A Design of a Simple Autonomous System

*Quan-ming Zhao, Tao Zhang , Pei-Pei Jin, Dong-yang Hu and Yi-wei Du

Abstract

With the development and popularity of vehicles and improvement of advanced sensors, autonomous systems can be developed within some limited spectacles. Researchers have called such systems approach "Intelligent Vehicles" or "Unmanned Vehicles". In an autonomous system, components such as environment perception, map building, path planning and path following are designed in term of pattern of information transfer. Although such an autonomous system is innovative and interesting, researches have pointed out the problem of poor practicability to meet with the real roads and the high cost of the sensors. To cope with this problem, in this study, a simple autonomous system is developed based on a simple engineering approach to meet the demand of some limitation spectacles. An experiment conducted in a startup company, IdriverPlus, has shown the effectiveness of this system.

Keywords: radar, autonomous system, AEBS, path planning

1. Introduction

With the development of automotive industry and information-based industries, more and more enterprises take part in developing "Intelligent Vehicles" [1]. While at the first stage, Advanced Driver Assistance System (ADAS) [2] is preferred by EURO NCAP and ANCAP [3]. To ensure the safety of the driver, AEBS (Autonomous Emergency Braking System) [5] was designed by lots of enterprises which lead to the standard declared by ISO [4]. The Defense Advanced Research Project Agency (DAPRA) of the USA has hosted a series of competitions named Urban Challenge Event (UCE) [7-8] aiming at research and development of full-sized autonomous road vehicles. In addition to develop such a system, researchers from some colleges and universities have built lots of high cost systems. Many of the systems almost meet the demand of the race in desert. [12-14]

*Corresponding Author: Quan-ming Zhao
(E-mail: qmzh @hebut.edu.cn)
[1] The school of Electronics and Information Engineering, Hebei University of Technology, No. 5340, Xiping Road, Beichen District, Tianjin China

In the past decade, the teams from UCE made a brilliant achievement. From sensors, a perception system is built, with the help of drivability map and navigator system, and the motion planner system could maintain the whole system, while controller receives the instructions from motion planner. That's why the autonomous system could finish its task all by itself.

As the sensors are produced by different enterprises, information fusion will be very difficult to make the raw information as one source. Taking information from sensors one by one, and labeling the information with weight, a perception system may be robust. Autonomous vehicles cannot use a traditional map to confirm its location, and GPS and preconditioning map called route network definition file (RNDF) [6] by DARPA make the road clear for an autonomous system. The limitation of each sensor makes the design of perception detect different. With the weight of each sensor in different areas, the perception could be some degree accurate [9].

Once the information of perception could use, build a map with the location of the vehicle, and the information makes great effort to describe the road vehicle needed to follow and the destination vehicle has to reach. The RNDF defied by DARPA includes the road position, number of lanes, intersections, and even parking space locations in GPS coordinates. It is a key point to precondition the information of the roads, especially to figure out the drivability area. When the autonomous system figures out the area to follow and is safe, path planning makes it reliable, so controller will lead the vehicle with increasing or decreasing throttle and brake. [17-18]

While in reality, due to the limitation of the cost, the autonomous system may not perform as well as the DAPRA asking for [10-11]. However, building such a system, the systems like autonomous buses or autonomous railways may make a contribution for our life soon or later.

2. Background and Motivation

Since the rapid development of the automotive industry, the safety of vehicles draws the people's attention, especially the concepts of Electronic Stability Control (ESC) and Autonomous Emergence Braking (AEB) [3] put forward. The collision avoidance system is the most important part of the ADAS. According to E-NCAP, there should be 3 features in an AEB system:

1. Autonomousness: The vehicle should all by itself;
2. Emergency: The system only works when it is really in an emergent situation;
3. Braking: The system should brake as soon as possible to avoid collision.

Mobleye, a famous Israel company, who is good at collision warning with the help of video camera, indicated that the time before collision could be set as the threshold value, especially talking about time to collision (TTC) and time headway (THW). ISO defines TTC and TWH as:

$$TTC = Dis / V_{rel} \quad (1)$$

$$THW = Dis / V_{host} \quad (2)$$

Where dis is the distance between the host vehicle and the target vehicle; Vrel is the relative velocity of the two vehicles; usually Vrel is equal to the velocity of the target vehicle minus the velocity of the host vehicle, when the result is positive, it means the target vehicle is faster than the host vehicle, otherwise slower. Vhost is the host of the target vehicle.

Since the company takes great benefit from its warning products, it shows that cameras or the means of video are quite important for perception, and the method of TTC or THW makes a contribute to warning systems.

It is much more complicated to control the vehicle when it determines when and how to take an emergency braking all by itself. Company MAZDA and HONDA use different algorithms. They both take more information into consideration. Actually, considering the effect of individual driving styles, the delay of the vehicle control system, the delay of the computing, the factor of the road, and the accelerate of the vehicle, they work together to decide the effect of a collision avoidance system. The system depending on distance will be better than the one depending on time.

Mazda's algorithm uses the following braking critical distance definition [4]:

$$dis = \frac{1}{2}\left(\frac{V_{host}^2}{a_1} - \frac{(v_{host} - v_{rel})^2}{a_2}\right) + v_{host} \cdot \tau_1 + v_{rel} \cdot \tau_2 + d_0 \quad (3)$$

Where Vhost and Vrel are the same vehicle velocity as described in TTC and THW; a1 is the maximum deceleration of the host vehicle; a2 is the maximum deceleration of the target vehicle; t1 and t2 are delay times, and d0 is a headway offset. The following parameter values were used: a1 = 6 m/s2, a2 = 8 m/s2, t1 = 0.1 s, t2 = 0.6 s, and d0 = 5 m. When Dis (calculated distance) is equal to or bigger than the real distance between the two vehicles, and Vrel is negative, the system will take over the controller to take brake until Dis is less than the real distance between the two vehicles. In this case, a vehicle moving in the opposite direction has been detected. It is usually assumed that a vehicle in the opposite lane is detected, and a warning is not given.

Honda's algorithm uses the following braking critical distance [5]:

$$Dis = \begin{cases} \tau_2 V_{rel} + \tau_1\tau_2 a_1 - 0.5 a_1 \tau_1^2 & \frac{V_{trg}}{a_2} \geq \tau_2 \\ \tau_2 v_{host} - 0.5 a_1(\tau_2 - \tau_1)^2 - \frac{V_{trg}^2}{2a_2} & \frac{V_{trg}}{a_2} < \tau_2 \end{cases} \quad (4)$$

Where Vhost and Vrel are the same vehicle velocity as described in TTC and THW; a1 is the maximum deceleration of the vehicle; a2 is the maximum deceleration of the target vehicle; Vtrg is the target vehicle velocity; t1 is the system delay, and t2 is the braking time. The following parameter values were used: a1 = a2 = 7.8 m/s2, t1 =0.5 s, and t2 = 1.5 s. The active condition is as same as the Mazda's algorithm.

There are some key points when dealing with the braking problems:

(1) Acceleration: Without apperceiving the friction coefficient of the roads in time, the acceleration for calculating may not be such precise. While ISO offers some normal values, such as the Mazda's algorithm and Honda's algorithm take.
(2) Relative velocity of the two vehicles: Data receiving from the senor of radar could get exactly the Relative velocity with the help of Doppler Effect.
(3) Time delay: In practice, the time delay often occurs when the program deals with changed situations, and the physical system transforms the electrical signal responding to the commands.
(4) The headway offset: To make the system safe, it is better to set a headway offset.

Our AEB algorithm uses the following braking critical distance:

$$Dis_{AEB} = V_{host} * TA_{delay} + V_{rel}^2 / (2a_A) + D_{offset} \quad (5)$$

By taking different values of the parameters, Warning and pre-braking system could be described in the following critical distance: [3]

$$Dis_{pre} = V_{host} * Tp_{delay} + V_{rel}^2 / (2a_p) + D_{offset} \quad (6)$$

$$Dis_{warn} = V_{host} * Tw_{delay} + V_{rel}^2 / (2a_w) + D_{offset} \quad (7)$$

Where Vhost and Vrel are the same vehicle velocity as described in TTC and THW; aA is the maximum deceleration of the vehicle; aP is the second deceleration of the vehicle when it is time for pre-braking; aW is the deceleration when it is time for warning. And Doffset is a set of distance being related to Vrel in negative; TAdelay, TPdelay and Twdelay are the time delay of the system. The following parameter values were used: aA = 5 m/s2, aP = 4 m/s2, aW = 3 m/s2, TAdelay =0.2 s, and TPdelay = 0.4 s, Twdelay = 0.6s, Doffset = 3m. The system flow chat is shown in Figure 1.

To make sure the AEB system run as designed, a completed and precise perception system is needed. A system perceives external environment with the help of sensors.

Actually, Radar, Camera and even Lidar are all needed when a system perceives precise. The detected distances of sensors are shown in table 1.

Table 1: The detected distance of sensors

The kind of the Sensor	Detected distance
Lidar	1-200m
Radar(microwave)	1-200m
Radar(sonic wave)	0.3-5m
Camera	5-100m

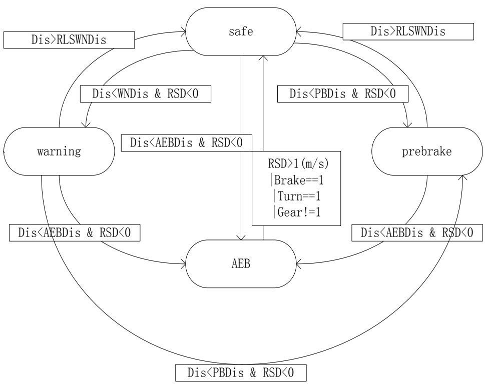


Figure 1: The system flow chat

The cost of these sensors may be huge for a normal vehicle, especially the price of LIDAR. It is important to build a system depending on the radar and camera so that the cost wouldn't be too much. Human is the main reason why traffic accident happened. An advanced assistance safe system could not keep the driver safe. Once a system gets the ability of perception, autonomous algorithm will make the vehicle autonomous driving possible.

3. The Design of the System

An autonomous system is built on sensor interfaces aiming at the safety of the vehicle, which makes the AEBS the highest level of the system. Especially, the Artificial Intelligence (AI) cannot help us human live.

The system contains 4 parts, as sensor interface, perception and mapping, planning and control and user interface. The flow chat of the system is shown in Figure 2.

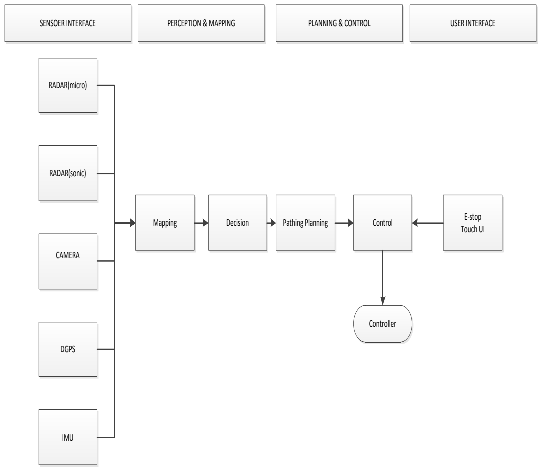


Figure 2: Flow chat of the system

The Differential Global Position System (DGPS) is much more precise than the GPS. The DGPS can identify the position less than 10cm, which is quite precise when the vehicle figures out exactly where it is. And with the help of the Inertial Measurement Unit (IMU), the control system could get a lot of parameters of the vehicle, leading to a better planning path. [15-16]

The information of the road or the RNDF is just set into the decision module. Dealing with the information from the mapping module, the decision module makes sure the vehicle system will follow the prefabricated route.

A grid map is used to locate the position of the vehicle and obstacles. The grid cell' size is 10 cm * 10 cm. The centrality of the map fixes the vehicle. Whole a map describes the area as large as 100m * 20m. The grid map of the system is shown in Figure 3.

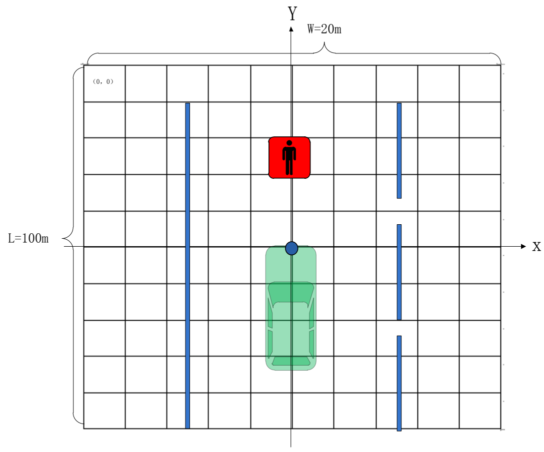


Figure 3: The grid map of the system

One obstacle may occupy some of the grids. By the distance apperceived from different sensors, such as radars and cameras, the obstacle will be tagged in same area.

There are two kinds of the obstacles, dynamic ones and static ones. The decision module was designed to handle how to deal with the obstacles and which route the autonomous vehicle system should follow.

There are six states when the vehicle drives,: car following, free driving, lane changing, turn, U-trun and emergence. The flow chat of the decision module is shown in Figure 4. And the states and the decisions are shown in Table 2.

According to the movement of the vehicle, the path planning module smooths the trajectory. The control module could follow the trajectory without odd motions which go against dynamics.

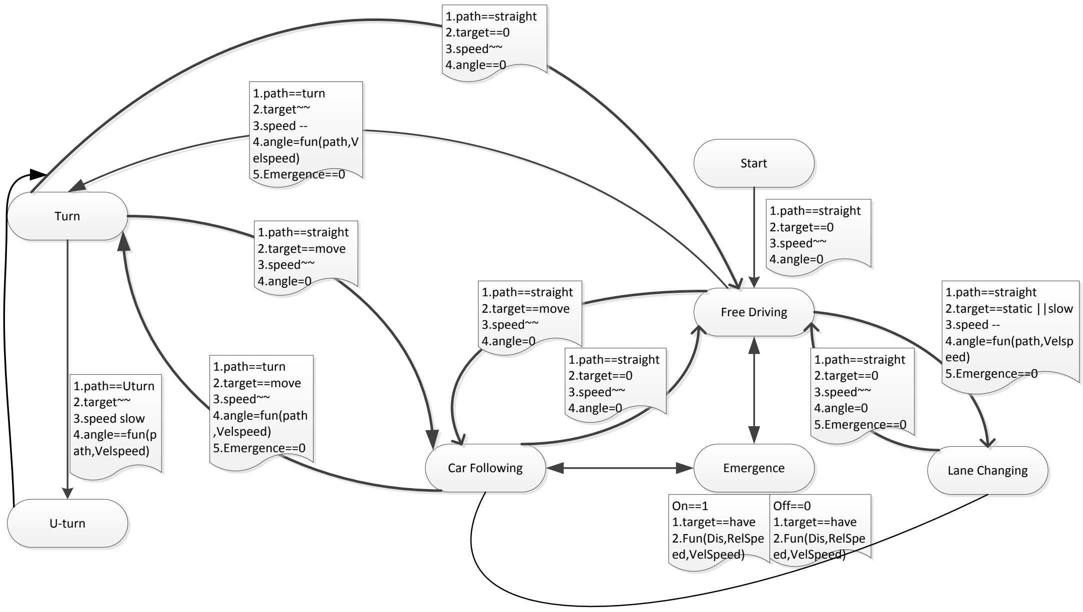
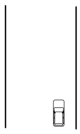
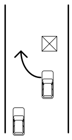
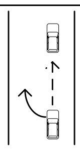
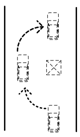
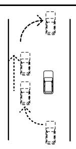
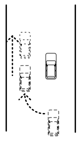
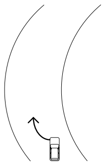
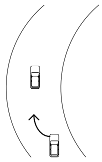
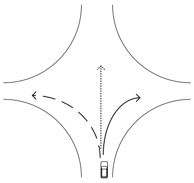
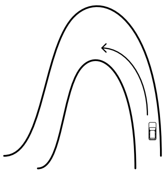


Figure 4: The flow chat of the decision module

Table 2: The states and the decisions

States	Decisions
	When the road is straight, there being no obstacles. Choose free-driving.
	During free-driving, apperceiving the static obstacle, check the road condition, if lane changing is possible, choosing lane-changing. Otherwise slow down till stop, waiting for lane-changing. AEBS may be triggered.
	During free driving, apperceiving the dynamic obstacle which could be set as target. The target is faster, choose car-following. The target is slower, choose slowing down car-following, if the target is too slow, choose lane-changing.
	When lane-changing has done, choose free- driving, check the changing road and original road, if lane changing is possible, change to original road.
	When lane-changing has done, choose free- driving, check the changing road and original road, if lane changing is possible, speed up then change to original road, otherwise keep in changed road ,wait to change back.

	On highway, choose free-driving, keep high speed, if apperceive the obstacle, choose lane- changing
	When choose free-driving, follow the route to choose turn.
	When choose car-following, follow the target to turn.
	Upon approaching the intersection, choose the turn as RNDF defines, like turn or free-driving.
	Choose U-turn as RNDF defines.

4. Experiment and Analysis

To evaluate the effectiveness of the autonomous system, a series of experiments were conducted on different roads in Beijing. The system should test its module one by one, then test the system in one setting route with both dynamic obstacles and static obstacles.

The test of the AEBS was set in the industrial park. During the daylight and night, the radar and camera work in different conditions [21-22]. In the daylight, when the camera could work well with less missing. The perception of the surroundings is a little more precise than the performance at night [23-24]. While during the emergence braking state, the system must check the target in at least multi frames or multi times, in case of missing the target in the perception module sometime. The camera was sensitive to human, so the strong light disables the effect of it [6].

Car following was tested in a half complete road, and a normal car was set as a target. The time delay may make driver feel slower than manual operation because of the limitation of Proportion Integration Differentiation (PID) controlling algorithm [25]. The PID controlling algorithm usually needs to set the parts of P and I due to lack of robustness [26]. This function will be active after apperceiving a dynamic target when following a set route [19].

Following one set route is the main working condition. [16] The route is a circular road; with the help of DGPS and IMU, the system could figure out the start point and the finish point. A trajectory was recorded by drivers. The vehicle was slowly driven when DGPS and IMU were working. The longitude, latitude and the vehicle heading angle were recorded as one point. Those recorded points made one trajectory followed. The test of the trajectory following is shown in Figure 5. And the test at night is shown in Figure 6.

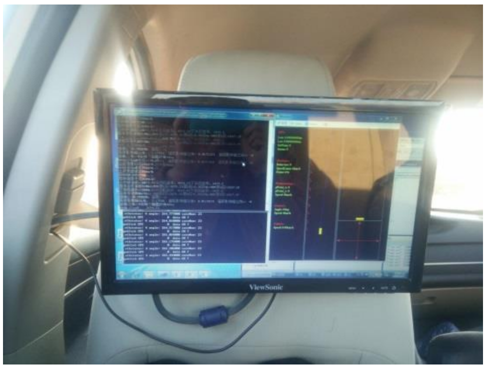


Figure 5: The test of the trajectory following

Figure 6: The test at night

It was quite important that choosing fit the look-ahead distance when the system followed the trajectory. Moreover, the longer the look-ahead distance, the more stable the vehicle drove itself, the worse the vehicle followed the trajectory. Dealing with curve, the look-ahead distance chose shorter would be better. Besides at any turn curve, the velocity should slow down first. During the experiment, the highest speed could meet 100km/h, while it was better at normal speed such as 30—80 km/h.

The final experiment was tested in a circle trajectory, with some other vehicles as random obstacles. When the system followed the recorded route, the target vehicle randomly disturbed the normal driving system, so that AEBS, car-following could be active. The lane-changing had to change the trajectory after path planning, which led the system to shake for a little while. The reason why the system shook was that the look-ahead distance change too fast while the vehicle itself could not change the body, or we could put the blame on the fast changing parameters. At any condition the changing of the parameters must be increased or decreased step-by-step, which was the key to keep the system stable. During the experiment, there was a system trying to make a right lane-changing when the environment failed the left lane-changing condition. Eventually, the system could record one route, following the trajectory, driving safely with the dynamic obstacles and static obstacles.

5. Conclusions

A method is described for a simple autonomous system designed to compete in following the recorded trajectory. The system used a comprehensive and low cost perception system feeding into a states-based dynamic motion decision algorithm to complete all autonomous maneuvers. This unified approach has been “test proven,” completing the circle route following mission and driving autonomously.

A key aspect of the system is that perception system based on the different sensors in preference to single sensor system. The states-based decision algorithm could handle recorded route following mission, due to the limitation of the situations tracking the trajectory. While with the distance-based AEB algorithm, the system could avoid most dangerous obstacles and better prepare for lane-changing when the conditions are satisfied. Mapping and location using DGPS and IUM system make the controller easy and convenient to adjust the posture of the vehicle.

Whereas the vehicle operated in the vicinity of human- driven traffic without incident, problems may encounter when interacting with other autonomous vehicles. So how to build a cooperated system with other autonomous vehicles make a great challenge for the future. Besides, LIDAR does do quite helpful for the perception system, it being worth to take one LIDAR to detect the surroundings. But the high cost of LIDAR really makes it impossible to be popular. Furthermore it is important for the system being updated to replace the human driver, so that make driving much safer.

Acknowledgment

This work was supported by the Fund No. 15227408D of Hebei Province Science And Technology Plan and the company Idriver Plus.

References

[1]. Pascal Minnerup and Alois Knoll, “Testing Autonomous Driving Systems against Sensor and Actuator Error Combinations,” IEEE Intelligent Vehicles Symposium (IV), pp. 561-566, June. 2014.

[2]. Julius Ziegler, Philipp Bender, and Markus Schreiber, “Making Bertha Drive—an Autonomous Journey on a Historic Route,” IEEE Intelligent transportation systems magazine, pp. 8-20, June. 2014.

[3]. Peter Seiler, Bongsob Song, J. Karl Hedrick, “Development of a Collision Avoidance System,” Society of Automotive Engineers, vol.103, no.9 , Feb. 1998.

[4]. ISO 22839, “Intelligent transport systems — Forward vehicle collision mitigation systems — Operation, performance, and verification requirements,” June. 2013.

[5]. Matteo Rizzi, Anders Kullgren, Claes Tingvall ,"Injury crash reduction of low-speed Autonomous Emergency Braking (AEB) on passenger cars," IRCOBI Conference 2014, pp. 656-665, Spt. 2014.

[6]. Hiroyuki Hatano, Tomoharu Mizutani, Kazuya Sugiyama, Members,and Yoshihiko Kuwahara, "Target Position Estimation Algorithm under Corrupted Measurement Data for radar Neetwork Systems," IEICE Trans. Fundamentals, vol. E95-A, no. 1, pp. 317-321, Jan. 2012.

[7]. Sebastian Thrun, Mike Montemerlo,Hendrik Dahlkamp, David Stavens,Andrei Aron, James Diebel, Philip Fong,John Gale, Morgan Halpenny, Gabriel Hoffmann, Kenny Lau, "Stanley: The Robot that Won the DARPA Grand Challenge," Journal of Field Robotics 23(9), pp. 661-692, 27 June. 2006.

[8]. Andrew Bacha, Cheryl Bauman, Ruel Faruque, Michael Fleming, and Chris Terwelp, &"Odin: Team VictorTango's Entry in the DARPA Urban Challenge," Journal of Field Robotics 25(8), pp. 467-492, May. 2008.

[9]. Chris Urmson, Joshua Anhalt, Drew Bagnell, Christopher Baker, Robert Bittner, M. N. Clark, John Dolan, Dave Duggins, Tugrul Galatali, Chris Geyer, Michele Gittleman, Sam Harbaugh, "Autonomous Driving in Urban Environments: Boss and the Urban Challenge," Journal of Field Robotics, vol. 25, no. 8, pp. 425-466, June. 2008.

[10]. Chris Urmson, Joshua Anhalt, Drew Bagnell, Christopher Baker, Robert Bittner, M. N. Clark, John Dolan, Dave Duggins,Tugrul Galatali, Chris Geyer, "Autonomous Driving in Urban Environments: Boss and the Urban Challenge," Journal of Field Robotics, vol. 25, no. 8, pp. 425–466, June. 2008.

[11]. John Leonard, Jonathan How, Seth Teller,Mitch Berger, Stefan Campbell, Gaston Fiore,Luke Fletcher, Emilio Frazzoli, Albert Huang,Sertac Karaman, Olivier Koch, Yoshiaki Kuwata, David Moore, Edwin Olson, Steve Peters, Justin Teo, Robert Truax, and Matthew Walter "A Perception Driven Autonomous Urban Vehicle," Journal of Field Robotics, vol. 25, no. 10, pp. 727–774, July. 2008.

[12]. So¨ ren Kammel, Julius Ziegler,and Benjamin Pitzer,&, "Team AnnieWAY's Autonomous System for the 2007 DARPA Urban Challenge," Journal of Field Robotics, vol. 25, no. 9, pp. 615–639, June. 2008.

[13]. Alonzo Kelly and Anthony Stentz, "Rough Terrain Autonomous Mobility — Part 1: A Theoretical Analysis of Requirements," Autonomous Robots 5, pp. 129–161, May. 1998.

[14]. Alonzo Kelly and Anthony Stentz, "Rough Terrain Autonomous Mobility—Part 2:An Active Vision, Predictive Control Approach," Autonomous Robots no. 5, pp. 163–198, May. 1998.

[15]. Alberto Broggi, Senior Member, IEEE, Michele Buzzoni, Stefano Debattisti, Paolo Grisleri,Maria Chiara Laghi, Paolo Medici, and Pietro Versari ,"Extensive Tests of Autonomous Driving Technologies," IEEE Transactions on Intelligent Transportation Systems, vol. 14, no. 3, pp. 1403-1415, Sep. 2013.

[16]. Xiang Gao, Yongsheng Ou, Yiqun Fu, Zhao Li, Dawei Dai, Liangliang Cui, Yimin Zhou and Weidong Guo, "A Novel Local Path Planning Method Considering both Robot Posture and Path Smoothness," Proceeding of the IEEE International Conference on Robotics and Biomimetics (ROBIO), pp. 172-178, Dec. 2013.

[17]. B. Mashadi and M. Maijidi, "Global optimal path planning of an autonomous vehicle for overtaking a moving obstacle," Latin American Journal of Solids and Structures 11 (2014), pp. 2555-2572, Apr. 2014.

[18]. Kuo-Ho Su, Tan-Phat Phan, Chan-Yun Yang, Wen-June Wang "Image-Based Smooth Path Planningfor Wheeled Robot", Conference on Control & Automation (ICCA), pp. 204-207, June. 2014.

[19]. Tobias Nothdurft, Peter Hecker, Sebastian Ohl, Falko Saust, Markus Maurer,Andreas Reschka, J¨urgen R¨udiger B¨ohmer, "Stadtpilot: First Fully Autonomous Test Drives in Urban Traffic," Intelligent Transportation Systems, pp. 919-924, Oct. 2011.

[20]. S. S. Ge and Y. J. Cui, "New Potential Functions for Mobile Robot Path Planning," IEEE Transactions on Robotics and Automation, vol. 16, no. 5, pp. 615-620, Oct. 2000.

[21]. Ulrich Kadow, Georg Schneider and Alejandro Vukotich Audi AG, "Radar-Vision Based Vehicle Recognition with Evolutionary Optimized and Boosted Features," IEEE Intelligent Vehicles Symposium Istanbul, pp. 749-754, June. 2007.

[22]. Andreas Reschka, J¨urgen R¨udiger B¨ohmer, Falko Saust, "Bernd Lichte and Markus MaurerSafe, Dynamic and Comfortable Longitudinal Control for an Autonomous Vehicle," Intelligent Vehicles Symposium Alcalá de Henares, pp. 346-351, June. 2012.

[23]. Ilya Bekkerman and Joseph Tabrikian, "Target Detection and Localization Using MIMO Radars and Sonars," Transactions on signal processing, vol. 54, no. 10, pp. 3873-3883, Oct . 2006.
[24]. Tomas Berglund, Andrej Brodnik, Håkan Jonsson, Mats Staffanson, and Inge Söderkvist, Mats Staffanson, and Inge Söderkvist , "Planning Smooth and Obstacle-Avoiding B-Spline Paths for Autonomous Mining Vehicles," Tansactions on Automation Science and Engineering, vol. 7, no. 1, pp. 167-172, Jan . 2010.
[25]. Mehmet Korkmaz, Ömer Aydoğdu, Hüseyin Doğan, "Design and Performance Comparison of Variable Parameter Nonlinear PID Controller and Genetic Algorithm Based PID Controller." Innovations in Intelligent Systems and Applications (INISTA), 2012 International Symposium on, pp. 1-5, July. 2012.
[26]. Kiam Heong Ang, Gregory Chong, and Yun Li, "PID control system analysis, design, and technology," IEEE Transactions on Control Systems Technology, vol. 13, pp. 559 – 576, June. 2005.

Quan-ming Zhao, is a professor of the School of Electronic Information Engineering in Hebei University of Technology, received Bachelor in Radio Technology from Hebei Institue of Technology in 1991 and Ph. D in Signal and Information Processing from Tianjin University in 2007. His research interest is electromegnetic field and microwave circuit design

Tao Zhang, is studying the Master Degree in the School of Electronics and Information Engineering in Hebei University of Technology, major in application of radar.