RECENT ADVANCES IN AUTONOMOUS VEHICLE TECHNOLOGY

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Abstract

Some new and remarkable innovation in the field of artificial intelligence, computer vision, control, and instrumentation have given contribution in development of autonomous vehicle technology. These recent advances make the autonomous vehicle possible will be on the road in the few decades. Because many of autonomous vehicle prototype have been tested and validated through miles of road experiment. Several top car manufactures and automobile industries have invested incredible amount of money in order to prepare the autonomous car entering the global market in the future. However, some challenges and issue are still need to be addressed in order to achieve the goal. Several technical and non-technical problems of autonomous vehicle remain unsolved for researchers, engineers, automobile industry leaders, and government. Several technical problems such as algorithm design, complex software simulation, sensors failure, and testing and validation on the road, which are still confuse and complicated for researchers and engineers. While, some non-technical problems such as government policy, insurance, and consumers satisfying are some problems that also still need to be addressed. Therefore, this paper presents a review of current development in autonomous vehicle technology. In this paper, we review some factors that are essential for the evolution of autonomous technology such as environment factors, model learning, navigation and path planning, sensors and instrumentation, testing and validation model, computer vision, and control and maneuvering. These applications are considered to be give impacts on the development of this autonomous vehicle. Thus, development of autonomous vehicle technology in terms of research result and innovation, has research a level of satisfied, however many efforts and researches are still needed before the vehicle entering the commercialized world.

Keywords: autonomous vehicle, artificial intelligence, computer vision, control, sensor and instrumentation

I. Introduction

In the next few decade, the human population will grow rapidly, which is lead t o some problems on earth, one of the problems is congestion due to the increase of the number of cars on the roads. This congestion problem lead to stressfull eff ect on the transportation infrastructure also such as the roads, parking lot, and fu el and charging station[1].

The number of vehicle ownership is increase rapidly due to the low cost of vehicle and the increase of people incomes. However, the growth number of vehicle on the road lead to increase of pollution and congestion [1][2]. Transportation infrastructure and energy resources also in high demand to support this large amount of vehicles. Therefore, a reliable and advanced transportation system is urgent to meet these expectation.

Implementation of autonomous vehicle as a part of intelligent transportation sy stem (ITS) is an effort to improve safety traveling, human convieniencece, solve c ongestion problem, human mobility, energy and time efficiency. The motivation b ehind development of autonomous vehicle is mainly due to of reducing car accid ents, growth of population cars occupy on the road, and improvement of infrastru cture.

An autonomous vehicle mainly is a computer car that is operated without hu man interaction. This future vehicles transform mechanichal vehicle into electroni cs vehicles which is accomplished with high-end sensing environment, fast decisi on, operate and navigate without human intervention, and maneuvering ability [1]. The vehicle technology basically is an integral application of advance technology such as information technology, control and algorithm, sensors and instrumentati on, etc. [3]. It evolution is closely relate to development in the fields of communication, embedded technology, navigation, sensor technologies, data acquisition and analytics [1]

Efforts to create a safe transportation mode have been conducted since the past few decades by implementing instruments technologies such as CCTV cameras, road sensors, and more [1] [4]. However, road accidents in the United States alone caused more than 35.000 in 2015 due to human error even these static technology have been implemented [5]. Therefore, many research have conducted in the field of connective autonomous vehicle and autonomous car in order to minimize accidents due to human errors and upgrade convenient transportation in the future.

This paper is organized as follows, section 1 is a general introduction of the motivation behind the emergence of autonomous vehicle and some technical aspect for autonomous vehicle development, section 2 is about environmental factor and its impact on development of autonomous vehicle, section 3 is about navigation and path planning factor in development of autonomous vehicle, section 4 is about model learning which is used in development of autonomous vehicle, section 5 is about sensor and instrumentation overview which is usually implemented in autonomous vehicle, section 6 is about testing and validation model for autonomous vehicle, section 7 is about computer vision implementation in autonomous vehicle, and section 8 is about control and maneuvering development in autonomous vehicle

The goal of this paper is to review recent development in autonomous vehicle technology based on some important technical aspect in the field of artificial intelligence, computer vision, control, and instrumentation which considering essential for the vehicle technology evolution. Therefore, this paper presents an extensive review of the recent research results and innovation for autonomous vehicle development including its technical design, implementation, testing and verification.

2. Environmental Factor and Its Impact on Autonomous Vehicle Technology

Driving environments have an important role in development of autonomous vehicle technology, which are include road geometry, road conditions, parameter uncertainty from environment, recognition, object avoidance, lane detection and auto-positioning. Recently, many autonomous vehicles have been able to run in any kind of road geometry from simple geometry until complex geometry such as narrow curve. Drive in narrow curve is the autonomous vehicle most challenge task because the vehicle could fall into drifting condition if it could not control its speed and follow the predefined path.

Currently, CNN has able to generate a smooth control commands to run autonomous vehicle in a curves road, even though it just stay for a short time[6]. While develop an integral lateral and longitudinal control also assure that the vehicle could track a curved road with various speed [7]. Other approach is develop an algorithm with modified velocity in order to generate a steering command that able to follow a circle predefined path, the algorithm name is Linear Parameter Varying (LPV) [8]. Moreover, Oh et all [9] also have been developed a reinforcement learning algorithm that has good tracking performance in curvature roads, the algorithm also able to control many uncertain parameter from imperfect road and challenging environment. Uncertain environment parameter also need to be considered in developing this technology, indeed, Hu et all in [10] and Baselga et all [11] have developed a robust $H\infty$ output-feedback control algorithm that able to track predefined path with consider disturbances and uncertain parameters from environment from the vehicle its self.

Lane detection, object detection, are other factors in environment that need to be addressed in autonomous vehicle technology. Recent technology in autonomous vehicle have been able to detect any lane marker or object also visual guidance especially autonomous vehicles that use artificial intelligence for computer vision purpose. Indeed, Bojarski et all [12] have been developed convolutional neural network algorithm for autonomous vehicle that able to learn the vehicle to drive on the road even without lane marking and unclear visual guidance. The vehicle only needs a limited amount of data to drive in a diverse environment such as highway or local roads in any kind of weather condition, sunny, cloudy, or rainy condition. However, the algorithm still need more efforts to improve its performance and robustness [12]. Another research also report that existing CNN shows remarkable result in lane detection and also other car detection in real time system [13]. Indeed, Chen et all [14] have experimented a deep convolutional neural network for autonomous vehicle prototype in a real driving environment.

In addition, road condition also crucial in developing autonomous vehicle technology. A research by Kuuti et all [15] has successfully developed autonomous vehicle that robust enough to track all driving scenario and even learn a new driving scenario. They use deep learning approach to teach their autonomous vehicle. Moreover, many research have proofed that autonomous vehicle able to drive in any kind of landscape even in difficult urban environment condition. A research by Turri et all [16] has shown that autonomous vehicle able to drive on a slippery road with low curvature shape. They use multi predictive control approach to keep the vehicle inside the lane and avoid any obstacles around it. Moreover, a research which is conducted by Goh et all [17] reported that autonomous vehicle perform well even in 45° high sideslip drifting values in curvature road. Although drifting always force vehicle to work beyond its limits, but the submodules demon_x0002_strate can follow predefined oval tracks robustly at the friction limits, the experiment conducts in simulation and real driving environment.[18][19]

Furthermore, the real autonomous car future environment is too complex and unpredictable and there will be unexpected condition that beyond normal driving condition that even human may fail to drive the vehicle along the road. Therefore further research need to be conducted before the car commercialized [20] [21].

3. Navigation And Path Planning

A good design path planning can generate control algorithm for maneuvering such as lane keeping, lane changing, object avoidance, etc [22] [23]. Indeed, recent autonomous vehicle technology has being able to perform fast maneuvering in order to avoid obstacles [6].

A lane change maneuvering research is conducted by Van et all [24] has shown an amazing result through experimental tracking for various trajectories. Another research also in automated lane change behavior is a completed by Wang et all [25] that able to lane changing in normal condition and even in unexpected driving condition. Lanes change can perform smoothly and efficient if autonomous vehicle able to avoid obstacle in the proving ground by overcome nonlinear constraint from vehicle model using optimization problem [26].

Moreover, lane detection also crucial in navigation and path planning, Song et all [27] developed a robust lane estimator to measure both lanes even are not detected by vision sensor. This lane estimator is designed with Kalman filter which result nearly precise estimator for lanes detection. Futhermore, autonomous vehicles also shows of good performance in lane keeping and obstacles avoidances for a low curvature and slippery road by using model predictive control formula and decoupled lateral and longitudinal motion control [16]. However in crowded road is still difficult for autonomous vehicle to work on changing lanes, avoid obstacles and also keep distances with other cars [24]. Apart from all the maneuvering and object detection research, Bojarski et al [12] show that autonomous vehicle is no more need to detect lane marking, also avoid the need to plan the trajectory and control. This approach using convolutional neural network algorithm and only need a small amount of data training to learn, however there is still need effort to improve its robustly condition.

4. Model Learning

Artificial Intelligence algorithm is essential for developing an autonomous vehicle. Recent advance technology in autonomous vehicle, mostly arise because of proper design of artificial intelligence algorithm such as deep learning, convolutional neural network, reinforcement learning, etc [28] [29] [30].

Deep learning is AI algorithm that highly apply in autonomous technology, but beyond deep learning there is “end to end” algorithm which also highly interesting for most autonomous vehicle manufactures and researchers. The benefit of applying end to end learning is the developer can eliminate design control system and motion planning by hand and directly take the input data from raw sensor data, which make the design process simple and efficient [12] [23]. However, Devineau et all [6] argue the safety level of autonomous vehicle using this end to end approach due to the simplify methods that only depend on its software[31]. Devineau et all [6] recommend end to end approach is used only in highly dynamic situation such fast maneuver in order to avoid obstacles, and its lateral and longitudinal dynamics should be coupled in order to overcome vehicle's limitation. While in normal situation is better to use decoupled rather than coupled lateral longitudinal end to end approach

In addition, Bojarski et all [12] shows the remarkable research result of end to end approach with CNN algorithm. This approach able to make the autonomous vehicle drive in traffic roads even without lane marking and unclear visual guidance, and this approach only using a limited amount of data to make the autonomous vehicle learning [12]. CNN is popular for computer vision application, so that CNN is often used in lane detection and object detection application and its always shows satisfied performance [13]. Indeed, A deep CNN can predict driving affordance of autonomous vehicle directly from a mapping images data, the algorithm perform good and robust both in simulation environment and real driving environment.[14]. Moreover, CNN capable to learn complicated nonlinear model and detect data images as well as planning the area for driving in front of ego vehicle.[32]. While, a deep fully convolutional neural network which is proposed by Badrinarayanan, able to develop an efficient image processing and analysis based on memory space and computational time [26] [34].

Another end to end approach which use deep learning algorithm has been able to improve its performance by combine autonomous vehicle dynamics and computer vision[35].[36], this is because of deep learning is popular in computer vision also appropriate for complex nonlinear model such as autonomous vehicle, indeed it even able to learn rules in new trajectory.[15]. On the other hand, A reinforcement learning algorithm capable to make autonomous vehicle to learn change lane autonomously in various scenarios and even unpredictable scenarios. Another idea is combine reinforcement learning and model predictive control in order to improve autonomous vehicle performance [26]. Moreover, reinforcement learning approach also can build a novel dynamic control architecture to support a high-speed vehicle that run in high curvature road. This research result shows an accurate tracking performance and autonomous vehicle also overcome many uncertainties from nonideal road.[20][36] [37].

In addition, supervised learning can be combined with control barrier functions in order to ensure autonomous vehicle safety and optimize trajectory problem for complex nonlinear model such as autonomous vehicle.[38] [37].

5. Sensors and Instrumentation

5. 1. Sensors

Autonomous vehicle sensors varies from affordable cameras to expensive LID AR, radar,sonar, and optimized GPS which is completed with digital maps. These sensors for object detection purpose in any kind of environment condition as well as thermal infrared for living organism detection[1].[3].

A low-cost camera in smart phone can be used as a sensor for a vision-based controller. This system using FLC approach and work to predict position and speed of vehicle [39]. Cameras are affordable and could generate a lot of images data for autonomous vehicle, cameras also provide reliable data if it is supported by advanced computer vision [3]. Even though cameras are quite proper to view vehicles surroundings, but the vehicle still needs devices that can convert the images data and proportional compute the speed of real-time data. Therefore radar technology is more efficient than cameras especially in tracking objects [1]. Radar quite sufficient for detecting object, but unable to distinguish various metal object, and hard to define objects position, so that it is not efficient to use in sharp bend road. While sonar only working properly in short range but it is suitable both high and low speed vehicle [3]. A long range radar can provide long range traffic view. Another option is LIDAR that capable to view 360-degrees long-range surrounding view and long-range object detection, therefore LIDAR usually mounted on top of the vehicles so that can view the surrounding easily. However LIDAR is not compatible for collision avoidance, parking resistance, bumper protection, but radar capable to do that functions [1]. LIDAR is also an expensive sensor and complex in installation [3]. Otherwise, Infrared devices can be used to avoid crash between front and rear bumper, short range radar function for lane-changing warning, detect object in short range and provide road traffic view. These devices then input real time data to vehicle processor in order to be processed, the processed data is then sent to decision support system in order to control speed, apply brake, apply lane change maneuvering and other maneuvering form in autonomous vehicle. All these devices are in network devices architecture that working cooperatively [1].

In addition, GPS also usually is used in autonomous vehicle, however GPS ha s its own weakness, in certain scenarios, GPS on its own is not suffificient. Since GPS is based on signals from in-orbit satellites, the signals may sometimes get bl ocked or deteriorated due to natural or artifificial phenomena, such as undergrou nd roads and tunnels. In such as cases, other means of inertial guidance and nav igation [1]. Therefore, gyrosopes and accelerometers are usually used to be com bined with GPS in order to generates online map for the vehicles. Some research in autonomous vehicle focus on testing the vehicles in real driving environment a nd creates online maps data from it [40] [2].[1].

A sophisticated LIDAR, an accurate GPS, and cameras, can generate a large video data which available for lane marking in any kind of weather conditions (rai n, snow, night, day.etc) [41] [3].

Moreover, besides various sensors, autonomous vehicle also is provided with numerous actuators, and communication devices to produce a lot of real time data. Many automobile manufacturers build on-board sensor and actuators that capable to do many features for autonomous vehicle property. These data is then processed by vehicles' processor and decision support system that is called Electronics Control Units (ECUs) in order to maintain many manouvers such as la ne changes, lane keeping, avoidance bumper coallision, control brake and speed etc [1]. For instance, an autonomous vehicle processor is NVIDIA DRIVETM PX that operates 30 frames per second [12] and The Berkeley DeepDrive Video data set (BDDV) is a dataset contains of real driving sources videos and GPS/IMU dat a that is appropriate to train autonomous vehicle [42]. Another on-board ECU, na mely AutoRally, which is developed based on a 1:5 scale RC chassis constist of s omse sensors and computational processing onboard. Computation processing i nclude neural network forward inference and model predictive control computatio n. The equipment can perform maneuvers with maximum spedd 60 miles per hou r.[32].

5.2. Actuators

Autonomous vehicle often used motors as actuators in vehicles, such as electronically commutated (EC) DC motors, usually it using gears to convert rotational motion into linear motion. These motors should be noise free, vibration free, certain temperature, and resistant to chemical agents and electromagnetic interference in onboard system. Solenoid valve also commonly use in vehicles as electromechanical actuator that convert electricity into mechanical. Another instruments that is often used as actuators in vehicle is stepper motor, which is convert electrical pulses into discrete movement. [3]

In robotics vehicle, an element H-bridge is used to convert low power digital signal into strong power current to power the DC motor. These motors convert electrical current into torque for powering the shaft. DC motors in AVs usually for control rear wheels of a car [3]. Moreover, an autonomous vehicle is also provided with servomotor in order to monitor position and speed of vehicle [3].

6. Testing and Validation Model

Developing an autonomous vehicle usually using some platform such as simul ation, software games, and testing and validation or road test

A real driving experiments is impossible to test in any type of scenario and it a lso high cost due to time and labour as well as its components. So that, autonomous vehicle model need to be analysed in simulation process before it is implemented in a robot vehicle prototype. Simulation can reduce the time to testi ng the vehicle on the road and it is a low cost tools also. Indeed, many simulatio n software also have been adequaite to use in terms of speed and accuracy [4 3]. Moreover, Matlab is often used for develop a driving scenario and simulate cl osed-loop control. In addition, virtual driving scenario can be used to constract r oad, vehicles, cameras and other sensors, road sign, and digital maps in order to create a virtual driving simulation before proceed to real world driving experiment .[44]. Moreover, a vision based controller using smart phone for robot vehicle wh ich is developed by Olson et all [39] also used Matlab. Matlab is used to simulate the system and analyse the model performance and it showed a good tracking p erformance. The model is than applied in a vehicle prototype and has been expe rimented in Universityof Arizona in a parking lot. However, the vehicle still operat es in low speed. Another simulation software, namely Caffe software, can also b e used for autonomous vehicle simulation. Jo et all [31] used Caffe to validate their deep learning approach, this method characteristic is consider its vehicle dynamics in controlling its steering angles. The simulation results shows a better performance than a vehicle control without considering its model dynamics.

CarSim also a car simulation software that is often used by researchers. CarSim is sophisticated software to simulate many algorithm and control method for vehicle, and also can construct many virtual scenarios [45] [46]. Fenyes et al l [8] also used CarSim to simulate a robot vehicle model which is controlled by a machine learning algorithm in their research. On the other hand, Jo et al.[47], [48] also developed a software architecture, AUTOSTAR-light [49], which is and open standard architecture for automative industry and research propose [1].

In addition, a virtual reality, namely Unity also always being a games simulation for testing autonomous vehicle algorithm. A research which is conducted by Alcala et all [50] used Unity for testing a combine nonlinear control method, Lyapunov and sliding mode-control.

Futhermore, a road experiment for autonomous vehicle is an important final design for vehicle in order to validate its performance and safety [51]. Many roads experiment of autonomous vehicle have been done for a long driving trajectory such as an autonomous vehicle which is developed by Bojarski et all [1 2]. The vehicle has been sucsessfully drove about 10 miles in Monmouth Countr y NJ. The prototype is called DRIVETM PX has been experimenced without perf orm lane changes. The prototype is the implementation of robot vehicle model w hich used CNN algorithm. Another, road experiment was also conducted by Broggi et al. [52], experimented an autonomous vehicle which is named BRAin driVE (BRAiVE) at Artifificial Vision and Intelligent Systems Lab (VisLab). The experiment is conducted along 13000 km road from Italy to Shanghai. This experiments was refered to as VisLab's Intercontinental Autonomous Challenge (VIAC). VIAC has acrrossed many unknown environments. The prototype was incomplete due to the unavailability of digital maps. However, the problem was solved in 2013, the prototype is called PROUD and it perform faster and better than VIAC, however the developers admits some limitation of the robot vehicles such as its efficiency, speed, and perception which is still need futher research.[1]. Moreover, road experiment in order to validate a lane change maneuvering is conducted by Nilson et all [53]. The driving experiment is conducted on an oval road in Sweden. The experiment vehicle is Volvo V60 completed with cameras, long range radar and a medium radar.

Additionally, a road experiment in order to validate a CNN method also conducted by Chen et all [14]. They are project an input images which correlate with the affordance of road for driving. [14]. Other road experiment is conducted in order to validate a lane estimator especially for curve road lane detection. The lane estimator is designed for substitute of fail vision sensor. The estimator is developed using Kalman filter that can estimates curve road information, in order to collect lane information [27].

7. Computer Vision

Autonomous vehicle must be able to have a human vision ability in order to identify the road, lane marker, visual guidance, and detect any object surround. Therefore, color information or images sequences is essential in detection road sign, vehicle and other objects. Research which is conducted by Lopez et all [54] shows that the accuracy about 97% of the target can be identified by vehicle vision itself. However, they still work on visual of nighttime images and information based on road shape for detection process. Other work by Chen et all [14] , proposed an autonomous vehicle model based on direct perception. They used a deep ConvNet architecture to predict the future decision of the vehicle and their experiments has been validated in the real environments also [55] [56].

In addition, one of the limitations of computer vision for autonomous vehicle is the limitation of data training that can be hadled by the vehicle. Indeed, Xu et all [42] research able to learn from large scale video data input from monocular camera. The approach used semantic segmentation method and it can predict the future motion of vehicle and improve its performance. Therefore, the size of images or video data is not a problem anymore for robot vehicle. Indeed, autonomous vehicle which is developed by Bojarski et all [12] have being able to drive with limited amount of data training and to drive even without lane marking and clear visual guidance. The vehicle is controlled by CNN algorithm, but more effort is needed in order to achieve robustness and improve performance of the vehicle.This end to end approach is popular among of computer vision for robot vehicle technology. Combining computer vision and vehicle dynamics of autonomous vehicle also can improve the performance of the robot vehicle. This end to end approach used deep learning to predict decision of robot vehicle, it learn driving behaviours from the images data input [27] [57].

Nowadays, images processing application has been improved fast especially for autonomous vehicle technology. The result of visual analysis are similar to human vision, for instance the research that is conducted by Mund et all [58], which use Convolutional Neural Network (CNN), CNN learn processing the image input and also predict the steering angles, the method is called a novel occlusion. Moreover, a research which is conducted by Huval et all [13] also shows that CNN give good performance in detection of all highway lane and vehicles. CNN train the vehicle to identify images input which is taken from camera, Lidar, radar, and GPS and it works proper in real time.

Futhermore, semantic segmentation and classification method have been highly accurate in prediction any images object. However, they are considered as not efficient due to complex algorithm, slow computation, complex architecture design. Therefore, classification and object detection usually use deep learning approach in order to improve their performances and automate processing [49] [59] [1]. So that, computer vision application in autonomous vehicle technology has reach another level, especially with the contribution of artificial intelligence algorithm to learn the vehicle to identify the lane marker of the road and detect any object surround them. Deep learning is one of popular algorithm that highly apply in autonomous vehicle technology, such as the work that is proposed by Chen et al [60]. They took video-images data from LIDAR as input and predict the output representation of video-images data into a three-dimensional (3D) images [1]. Deep learning in vehicle vision transform a 2D input images into 3D images which is essential for motion planning purpose [61] [62] . In another work, Chen et all [63] also used CNN method in order to predict a 3D images from a single monocular camera, they used a semantic segmentation method to classify the object. While, machine learning also has been applied for classification process [1] [64].

In addition, Oh et all [20] said in their research work that the problem of images processing for high speed autonomous vehicle is another problem that need to be addressed. Drews et all [32] in their research work also agree, they said that driving in aggressive task and high speed mode are a challenge for autonomous vehicle especially in terms of perception. Therefore, they developed modified vision-based control that taken benefit from model predictive control approach which also combined with convolutional neural network. The approach successfully able to produce map prediction for driving area in front of vehicle. Moreover, a computer vision application for autonomous vehicle technology can be studied comprehensively in [65] [66] [67] [68].

8. Control and Maneuvering

Control and maneuvering always become an essential part for autonomous vehicle technology. Motion and planning control include trajectory control is one of crucial control problem that need to be addressed in autonomous vehicle technology. Therefore, choosing a control method is essential in developing the robot vehicle [69]. An integral lateral and longitudinal control method is suitable for tracking control, the method help the vehicle to follow the predefined trajectory even a curved trajectory. Other benefits of the method are ensure dynamic stability of vehicle model and also simple and can be applied in any given speed [7]. So that, trajectory planning is essential step in developing autonomous vehicle technology [70] [71]. On the other hand, a research by Wang [25] proposed an optimal trajectory planning for task such as lanes changing, obstacles avoidances on a busy road. Their research shows a safe and comfortable driving and maneuvering using their developed approach.

Autonomous vehicle is known as a complex highly nonlinear model[11]. Therefore, nonlinear control approach is often used to solve the problem of nonlinear model such as autonomous vehicle. Lyapunov method and sliding mode control are popular method among nonlinear control in creating robustness to solve nonlinearities and parameter uncertainties from the vehicle model. A work by Bajpayee et all [3] has validated the combine control algorithm (lypunov and sliding mode control) in Unity, a car simulation software. Both controllers have shown a robust performance of autonomous vehicle. Moreover, a nonlinear controller such as backstepping and forward control are developed by Jiang et all [22] . Their goal is to solve asymptotic stabilization problem of nonlinear autonomous vehicle model and control the lateral motion of the vehicle. This approach is used for lane change maneuvering and the research result shows good tracking performance. However, there is still need more effort to control the lateral dynamics of vehicle model with considering disturbance and parameter uncertainties. While, Dai et all [72] also proved that nonlinear control is powerful strategies in solving nonlinear problem. In their research work, they used two nonlinear control strategies which are Lyapunov direct method and sliding mode control method. Both controllers shows robust tracking performance and successfully eliminate nonlinearities which arise from parametric uncertainties and noise.[50] .

In addition,a control approach which also good enough for solving control problem in autonomous vehicle is a vision-based control. This approach can be developed by using a low-cost vision sensor of a smart phone. The approach used a fuzzy logic controller in order to control speed of the lead-follower system [39]. However, the vision-based lane detector sometimes fails, so that a lane estimator based on Kalman filter can be developed. The developed method can give curvature information accurately and it works efficiently even when both sides lanes fail to detect. The simulation result shows the robustness from the proposed method.[27].

Complexity in vehicle lateral control usually arise when consider lateral velocity,

especially when it is measured with low-cost sensors. Therefore, an approach which is called Robust H∞ output-feedback control is developed in order to be able to track the trajectory without lateral velocity information. The developed controller also can overcome external disturbances and from the vehicle and environment [10]. While, a combine of adaptive-pursuit controller and scheduled feed-forward PID controller also sophisticated enough to control lateral motion and longitudinal motion. This approach gives a good path tracking performance and also realize obstacle avoiding task. The approach also can overcome nonlinear constraint from the vehicle model that produce a good lane change maneuvering [24]. Another research related with lateral motion is a work by Dollinger et all [73]. The active yaw control method, is an approach to achieve lateral acceleration. This method can reduce the time to testing vehicle on the road experiment and also can remove human intervention when vehicle achieve stability limit. So that this experiment can skip simulation process and it is directly implemented in autonomous vehicle for road experiment.

Furthermore, a model predictive control also often uses in autonomous vehicle control system due to the remarkable result of this system. A work which is conducted by Dai et all [72] combine model predictive control with adaptive preview characteristic. The result is sophisticated enough for a safe path tracking task, and consider preview characteristic of driving while the vehicle speed is kept constant. In autonomous driving, model predictive control approach can also control longitudinal motion as well as solve the control problem that arise from lateral interruption such as oscillation, overshoot, and cut-ins from adjacent lanes. The model has been experimented in car simulation software, CarSim, but has not been validated in road experiment.[46]. While, a novel NMPC is also presented by Laurence et all in their research [74]. The approach able to perform integrated lateral and longitudinal control in real time mode, and it also can drive close to the limit of tire-road friction. Other approach related with friction limit in vehicle tire-road is developed by Kritayakirna et all [18]. The goal is to drive the vehicle at the friction limits, and the approach shows a robust and good performance of vehicle when tracking the desired trajectory. The model has been validated in virtual environment and real environment on an oval track. In addition, still relate with model predictive control, a work which is conducted by Turri et all [16] research about lane keeping and obstacles avoidances on low curvature roads. They used a linear model predictive control and decouples lateral and longitudinal dynamics. Simulation result shown that the approach able to perform the task even on a slippery road.

Drifting often become a major problem for autonomous vehicle particularly when tracking a curve and slippery road. Indeed, a drifting stabilizing controller is developed by Baur et all [75] that could control vehicle in drifting condition due to the parameter uncertainties and disturbances from vehicle model. While, Goh et all [17] also developed a simple and efficient controller for autonomous vehicle particularly in drifting condition. The approach can perform simultaneous tracking and can track a complex path such as a path with a 45° sideslip value [55].

Conclusion

The popularity of autonomous vehicle is increasing in the last few decades due to some major problems that earth facing today, such as population growth, congestion, energy deficiency, pollution, etc. Many leading companies in automobile industry and university researchers are still researching and developing the new technology for autonomous vehicles. However, developing an autonomous vehicle technology is complex and require concern from many stake holders (government, academia, researchers, engineers, and automobile industry leaders). Although, challenge in autonomous vehicle are divided into two groups, technical and non-technical, this work only reviews some important function which are essential in developing autonomous vehicle technology. This function can be considered as important step and influence factors for developing the robot vehicle, which are includes, environmental factors, model learning, computer vision, control system, sensors and instrument, navigation and path planning, testing and validation. Moreover, autonomous vehicle development still facing more problems and challenges in its development technology particularly in technical aspect such as, planning, control, algorithm, simulation, sensors, and prototype as well as road experiment. In the future, we interested in investigate more about some issue or problems from above factors in order to support research in development of autonomous vehicle.

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