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Future vehicles: learnable wheeled robots

Deyi LI[1], Nan MA[2,3*] & Yue GAO[4]

[1]*Academy of Military Science, Beijing* 100036*, China;*
[2]*Beijing Key Laboratory of Information Service Engineering, Beijing Union University, Beijing* 100101*, China;*
[3]*College of Robotics, Beijing Union University, Beijing* 100101*, China;*
[4]*School of Software, Tsinghua University, Beijing* 100084*, China*

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Abstract As one of the important signs of the third wave of artificial intelligence, wheeled robots not only inherit knowledge but also learn independently, which brings about to learnable wheeled robots that use a driving brain to achieve data-driven control and learning. Presently, most existing technologies for self-driving vehicles can learn positively from the benchmark drivers to guarantee safe driving. However, in many unpredicted situations, such as rollover, human drivers often cause the behavior of irrational subconscious on account of human emotions like panic. In this paper, we propose a learnable wheeled robot using the driving brain by taking the rollover as an example, which is the most serious and dangerous situation in dynamic vehicle operations. Then, based on the analysis of rollover accidents, we utilize the driving brain reversely and conduct negative learning, materializing, and condensing the group intelligence of accident experts, to solve the problem of the lack of individual intelligence in emergencies and further promote real-time response to other dangerous conditions, such as puncture for self-driving vehicles.

Keywords wheeled robots, driving brain, swarm intelligence, negative learning, data-driven self-learning

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1 Introduction

1.1 Wheeled robots: the trend of self-driving

Generally, the third industrial revolution that commenced after the Second World War was the beginning of the information age. The advance in scientific theory after the first industrial revolution in the 18th century is the creation of mechanical vehicles based on steam engines. In the second industrial revolution of the 19th century, the improvement and use of internal combustion engines and generators promote the development of modern electrified vehicles. Furthermore, in the 20th century, during the third industrial revolution, the automobile from the electrical era has been developed by information technology, which greatly improves the performance of automatic control.

In recent years, the development of human society has been transformed into the fourth industrial revolution known as the “Smart Age”. Hence, the development of intelligent technology will endow the machines with the ability of self-learning and self-cognition through cyber-physical systems (CPS). The key development of automotive engineering is gradually shifting from the vehicle dynamics by the driver to the wheeled robotic dynamics by the driving brain.

The new generation of automobiles [1] is a comprehensive carrier for the development of technologies such as artificial intelligence (AI) and new energy, which is also the core integration of the fourth industrial

* Corresponding author (email: xxtmanan@buu.edu.cn)

revolution. A new generation of cars shown in the form of wheeled robots will greatly change human economic production activities and social forms. During the transition period of the development of the information age and intelligent age, self-driving technology is an important driver for global development. For instance, micro-nano electronics and optoelectronic engineering [2], communication engineering [3], computer science and technology [4], and control science and engineering [5] are important impetuses for the development of electrical automobiles. After advancement in half a century, information technology has been well deployed in automobiles to meet the barriers at the end of the 20th century.

Then, entering the 21st century, the advent and application of AI technology brought new opportunities to the new generation of vehicles. The "Smart Chip", "Intelligent Network", "Smart Computing", and "Intelligent Control" created by the cross combination of AI and several other fields will become important driving technology for self-driving. These fields include micro-nano electronics and optoelectronic engineering, communication engineering, computer science and technology, control science and engineering. Especially, future vehicles will be shown in the form of wheeled robots and greatly developed.

1.2 Safety accident: the stagnation trap of automated driving

With the continuous development of AI and vehicle intelligence, the driving style gradually changes from manual driving to machine self-driving [6–8]. Recently, concepts such as unmanned driving [9], self-driving [10], automated driving [1], and autonomous driving [11] have been introduced. In 2014, the American Society of Automotive Engineers (SAE) developed the Taxonomy and Definitions for Terms Related to Dricing Automation Systems for On-Road Motor Vehicles (SAE J3016), in which the autonomous driving technology is divided into six levels from SAE L0 to SAE L5 [12]. These standards are based on driving operations, surrounding environmental monitoring, executives of dynamic driving tasks in complex situations, and road conditions supported by the system. As an international industry reference standard, SAEJ3016 leads the level rating of automated driving technology. However, there is no standard on the coping technology when an accident occurs. The frequent occurrence of safety accidents is the biggest trap that causes problems in the development of autonomous driving technology. The prevention and treatment mechanism for emergencies caused by this technology is the most urgent problem at this stage.

2 The essence of wheeled robots learning

The learning mechanism is the crux of autonomous driving technology. In such a high-tech era, we need to adopt innovative thinking methods to consider autonomous driving [13]. After entering the intelligent age, the positioning of automobiles will gradually evolve from human mobility tools and human-controlled machines to cognitive wheeled robots. The traditional laws of the automotive industry will be renewed, and the software structure and codes of traditional automobiles will also be changed dramatically, where the cognitive subject will also switch from the driver to the driving brain. The future vehicles will conduct the cognitive function using inherit learning and self-learning, in which negative learning is a significant way for self-learning.

2.1 Inherit learning and self-learning

Wheeled robots will accept and use existing information in an inheriting way and cultivate the ability to accept and use knowledge to adapt the human social ecology. For vehicles, the existing information and knowledge are road traffic regulations, social ethics, and conventional driving methods. As the basic rule of road traffic, traffic regulation manages the road safely and plays a normative role with a special social norm for society. Inherit learning will learn traffic rules and social standards as a priori knowledge of wheeled robots using deep learning, and such vehicles ought to be driven along the right to avoid the zebra crossing. Some examples are as follows: when the traffic rules are involved, vehicles should be driven under the control of traffic signals and must wait until the red-light changes; when the constraints are

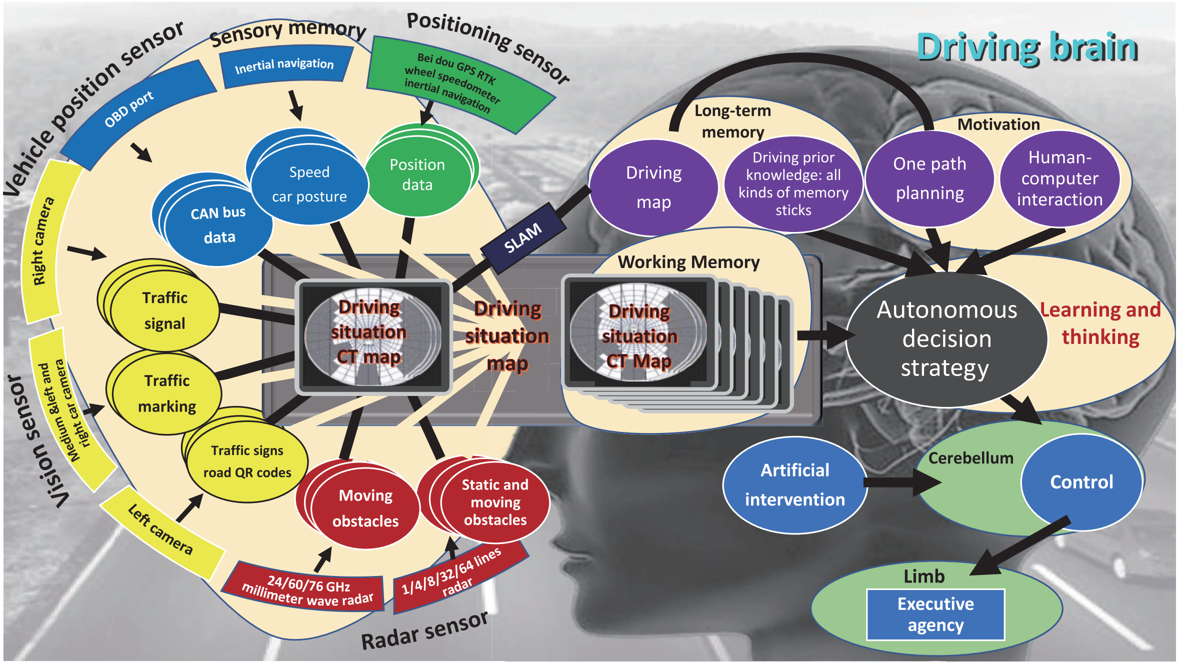

Figure 1 (Color online) The structure of driving brain.

involved, during the working day, other vehicles should not occupy bus lane in some districts in Beijing from 7:00 AM to 9:00 AM and 5:00 PM to 7:00 PM.

Basically, self-learning is the ability to generate experiences, skills, and new knowledge through its own practice. During the driving process, there will be most of unconventional situations that are not described in detail in the traffic regulations, such as overtaking, roadside parking, narrow road meeting, tire blowout, road rights preemption, snow driving, trailing, fuel-saving strategy, plug-in team, drifting into position, rollover prevention, and so forth. The self-learning makes the repeat of practice become an instinct, which is based on experience, sensing, and understanding. The self-learning can transform the repeated practice into an experienced knowledge under such special circumstances, calculate and store the processing models for these special cases.

2.2 Driving brain: the implementation of self-learning

Figure 1 shows the driving brain, which is composed of chips of several processors, switches, and memories equipped with various sensor interfaces, related software, and data packets. The cognitive subject of driving can be changed from the driver into a driving brain that is highly isomorphic with human cognition and more processing performance. The driving brain can not only realize self-learning through AI but also complete the substitution of human driving cognition. It also has the information gathering capability, the learning and retrieval ability of experience, the control precision of the machine, and robustness to external environmental factors such as emotions, which is far beyond the conventional human driver. The driving brain is the powerhouse of the future car (the wheeled robot). It integrates with sensors, intelligent algorithms, and assembles vehicles closely, which is an important part of the industry chain of self-driving. Unlike the conventional automated driving algorithms, the driving brain of the devices and vehicle computers for environment perception aim to simulate the cognition and function enhancement of human drivers. It contains computational cognition, memory cognition, and interactive cognition, and especially highlights the self-learning ability. It can adapt to different vehicle platforms, different sensor configurations, different landing application scenarios, and has broad development perspectives in the intelligent driving industry.

The targets of wheeled robot inherit learning are benchmark drivers, ordinary drivers, and accident drivers. By collecting the process data of human driving, such as driving posture and compliance with

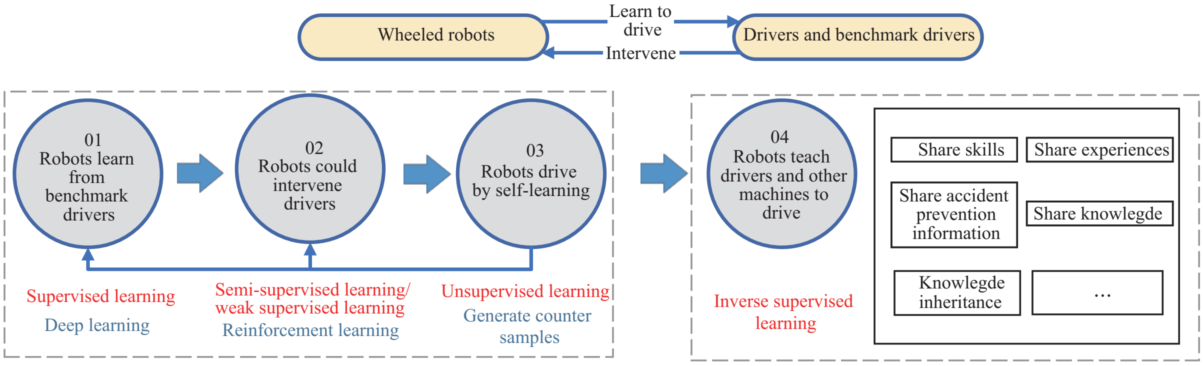

Figure 2 (Color online) Four working states of driving brain.

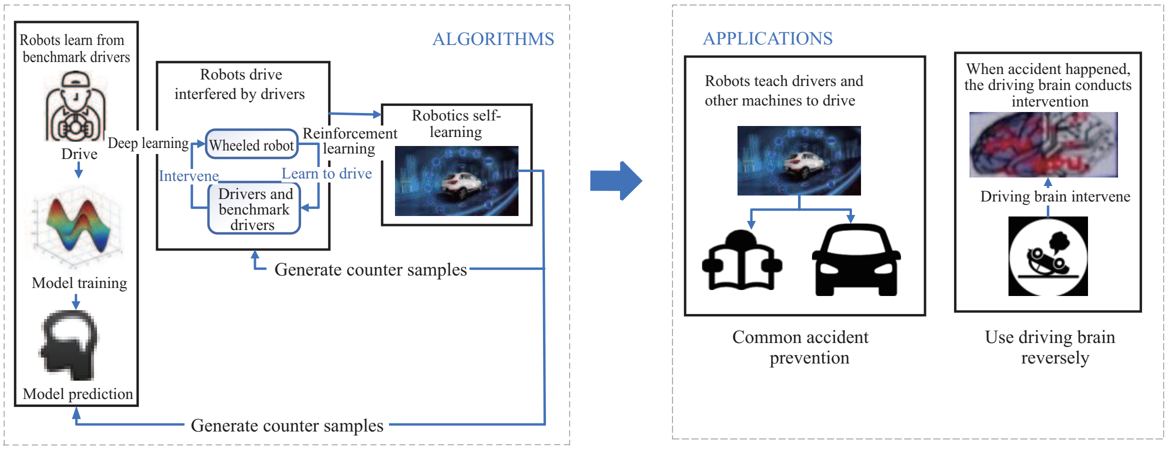

Figure 3 (Color online) Learning process of driving brain.

traffic regulations in every 100 ms, we can have a large number of data samples to supervise the training process using supervised learning and the acquisition of prior knowledge. The driver's situation can be sampled every 100 ms to create a large number of automatically labeled samples during driving. The working mode of the human driver and the wheeled robots can be divided into four working states, as shown in Figure 2. The first state is the learning from the benchmark driver. In this stage, prior knowledge is obtained using supervised learning algorithms. Then, the driving brain will collect the driving mode of the benchmark driver. For example, the driving situation and the operation information of the benchmark driver during the driving process can be acquainted with a certain frequency to generate the data set for learning. The second state is autonomous driving under manual intervention. In this process, the driving brain conducts reinforcement learning for human intervention in the form of semi-supervised learning or weakly supervised learning.

The third state is the complete machine autonomous driving. In this process, the driving brain achieves independent learning of special situations and captures experience through unsupervised learning. The fourth state is training the human driver or blank driving brain by trained driving brain, which is conducted by the accumulation of previous knowledge and experience. In this stage, the machine becomes a wheeled robot coach by inverse supervision and executes iterative inherit learning by treating driving skills, special situation handling and accident prevention experience as updated prior knowledge. In this way, wheeled robots can achieve skill sharing, experience sharing, accident prevention sharing, knowledge sharing, and knowledge promotion, which spreads and shares knowledge between different driving brains faster than that of humans. Wheeled robots can even become "duty traffic police" and "road inspectors". By illustration, the learning process of the driving brain is shown in Figure 3. To generate the experience, the driving brain can employ supervised and reinforcement learning methods to update the previous detection and decision-making model from the new data and information. Therefore, the self-learning

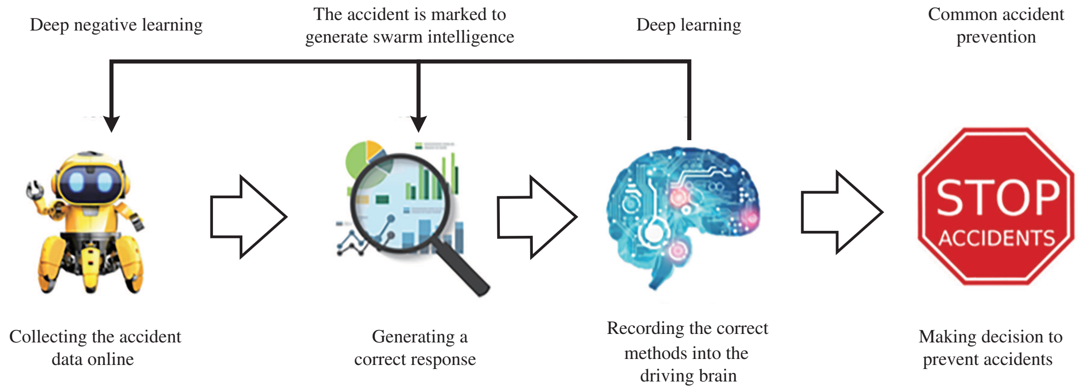

Figure 4 (Color online) Group intelligence and negative learning deal with accidents in golden one-second period.

module is able to achieve better decision-making performance.

2.3 Negative learning: the core of accident prevention

The negative learning [14] is one of the major mechanisms for automatic accident prevention of driving brain. Accident simulation and accumulation of cognitive experience are used to replace human drivers' conditional reflex processing during the accidents to reduce the probability of secondary disasters.

2.3.1 *Analysis of rollover accident based on human swarm intelligence*

According to the traffic accident statistics of the IEEE Symposium on Computational Intelligence for Security and Defense Applications, rollover is a traffic accident with very low probability but has serious consequences. The rollover of a vehicle is mainly caused by the deviation of the gravity center, leading to bouncing, overturning, tripping, tumbling, rolling, and other derivative accidents. In the situation of high-speed driving, any operation with deflection of gravity center could cause obvious rollover, such as steering and sudden braking. Moreover, the occurrence of rollover is also directly related to improper operations of the driver. For example, the driver lacks reasonable decisions in urgent moments and fails to adjust driving speed on time under the road trend, ground material, and other conditions. It is difficult for human to control directions of the vehicle and reverse the rollover trend in a very short time, so is difficult to reduce the collision loss and the possibility of rollover. Thus, many traffic accidents occur under special circumstances, which are different from safe driving. However, most human drivers do not have enough experiences in dealing with such emergencies.

By reproducing the accident scenario and analyzing the mistakes and lessons in negative cases, accident assessment experts found that the occurrence of accidents could be effectively avoided if the accidents can be reasonably dealt with in the "golden one second period" before and after the emergency, as shown in Figure 4. Therefore, the driving brain ultilizes swarm intelligence to solve the lack of individual intelligence in urgent situations, and further extend it to real-time response in other dangerous situations.

2.3.2 *Driving brain solves the lack of human intelligence in urgent situations*

To solve the lack of human intelligence in urgent situations, the driving brain learns human drivers' experiences of dealing with accidents within the "golden one-second period", and conducts negative learning [9] to gather expert swarm intelligence, which is the analysis on experiences of accidents. Then, it learns to generate swarm intelligence. Also, the driving brain learns to deal with accidents through simulating the accident occurrence process and then accumulating accident simulation experiences. When an emergency occurs, the driving brain can take over the control of the vehicles forcibly instead of the driver's stress-coping behaviors under the emotional fluctuation. As a result, the rollover can be correctly handled by optimal standard operation within the golden one-second period. In this process, the driving brain also sets up the memory stick for accident prevention. Therefore, when the accident is about to

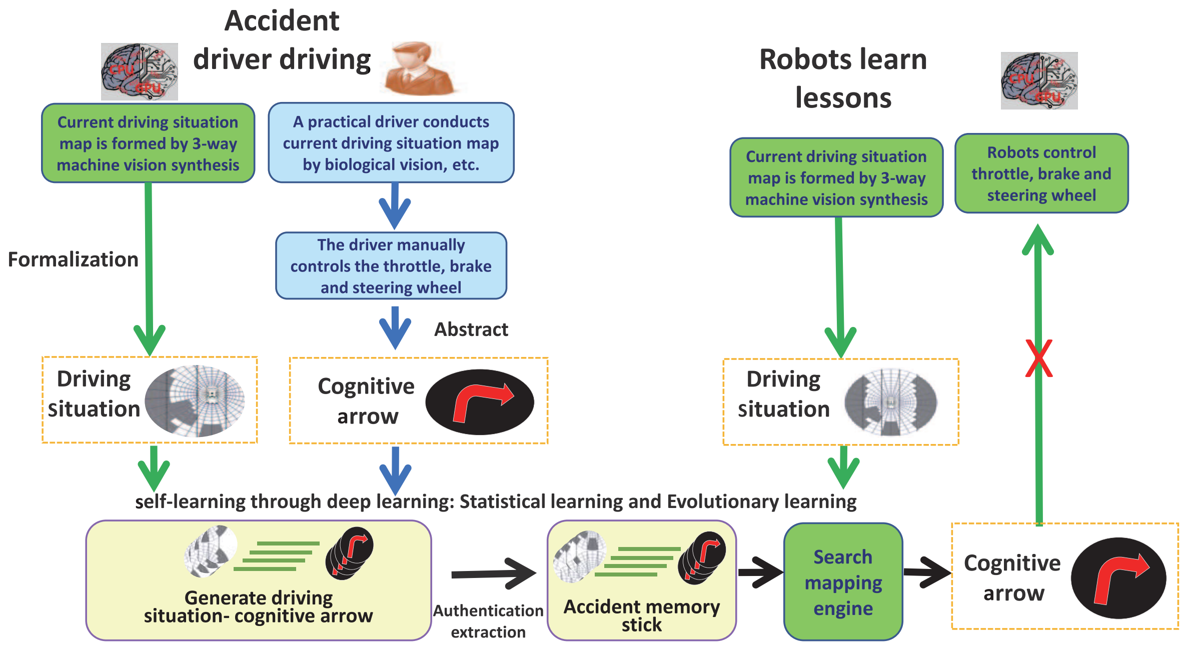

Figure 5 (Color online) Negative learning process of the driving brain.

occur, the memory stick for rollover accident prevention can be formed by the robot. Figure 5 shows the negative learning process of the driving brain. Given the negative training samples, the driving brain can learn the features of an emergency, and thus detect the possibilities of a future accident. In this way, the driving brain can predict whether the emergency may occur and take over control of the vehicles. Specifically, the total length of an accident is usually only about 3 s, hence being the reason why the golden one-second period is very important in developing the model.

For the wheeled robot controlled by the driving brain, the disposal of time slice within the golden one-second period can be interpreted by "slow-motion". Taking samples in every 100 ms, 30 driving situations can be obtained. So, the driving brain can make 30 decisions of intervention, which is much faster than human response and continuously simulates to obtain the best solution to avoid risks. The driving brain samples data every 100 ms, and then these data will be processed for decision-making. Under such circumstances, the intervention can be conducted after the decision-making procedure. If the decision-making procedure costs about 0.1 s, it can achieve 30 decisions of intervention in 3.1 s. It is noted that this time delay is associated with the computational capability, and fast response is required in practice.

3 Prospects for the future automotive industry

In 1886, Karl Benz acquired the first invention patent of automobiles in the world and achieved the brilliance of the automobile in the past 100 years relying on two magic weapons: large-scale production and meticulous management [15]. As the direct application carrier of many frontier technologies, the automotive industry will become the benchmark of the intelligent age in the future. The vehicles shown in the wheeled robots are composed of three important parts: muscle machine, power machine, and brain-machine. As shown in Figure 6, the muscle machine is the computer numerical control (CNC) chassis, the power machine is the wheeled robot using new energy, and the brain-machine is the driving brain intelligence.

The main difficulty of autonomous driving is uncertainty driving, i.e., edge driving. The research of wheeled robot regards "the last-kilometer problem" as "the first-kilometer problem" and studies various kinds of uncertainties frequently encountered in the driving process. The wheeled robot with the driving brain as the main body can automatically adapt to rainy, snowy, and other complex natural environments,

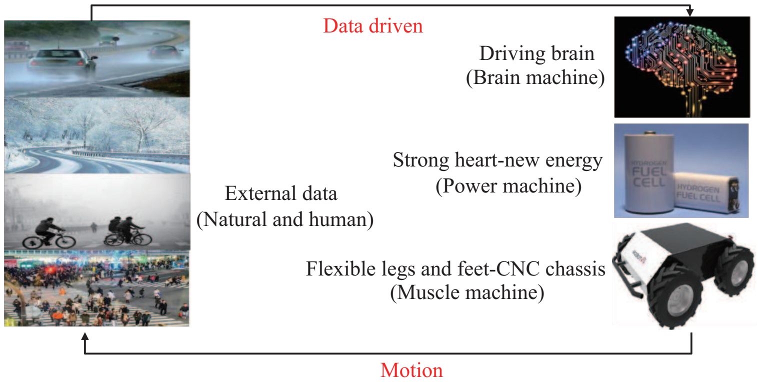

Figure 6 (Color online) Wheeled robots: data-driven control and learning.

and also automatically adapt to different social environments such as traffic regulations according to different priori knowledge databases. Therefore, the wheeled robot can achieve much better understanding and driving ability than human.

The most revolutionary technology in the 21st century is unmanned driving. It cut across almost all the cutting-edge technologies of AI. It can be used not only in human travel, but also in all aspects of human life, such as elderly care and disability assistance. The wheeled robot industry should not only be modularly customized but also the backbone of the intelligent industry. Data-driven control and learning have been deployed and become the technology service provider for future travel. The past automobile control engineering based on a mathematical model or nominal model has gone through the peak. The model-based automobile control engineering and methods are challenged, whereas the era of data-driven control and learning has just arrived. The vehicle dynamics by drivers should be derived from the dynamics by the driving brain, and the current dynamics of wheeled robots are exactly controlled by the driving brain as well.

4 Conclusion

Automobiles have changed human life. In nowadays, the living style of shared travel will change automobiles in a revolutionary way. The learnable wheeled robots should be able to drive, learn, interact, and have personality and insight. They should not only be modularly customized but realize data-driven control and learning by the driving brain, and should become the backbone of the intelligent industry. The wheeled robots aim to eliminate fatigue driving and drunk driving and be able to prevent serious accidents, such as tire burst and rollover. In addition, the research and development of the driving brain also have high economic value and will change the way of human travel in the future society.

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