEEE International Conference on Computer Vision (ICCV), 2722-2730*. https://doi.org/10.1109/ICCV.2015.312

[13] Paul, N. & Chung, C. (2018). Application of HDR algorithms to solve direct sunlight problems when autonomous vehicles using machine vision systems are driving into sun. *Computers in Industry, 98, 192-196*.

Автономды жүргізудің жалпы тәжірибелері мен міндеттеріне шолу

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Аңдатпа. Автономды жүргізу технологиялары соңғы жылдары айтарлықтай назар аударып, көлік жүйелеріне трансформациялық әсер етеді. Көлік индустриясы жүргізушіге көмек көрсетудің озық жүйелерінен (ADAS) толық автономды көліктердің өршіл мақсатына дейін көліктердің автономиясына қол жеткізуге бағытталған терең өзгерістерді бастан кешіруде. Бұл мақалада автономды жүргізудің күрделілігіне тереңірек үңіліп, осы парадигманың ауысуына әкелетін жетістіктерді де, оның күнделікті өмірге біркелкі енуіне кедергі болатын күрделі қиындықтарды да зерттейміз. Автономияға апаратын жол дәл навигация үшін сенсорларды біріктіруге маңызды назар аудара отырып, сенсорлық технологиялар, жасанды интеллект және коммуникациялардағы жетістіктерді қамтиды. Шолу машинаны оқытудағы, компьютерлік көру және сенсорлық технологиялардағы негізгі жетістіктерді көрсетеді, олар автономды жүргізу жүйелерін негіздейді және олардың қазіргі мүмкіндіктері мен шектеулері туралы түсінік береді. Бұл шолудың синтезі зерттеушілер, практиктер және жалпы жұртшылық арасында ақпараттандырылған пікірталасқа жәрдемдесіп, автономды жүргізудің қазіргі жай-күйін тұтас түсінуді қамтамасыз етуге бағытталған. Жетістіктерге де, қиындықтарға да жарық түсіре отырып, бұл құжат автономды көлік жүргізудің болашағы туралы жалғасып жатқан дискурсқа үлес қосады және осы трансформациялық технологияны кеңінен енгізуге тән қиындықтарды шешуге арналған стратегияларды әзірлеу туралы хабарлайды.

Негізгі сөздер: *автономды көлік, өзін-өзі басқаратын көлік құралдары, жасанды интеллект, сенсорлар, терең оқыту.*

Обзор распространенных практик и задач автономного вождения

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Аннотация. В последние годы технологии автономного вождения привлекли к себе значительное внимание, обещая преобразующее воздействие на транспортные системы. Транспортная сфера претерпевает глубокую трансформацию с акцентом на достижение автономности транспортных средств, начиная от передовых систем помощи водителю (ADAS) и заканчивая амбициозной целью создания полностью автономных транспортных средств. В этой статье мы углубимся в сложность автономного вождения, исследуя как достижения, способствующие этому сдвигу парадигмы, так и сложные проблемы, препятствующие его плавной интеграции в повседневную жизнь. Путь к автономности предполагает прорывы в сенсорных технологиях, искусственном интеллекте и средствах связи, при этом решающий упор делается на объединение датчиков для точной навигации. В обзоре освещаются ключевые достижения в области машинного обучения, компьютерного зрения и сенсорных технологий, лежащих в основе систем автономного вождения, а также предлагается понимание их текущих возможностей и ограничений. Обобщение этого обзора направлено на то, чтобы обеспечить целостное понимание текущего состояния автономного вождения, способствуя информированным дискуссиям среди исследователей, практиков и широкой общественности. Проливая свет как на достижения, так и на проблемы, этот документ вносит свой вклад в продолжающийся дискурс о будущем автономного вождения и дает информацию для разработки стратегий для решения сложностей, присущих достижению широкого внедрения этой преобразующей технологии.

Ключевые слова: *автономный транспорт, самоуправляемые транспортные средства, искусственный интеллект, сенсоры, глубокое обучение.*

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