Braking and acceleration mapping control for autonomous overtaking to avoid fatality crash in undivided road

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Abstract. Autonomous vehicle control needs two essential algorithms, the first path planning, it covers either finding vehicle subject position and destination point and environment identification to avoid obstacle within tailgating, lane change and overtaking. The second to be tracking control to realize drive, brake and steering action based on complexity of path planning. This research contribute to a path planning for unidirectional and bidirectional on non-lane undivided roads overtaking. It need to be designed and investigated the desired acceleration of vehicle subject for tailgating and overtaking vehicle object 1 in front and has same direction without crash with vehicle object 2, what come from the opposite direction. The results of the investigation show that the desired acceleration of the subject vehicle can be properly mapped under condition of varied position, velocity and acceleration of overtaken vehicle object 1 and vehicle object 2. The maximum desired acceleration was eliminated by consideration of critical rolling and sliding velocity of vehicle subject. The acceleration mapping can be used for safety overtake planning.

1. Introduction

In the field of autonomous vehicle research, there are 3 level of technology namely (1) Drivers assistant (2) Partial automation (3) Conditional automation (4) High automation (5) Full automation.

Figure 1. Level of driving automation

Driver assistance should covers likely technology such as environment-identification, vehicle dynamic control assistance, cruise control and driver warning. Partial automation covers technology what can perform steering, acceleration and braking like ADAS, while the driver still monitor all task but he can take control at any time. Conditional automation make vehicle support more complex task
such as environment detection capability, steer actuating, drive control and braking used for tailgating, lane change and overtaking but driver override is still required. High automation covers technology what can act all driving task under specific circumstance and geo-fencing is required and driver override still an option. Full automation should be the final autonomous control, vehicle can perform all driving task under all condition and no driver attention or interaction is required. Drivers assistant level were proposed by several researcher such as a real-time on board safe overtaking monitoring system vehicle parameters like speed, engine speed, brake pedal status and steering angle. Microcontroller based embedded board are used to measure all above parameters. The distance from the surrounding vehicles are measured by four laser sensors attached to vehicle. Systems monitor these parameters and based on algorithm it gives alert to driver if overtaking is not safe [1]. The overtaking characteristics of vehicles on undivided roads under mixed traffic conditions are studied by collecting details of overtaking data on a two-lane two-way undivided road using moving car observer method and registration plate method.

The overtaking characteristics of all types of vehicles under mixed traffic conditions were observed and mathematically modeled [2]. The Overtaking Assistance System (OAS) use decision-making system based on fuzzy logic was also proposed. The inputs variable of the decision-making system are the distance of the subject vehicle and the object vehicle 1 that as well as the distance of the subject vehicle and the object vehicle 2 in the other lane. Decision-making system concern how the vehicle should perform the approaching, tailgating, and overtaking object vehicle 1 without crash with object vehicle 2 opposite from the other lane. The results from hardware simulation using a remote control car show that the decision-making system algorithm can work according to the design [3]. A real-time video feed from the vehicle located just in front provides drivers with overtaking assistance, provides a better view of the road ahead, any vehicles in a front and in opposite direction, being especially useful when the front view of the driver is blocked by large vehicles [4]. An ontology model is used for assisting vehicle drivers by warning safety messages during time critical situation simulation. The simulation test bed is developed by using Java framework to generate safety alerts in various driving situations. The response time graph for the simulation of context IDAS is depicted and analyzed. The VANET scenario is used by the system to works in, which adapt to environment changes and to vary according to the context [5]. Partial automation driving is the development of assistance system, it was also proposed by many researchers for example the system of advance driver assistance system (ADAS). Potentially considerable because of the significant decrease in human suffering or stress, economical costs is the benefits of ADAS implementations are [6]. Advance driver assistance system (ADAS) combined with vehicle positioning, detailed digital maps and advanced map-matching algorithms, establish the decision algorithms of powerful ADAS systems. The evaluation experimentation of algorithms to be implemented in the control unit use artificial Intelligence and simulation. Finally, the driver is warned if a risk is detected and if necessary by the system is designed, to take control of the vehicle [7]. An advanced graph-based optimal solution to overtaking scenarios for autonomous vehicles was also proposed. There is a probability-based approach in the background of the graph-based route selection optimization, with which the motions of the human-driven vehicles are predicted. The result of the method is the road and the velocity profile of the autonomous vehicle, with which emergencies and even collisions can be avoided [8]. An optimal control uses speed and acceleration signals from the surrounding vehicles. In order to achieve probability density functions and predict their expected motion theses signals are processed with clustering methods. The strategy includes several additional layers, such as the tracking control of the vehicle, decision making concerning the maneuver and the computation of the required trajectory. A robust Linear Parameter Varying (LPV) control design method is proposed to guarantee the tracking of the computed reference [9]. Conditional automation performs environment detection and most driving task. Schemes use guidance based also real-time applicable. It ensures safety and passenger ride comfort. The passing vehicle is guided in real-time to match the position and velocity of a shadow target during the overtaking maneuver based on the principles of Rendezvous Guidance, [10]. Path-tracking and lane-change capabilities are implemented for an overtaking system for autonomous vehicles. For mimic human behavior and reactions during overtaking maneuvers the system uses fuzzy controllers is used. The system is based on the information that is supplied by a high-precision Global Positioning System and a wireless network environment [11]. High automation of
autonomous vehicle have ability perform most driving task under specific circumstance and geo-fencing and driver role is only an option. To emulate how humans overtake A fuzzy-logic based controller was developed. Information from the vision system and from a positioning-based system consisting of a differential global positioning system (DGPS) and an inertial measurement unit (IMU) are used as inputs. Its output is the generation of action on the vehicle’s actuators, i.e., the steering wheel and throttle and brake pedals. To quantitatively assess when a simple static simulation model can be used to approximate a complex dynamic simulation a systematic statistical testing approach is presented. Results show that a static simulation can be used to determine the required joint motor torques under slow operation speeds. It also become a proof that a dynamic simulation model to determine the maximum allowable moving speeds for UGVs to safely operate on roads with various levels of roughness and bumpiness is needed. A heads-up-display (HUD) and driving information rear display (DIRD) are required by the system, and this configuration outputs information from the ADAS into DIRD and the front and rear windshields HUD are built by combining navigation tracking provided by a mobile phone and vehicle M&R information, where vehicle information is provided by the electronic control unit (ECU). To carry out a test drive the VisLab Intercontinental Autonomous Challenge (VIAC), an autonomous vehicles are implemented. The vehicle equipment is explained introducing the sensing systems which were tested during the journey. To gain insights into vehicle control at the friction limits an autonomous racing controller is designed. To imitate drivers doing steering and throttle corrections according to the vehicle responses Lane keeping steering feedback and wheel slip feedback controllers are used. The controller can track a path while operating at the limits of tire adhesion robustly and provide insights for the future development of vehicle safety systems. To avoid well-known moving obstacles the system used an occupancy grid – which has been used to avoid stationary obstacles in an uncertain environment – in conjunction with velocity obstacles – which allow a subject vehicle. The combination guidance of these techniques leads to Velocity Occupancy Space (VOS). Fuzzy logic techniques to both address common challenges and incorporate human procedural knowledge into the vehicle control is utilized for Automated versions of a mass-produced vehicle use. For formulating the path-tracking problem in state space format a two degree-of-freedom dynamic model is developed. A newly developed adaptive-PID controller will be used. Target steering is the desired angle of the subject vehicle to the overtaking goal place and the obstacle avoidance direction is the angle of subject direction to avoid crash with the object vehicle. By adding two steering value, the fuzzy can inference the final steering direction over time. For trajectory tracking of wheeled mobile robots (WMRs) an optimal Mamdani-type fuzzy logic controller is introduced. Matlab/Simulink environment was implemented in the dynamic model of a non-holonomic mobile robot. PID controller coefficients and the parameters of input and output membership functions are optimized simultaneously by random inertia weight Particle Swarm Optimization (RNW-PSO). A computer vision is used for lane detection while the fuzzy logic control is employed for positioning and regulating the speed of the racing car. A multi-sensor target tracking system that combines data from a Frequency-Modulated Continuous Wave (FMCW) radar, multiple Short-Range Radars (SRR), a camera-based object detection system and vehicular dynamic sensors is described. A vehicle yaw motion and control driver’s steering sensitivity based on human sensorial characteristics firstly. Reaction torque of a steering wheel is used to consider the linearization control of steering sensitivity enables the driver to recognize vehicle and road state. Based on human kinesthetic sense is done by electric power steering to determine the power assist. Secondly, with in wheel motors the control of vehicle yaw motion is linearized. Semicircular canal and vision is used for humans feel rotational motion. A driver controls yaw motion with the steering wheel. Such sensors includes imaging sensors operating in different wavelength bands of the visible (i.e., video cameras) and IR spectrum, as well as ranging sensors such as ultrasonic, radar and lidar are the common used in here. The non-imaging ranging sensors are useful for applications that do not require object recognition/classification or scene understanding. Inexpensive vision sensors, on the other hand can capture the scene image in high spatial resolution and a wide field of view. Sensors makes them ideal for object recognition and lane following under most conditions. A vehicle Rear-End collision
avoidance system using Pre-Collision System (PCS) algorithm. It allows evaluating the potential effectiveness of the pre-collision system (PCS) algorithms: 1) forward collision warning 2) Pre-crash brake assist; and 3) Autonomous pre-crash brake [26]. All of the previously research was talking about the ADAS control system, which installed and exploited within the vehicle. As good as the its technology, it is not ensure the accident if the driver do not take awareness in it. The assessing of the awareness and acceptance of selected advanced driver assistance systems among a sample of Czech drivers, as well as the factors that might influence it was a current research. Together, 526 drivers participated in the questionnaire study. A half of drivers was not aware of any further information besides the existence of ADAS and more than 70 % did not drive with such systems yet. As for the acceptance, at least 50 % of the respondents desired most of the systems, but the majority was not interested to pay any extra money for the systems[27].

2. Method of patch planning
Vehicle autonomous technology focus on two essential works, firstly is patch planning, phase how to plan a desired path, where can achieve a destination point and how to avoid the obstacle within road and traffic environment. Achieving destination is needed to understand the effective route of the road traffic until vehicle approach the destination point. Avoiding obstacle means, how to do tailgating, overtaking, turning, deceleration, acceleration and cruise within desired lane, shoulder road. Secondly, it is work to plan tracking control, how to control acceleration, deceleration and steering direction to achieve according to the patch planning. This research can be defined as a new solution for patch planning phase method, especially to setup turning, deceleration, and acceleration within tailgating and overtaking.

3. Proposed patch planning

3.1. Path Planning Strategy
The path planning strategy is divided in 2 strategy, namely macro strategy and micro strategy. The first is used to find global tracking between start points to destination point. The second is exploited to avoid all barrier to entry of environment around the subject vehicle, such as others vehicle, lane and shoulder of road, traffic signal etc. (fig.1)

For global path planning, a set of GPS, its device and vehicle probes are implemented properly. The GPRS will be even very useful for transferring communication and actuating from external device such as normally solution for vehicle to infrastructure or vehicle to vehicle and vehicle to someone (X). The micro strategy is used to identify the environment close a round the subject vehicle like object vehicle in front, which has a same direction, object vehicle even in front but opposite direction, pedestrian road, divider of road, shoulder of the road, side tree, traffic signal etc. it use a lot of sensing unit such as Lidar sensor, camera, ultrasonic sensor, speedometer, radar sensor. It sensor will be processed as a input signal for identification and decision are done by main control unit to plan tracking to trigger steering, braking and drive actuator.
3.2. **Longitudinal path planning distance of vehicle subject**

Longitudinal path distance planning of vehicle subject, which with boundary condition in zero position X=0 and Y=0 as shown in figure … can be formulated as follow

\[ S_A = V_{LA} \cdot t + \frac{1}{2} \cdot a_{LA} \cdot t^2 \]  \hspace{1cm} (1)

Longitudinal path distance of vehicle object 1, which with boundary condition in zero position X= \( D_{AB} \) and Y=0 as shown in figure 1 can be formulated as follow

\[ S_B = V_{LB} \cdot t + \frac{1}{2} \cdot a_{LB} \cdot t^2 \]  \hspace{1cm} (2)

Longitudinal path distance of vehicle object 2, which with boundary condition in zero position X= \( D_{AC} \) and Y=0 as shown in figure 1 can be formulated as follo

\[ S_C = V_{LC} \cdot t + \frac{1}{2} \cdot a_{LC} \cdot t^2 \]  \hspace{1cm} (3)

Lateral path distance of vehicle object 1 and vehicle object 2 are same and defined by position Y = 0, while the lateral tracking of vehicle subject can be defined as follow.

\[ Y = \frac{H}{2} \cos \left( \omega \cdot t + \frac{1}{2} \cdot \alpha \cdot t^2 \right) \]  \hspace{1cm} (4)

**Figure 3. Tracking dynamics of overtaking**

\( s_A = \text{Pathdistance of subject vehicle} \)

\( s_B = \text{Pathdistance of Object vehicle 1 (sametdirection)} \)
\[ s_c = \text{Path distance of object vehicle 2 (opposite direction)} \]
\[ V_{LA} = \text{Longitudinal velocity of subject vehicle} \]
\[ V_{LB} = \text{Longitudinal velocity of object vehicle 1} \]
\[ V_{LC} = \text{Longitudinal velocity of object vehicle 2} \]
\[ a_{LA} = \text{Longitudinal acceleration of subject vehicle} \]
\[ a_{LB} = \text{Longitudinal acceleration of object vehicle 1} \]
\[ a_{LC} = \text{Longitudinal acceleration of object vehicle 2} \]
\[ H = \text{Lebar antara sumbukendaraansaat overtaking} \]
\[ \omega = \text{kecepatan angular body kendaraansbject} \]
\[ \alpha = \text{percepatan angular body kendaraansbject} \]
\[ t = \text{continuous time} \]

4. Vehicle overtaking model

4.1. Divided Road

4.1.1. Model overtaking in divided road

\[ \frac{1}{2}(a_{LB})t^2 + (V_{LB})t + (X + S + D_{AB} - D_{AC}) = 0 \quad (5) \]

4.1.2. Safe boundary condition

\[ D_{AC} \geq D_{AB} + S_B + S + X \quad (6) \]

\[ S_A = D_{AB} + S_B + S \quad (7) \]

\[ Y = \frac{H}{2} \]

4.1.3. Critical overtaking time

\[ t \geq \frac{-(V_{LB})\pm \sqrt{(V_{LB})^2 - 2(a_{LB})(X+S+D_{AB}-D_{AC})}}{(a_{LB})} \quad (8) \]

4.1.4. Critical longitudinal overtaking acceleration

\[ \alpha = \frac{2.\cos^{-1} \left(\frac{2Y}{H}\right)}{t^2} - \frac{2\omega}{t} \quad (10) \]
4.2. Un-divided Road

![Figure 5: Tracking dynamics of undivided overtaking](image)

4.2.1. Model overtaking undivided road

\[
\frac{1}{2}(a_{LB} + a_{LC})t^2 + (V_{LB} + V_{LC})t + (X + S + D_{AB} - D_{AC}) = 0
\] (11)

4.2.2. Safe boundary condition:

\[ D_{AC} \geq S_B + S_C + S + X + D_{AB} \] (12)

4.2.3. Critical overtaking time

\[
t \geq \frac{-(V_{LB} + V_{LC}) \pm \sqrt{(V_{LB} + V_{LC})^2 - 2(a_{LB} + a_{LC})(X + S + D_{AB} - D_{AC})}}{(a_{LB} + a_{LC})}
\] (14)

4.2.4. Critical overtaking acceleration

\[
a_{LA} \geq \frac{A_{LB}t^2 + 2(V_{LB} - V_{LA})t + 2(D_{AB} + S)}{t^2}
\] (15)

4.2.5. Critical angular overtaking acceleration

\[
\alpha = \frac{2 \cos^{-1}\left(\frac{\omega}{\lambda}\right)}{t^2} - \frac{2 \omega}{t}
\] (16)

4.3. Overtaking Time Series

The movement of the three vehicles starts from the initial condition, speed, acceleration of each position and then starts with the same initial time and investigates the movement. From the graph it can be seen for tracking the longitudinal position of the subject vehicle (green), tracking the longitudinal position of the object 1 vehicle (blue) and tracking the longitudinal position of the object 2 vehicles (red).
Figure 6. Time series of undivided overtaking

\[ NS = \text{safety preovertaking distance from vehicle object 1} \]
\[ S = \text{safety after overtaking distance from vehicle object 1} \]
\[ X = \text{safety overtaking distance from vehicle object 2} \]
\[ D_{AB} = \text{Initial boundary distance vehicle subject to vehicle object 1} \]
\[ D_{BC} = \text{Initial boundary distance vehicle object 1 to vehicle object 2} \]
\[ D_{AC} = \text{Initial boundary distance vehicle subject to vehicle object 2} \]

5. Overtaking safety

d is the relative distance between the vehicle and front vehicle object 1 or 2, while \( \varepsilon \) is indicated by the symbol of risk factor. If \( \varepsilon > 1 \), then \( d_w > d \), it means that the vehicle is in a collision-free phase; If \( 0 < \varepsilon < 1 \), then \( d_w > d \), it indicates that the vehicle is involved in an increasing danger. It is necessary to use certain warnings to remind the driver of taking appropriate actions to avoid the occurrence of a collision; If \( \varepsilon < 0 \), then \( d_b > d \), it indicates that the degree of danger is extremely high and the driver is required to immediately slow down the vehicle speed. The AEB system is required to immediately perform the highest level of braking to avoid the occurrence of accident or reduce collision speed to minimize the consequent damage.

\[ \varepsilon = \frac{d_b - d}{d_w - d_b} \] (17)

Where \( d_b < NS < d_w \)
\( \varepsilon \) = level of dangerously
\( d_b(t) = \text{safe warning overtaking distance} \)
\( d_w(t) = \text{safe overtaking distance} \)
d(t) = real time vehicle subject position  
\[ t = \text{critical overtaking time} \]

6. Matlab simulation and discussion

Figure 8. Simulink model of overtaking

Figure 9. overtaking response 1

Figure 10. overtaking response
Figure 11. safe overtaking response

Figure 12. dangerous overtaking response (3 vehicle crash)

Acceleration Mapping of vehicle subject based on simulation

| Acceleration need vehicle subject for safety overtaking | Acceleration VO2 1m/sec² | Acceleration VO2 2m/sec² |
|--------------------------------------------------------|--------------------------|--------------------------|
| Under same velocity with vehicle subject 1 (m/sec²)  | velocity object 2 (km/h) | velocity object 2 (km/h) |
|--------------------------------------------------------|--------------------------|--------------------------|
| Acceleration VO1 1m/sec²                              | 30 | 1.7 | 1.8 | 2.3 | 2.8 | 3.5 |
| Velocity object 1 (km/h)                              | 60 | 2.2 | 2.7 | 3.3 | 2.8 | 3.7 | 4.5 |
|                                                       | 100 | 3.8 | 4.3 | 4.7 | 3.5 | 3.9 | 5.1 |
| Acceleration VO2 2m/sec²                              | 30 | 2.2 | 2.8 | 3.5 | 2.7 | 3.5 | 4.2 |
| Velocity object 1 (km/h)                              | 60 | 2.8 | 3.5 | 4.3 | 3.5 | 4.2 | 5.0 |
|                                                       | 100 | 3.5 | 4.2 | 4.8 | 4.1 | 4.8 | 5.5 |

Boundary condition setup

| X   | NS  | S   | D_AB | D_BC |
|-----|-----|-----|------|------|
| 15 m| 15 m| 15 m| 170 m| 200 m|
7. Conclusion
There three factor cause the fatal accident namely

- Distance between three vehicle
- Velocity between three vehicle
- Acceleration between three vehicle

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