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Comparative study of different controllers in an autonomous vehicle system

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ABSTRACT

In recent days the entire world moving towards autonomous driving vehicle. For the last decades, the world started more research on Autonomous or Auto-pilot vehicle. It faces lot of challenges to design such a system. In recent, Google and tesla designs an autonomous vehicle in the name of waymo. The main aim of this research work is to provide healthy transportation with high safety and security. This waymo vehicle is now under testing with conditional and unconditional environment. In this paper it is focused on a controller part to take care of the vehicle in critical and non-critical environmental situation. In this perception, this research gives the overview of the various controllers with its merits and demerits. The controller is to imitate like a human driver. Normally the human eye focus on mobile and immobile objects, road sign, pedestrian etc., the controller need to focus the road condition, optimal steering control with less tracking error and cruise control.

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1. Introduction

Autonomous driving system is one of the emerging technologies which are under process to deploy in the vehicle for the alternative to the human being. To imitate like a human behaviour, these controllers to be design with multi system and sub-system with multilayer sensor to fetch the real time road condition. And also the controller needs to provide pre-emptive action during the critical condition. There are various controller is available like analog controller, Neural controller, Fuzzy controller, Neuro-Fuzzy controller, Discrete controller etc., First and foremost it is to be divide the controller in three ways, they are Vehicle to vehicle controller (V2V controller), Vehicle to infrastructure controller (V2I controller), Vehicle to pedestrian controller (V2P controller) (Table 1).

In V2V interaction, each vehicle act as a node. It interacts with neighbour vehicle to fetch the data of on-going road traffic prediction. For example if any autonomous vehicle encounters an accident it reports its status to nearby vehicle through wireless transmission. The same information is to be communicated to all upcoming vehicles in the same route. By means of this information the other vehicle may plan the road map in other alternative way. In V2I interaction provides the intelligent parking system. Before it reaches the destination it gets the reserved place for parking. In V2P controller it gets the upcoming pedestrian details through LiDAR sensor or some imaging sensor in advance.

2. Related works

Shaobing Xu et al. [1], In this paper analysed with two nested control for lane keeping control in autonomous vehicle. One is feed forward control / preview control to forecast the environment like future lane curvature and another one is feedback control for to stabilize the tracking error. With the help of preview control algorithm it easily gets the details of the uncertainties and fed to the feedback control to optimize the tracking operation. Here the safety barrier control also developed for bounded tracking problem [1]. It acts as a supervisor to the preview control [1]. This barrier control is active only when the tracking lane elevates out of or close to boundary. This nested controller developed and tested with Mcity autonomous vehicle. The test result produces more accuracy for lane keeping and ensures the safety.

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Kazuhide Okamoto et al. [2], In this article to mimic the human behaviour for autonomous vehicle, here used three different category namely, mediated perception (MP), behaviour reflex (BP) and direct perception (DP) [2]. In mediated perception the environment objects are detected with different sensor and construct the real world to the autonomous vehicle [2]. Based on the virtual view it generates the control action. To bring the real world environment it has to have multiple sensors to detect the objects. It leads cost sensitive to develop the autonomous vehicle. In behaviour reflex (BR), it uses end to end conventional neural network (CNN) training mechanism. Developing in end to end method has the problem of interpretability. To avoid the issues in the above two mechanism it has developed direct perception (DP). It proposes two-point virtual control driving model (TPVDCM). It exactly reconstruct the road view of two point method and based on that it decide the control of driving acceleration, yaw angle etc.,

Hamid Taghavifar [3], This paper focuses on the effective controller design for autonomous ground vehicle (AGV) with multi-constraint non-linear predictive controller (NMPC). This controller needs to react to the various uncertainties and try to pull down the transient time for control action. To impart this mechanism it uses the neural network autoregressive with exogenous input assistance [3]. This NMPC controller is not like a single input and single output (SISO), rather it have multi input and multi output (MIMO). Because it fetch the multi-constraint input from environment and it lead to system complexities. This controller is tested with carsim/MATLAB frame work and compared with traditional NMPC. It produces better regression and reduced the transient state during the critical manoeuvres.

Boyuan Li et al. [4], This controller proposed a spatiotemporal-based trajectory planning control. Compared to spatial based method, it handles better stability performance. This trajectory mechanism, have multiple model like, digital maps, behaviour planner, localization and perception system and trajectory controller. The real world vehicle position can be located with the help of perception and localization system. Based on the localization it constructs the digital map. After generation of this map the behaviour planner gives manipulated input to the trajectory controller. Finally it gives the acceleration output with required yaw angle. The trajectory planner has upper level and lower level for localization of the vehicle. First it manipulates the planner with upper level and to optimize the tacking error with the help of lower level. This proposed approach is evaluated with numerical simulator for two wheeler and four wheeler independent steering and independent electric vehicle during junction point and over taking the vehicle one another. The results are showing guaranteed vehicle handling and stability. Based on the future road density, the upcoming complexity is required to test.

Shaobing Xu et al. [5], In this paper a preview controller which is discrete time in nature was designed and tested in autonomous vehicle for the purpose of path tracking control in servo loop. This controller deals with curvature of the road which will be varies with respect to time and other disturbance creating objects those are available in the environment. A finite preview window state vector is formulated by this controller. This preview control have two parts namely, feed forward controller to deal with future road time varying constraint and feedback controller to optimize the tracking error. Usually the tracking error is the main parameter to stabilize the autonomous vehicle but this feed forward control act as an additional control to forecast and report to the feedback controller if there is a large number of tracking error.

Hongtao Xue et al. [6], In this article presented a fuzzy controller for intelligent autonomous vehicle to detect the running environment obstacles. This controller constructed with rough set (RS) and adaptive neuro-fuzzy inference system (ANFIS). This rough set generates the pyramid normalization (PN) for normalizing the state parameter (SP) [6]. It defines the various parameters such as obstacle and target pathway, distance and angle among the vehicle, which helps to improve the performance for the adaptable environment. Then the ANFIS frame a self-position azimuth correction (SPAC) to bring the control action for obstacle avoidance and trajectory tracking. This proposed system implemented in "ROBOCAR" and tested with neural and fuzzy system [6]. The PN-ANFIS controller gives time save of 7.6%, maximum tracking error to 8.1% and mean tracking error 8.5%.

Chuanyang Sun et al. [7], This Model predictive controller is planned to propose for maintain the stability of the autonomous vehicle during transient and steady state. To identify the vehicle situation, a fuzzy logic based classifier is used to classify the autonomous vehicle is in steady state or transient state. The proposed MPC controller is simulated with normal and aggressive way. The result are showing desired path accurately with less switched tracking error for steady state and transient state. The only drawback is, it is not designed with future road side uncertainties.

Chuan Hu et al. [8], This paper investigates the lane keeping control of Autonomous vehicle when the vehicle taking a turn on the road there should be specific angle to rotate, if it exceeds the limit then it will loses the centrifugal force and it is required to maintain it in order to avoid crash or accidents. So, the vehicle rotation is always 90 degrees or more about the longitudinal axis. It is required to track the lane with a minimal error and maintain the angle of rotation of the vehicle on road, both are well defined in a specific road boundaries and it is the proposal of an enhanced sliding mode control. To achieve this, the control function divided into three categories, first the error transformation can be maintained with in a prescribed level by means of varying the control variable, second is maintain the stability during the change of angle when the vehicle taking a turn on the road and closed loop system improve its performance with respect to time. It also maintain the stability of the vehicle by preventing over turning on the curved path and maintain the lane track when the vehicle travelling on the straight road. Third, in the presence of unknown disturbances and saturated value of the input the system meet the requirements of lane keeping and maintain the stability under the roll-over condition with the help of modified sliding mode control (SMC). Finally the effectiveness of this controller is verified with CarSim-Simulink to test the robustness of the proposed controller.

Hazem M. Fahmy et al. [9], This paper presented a developing a risk-assessment algorithm for optimize, particularly in keeping the lane and avoid the collision with obstacles in different velocities. From the various state of the vehicle like position, time sampling, orientation and slip angle of tires [9] the risk assessment algorithm can be defined. The path tracking can be performed more feasibly with low cost by developing this optimization process. The parametric function generated for obstacle and tested for flexible environmental collision avoidance. For the proposed method, four wheeler vehicles is being used and tested for the different surfaces of the track path. The results have been observed in collision avoidance scenarios under different speed conditions. Simulation results are tested between 3 m/s and 18 m/s.

Jingjing Jiang et al. [10], This article contributes to address the approaching towards the given value of stability in nonlinear systems and using the solution to solve the lateral control problem. To develop this by back stepping and feed-forward ideas together is used to minimize the lateral control problem for autonomous vehicle. This proposed controller is producing feasible lane control with reference path with constant speed and lateral deviation converges to zero within a short period. The main feature is, it is not only designed for lane-keeping case, but it also applicable for lane-changing and other cases. When it is created proper path planning, this gives feasible control for autonomous vehicle. This is only

Table 1
Shows comparative study of different controllers in an Autonomous vehicle system.

Ref. No.	Type of controller	Merits	Demerits
[1]	Preview Lane Keeping Control	It uses two nested controller for lane keeping and to face road side dynamics. It gives more accuracy than single controller.	Because of the nested controller, the transient and steady state delay gets increased. Even though it uses preview control during environment dynamics the delay is persisted
[2]	Two-point virtual control driving model (TPVDCM)	This is proposed for imitate the human driver view in virtual using virtual. To attain this, it creates the real environment before take any control action. To bring this it develops an end-end conventional neural network (CNN)	To construct the real time environment it should design with multi-sensor to detect the mobile and immobile objects. This is the challenging constraint. And also it uses conventional neural network (CNN) instead of deep neural network (DNN). Because of neural network it takes much for learning.
[3]	Multi-constraint non-linear predictive controller (NMPC)	This uses multi-constraint non-linear predictive controller. It uses Multi-input multi-output (MIMO) which fed to neural network for autoregressive and exogenous. This controller producing better regression and reduced transient state.	Due to multi-constraint scenario, it needs to collect the road side environment with multiple sensors. That sensor input and output act as a MIMO system. It leads to system complexities.
[4]	Spatiotemporal-based trajectory planning control [13]	The spatiotemporal-based trajectory planning control performance better than the spatial-based trajectory system [13]. This control effectively self-optimised when the vehicle meeting the road side junction. And also it produces effective trajectory of the vehicle with exact acceleration and yaw angle.	When the road extension and vehicle complexities increases, then this controller need to test with future road conflicts.
[5]	Discrete time preview controller	This is deals with time varying disturbance of the environment like road curvature and other objects. It is also using feed forward and feedback controller for smooth functioning of the vehicle. Feed forward controller detects the future road conflicts and intimate to the feedback controller to avoid huge tracking error.	Due to multiple controllers the tracking error can be minimized but the same time the transient state performance of the vehicle quite unfair.
[6]	PN-ANFIS controller	It uses pyramid normalization adaptive neuro-fuzzy inference system (PN-ANFIS). Along with neural network fuzzy system also used here for crisp decision making of the controller [6]. The PN-ANFIS controller gives time save of 7.6%, maximum tracking error to 8.1% & mean tracking error 8.5%	In the beginning it generates rough set normalization. Based on the date collected in the environment it reconstructs the pyramid normalization. It takes some time to achieve maximum efficiency
[7]	Model Predictive Controller With Switched Tracking Error	It maintain the stability if the autonomous vehicle during transient and steady state. The switched tracking error is optimized with this proposed controller.	The only drawback is, it is not designed with future road side uncertainties.
[8]	sliding mode control (SMC)	In the presence of unknown disturbances and saturated value of the input the system meet the requirements of lane keeping and maintain the stability under the roll-over condition with the help of modified sliding mode control.	This proposed controller is verified only with CarSim-Simulink to test the robustness of the proposed controller. It is need to test in the real road environment.
[9]	Lane-Keeping and collision avoidance control	This proposed control frame work focuses the Lane-Keeping and collision avoidance. This controller tested with smooth and rough obstacle track. It produced optimized solution for a speed of 3 m/s to 18 m/s.	This controller tested with the velocity speed of only 3 m/s to 18 m/s. for other velocity speed need to evaluate with different smooth and rough obstacle track.
[10]	Lateral control	This controller designed for lane-keeping and lane-changing constraint with lateral control. By introducing proper planning it produce a feasible lane control for the autonomous vehicle.	This controller is evaluated without any disturbances and uncertainties. In future it is to be implemented for an autonomous vehicle
[11]	Higher order sliding mode (HOSM) controller	This controller specially designed for the driver perception. By using a fuzzy classifier an autonomous vehicle manipulated for different speed such as Calm, Moderate, Aggressive and Very Aggressive. This also reduces lane tracking errors.	It is designed for only limited driving style. In future, an artificial intelligence needs to implant to acquire the study of various driver styles.
[12]	predictive maneuver control planning	This control frame work formulates the output control speed with reference speed for various lanes. This control reduces the computation complexity.	This controller tested with limited situation and for that it gives feasible solution. And also it is not verified with heterogeneous vehicle and other uncertainties.

focusing the lateral control but in future it may be included with control of vehicle for disturbances and uncertainties.

Jagat Jyoti Rath et al. [11], This article presents an autonomous vehicle works as a Adaptive Driver Assistance Systems (ADAS) for driver style. Actually the operating style of the vehicle is changed with different driver. Hence, for their comfort driving, a fuzzy based control mechanism is derived. Based on the driver style, Calm, Moderate, Aggressive and Very Aggressive factor are developed for the assistance variable torque [11]. For those above linguistic variable, different torque dynamics are formulated to the identified driver style. To bring this environment a higher order sliding mode (HOSM) controller is proposed. With the help of fuzzy classifier, the controller assists and brings the various torque mechanism for different driver. This proposed controller also reduces lane tracking errors.

Qian Wang et al. [12], This paper proposed a predictive maneuver planning which integrates discrete maneuver planning and motion trajectory planning. It is applied to the autonomous vehicle with uncertainties (sensor noise and obstacle disturbances). In this prediction horizon, a reference speed is used for each lane. Using the rule based reference speed, this control frame work simultaneously generate the optimized control selection and control trajectories. The earlier controller not formulated with this type of reference speed mechanism for the various lane. This helps to accommodate the autonomous vehicle in the environment in better way. This model predictive control (MPC), periodically check the lane position with reference path. And it reconfigures the control parameter and trajectory. It also reduced the computational complexity.

3. Comparison of different controllers

3.1. Conclusion

In this paper a brief overview is given for the controller design aspect before to deploy in the Autonomous vehicle. Each and every controller has some merits and demerits. Even though an effective controller is designed for the autonomous vehicle, the system must be designed with manual and automatic mode. Because the available controllers never be decided by itself during critical situation. Normally all the automatic driving assistive system is designed with specific static road rules. But it never helps in the catastrophic situation. Hence the future driving assistive system must have artificial intelligence to study the environment and self-restructure the road rules in critical situation.

CRediT authorship contribution statement

T.S. Balaji: Conceptualization, Methodology, Software, Visualization, Writing - original draft. **S. Srinivasan:** Data curation, Supervision, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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