Principle Analysis and Application Prospect of Mechatronics Drive System

Junhao Tuo *

School of mechatronic engineering and automation, Shanghai University, Shanghai, 200444, China

* Corresponding Author Email: 3513468651@shu.edu.cn

Abstract. With the progress of science and technology and the change of application demand, mechatronics drive system will face new challenges and opportunities. The purpose of this paper is to deeply analyze the mechatronics drive system, and discuss its application prospect. First of all, the paper introduces mechatronics technology, including definition, characteristics and development history, to better understand mechatronics technology. Secondly, the thesis focuses on the principle analysis of the mechatronics drive system, including the structure of the drive system, the matching principle of the motor, the control principle and the related algorithm. Through the detailed analysis of these principles, the working principle of mechatronics drive system can be better understood. Finally, through the above discussion, the paper analyzes the application potential and potential defects in various aspects, and puts forward the possible development direction in the future. This paper reveals the application prospect of mechatronics drive system in different fields, and provides useful information and enlightenment for relevant researchers and engineers to promote the development and application of mechatronics drive system technology.

Keywords: Mechatronics; drive system; application prospect.

1. Introduction

With the rapid development of science and technology, computer technology has also been greatly improved, which is bound to bring a technological innovation. Computer and mechanical and electrical more effectively combined together, making mechanical and electrical integration technology has been improved in all aspects, but also make mechanical and electrical integration technology has gradually become one of the cores of modern manufacturing industry and an important means to achieve automated and intelligent production. With the wide application of mechatronics, the degree of intelligence of all walks of life will be higher and higher, and the machinery industry has also made great progress in production efficiency and production quality.

Mechatronics drive system will mechanically structure, electronic control and sensor technology effectively combined together, the use of computer, Internet and other high-tech network system to improve the car in many aspects, to achieve a high degree of integration of force, motion and control, for the production and manufacturing of the automotive industry has brought great convenience. Additionally, by effectively utilizing mechatronics technology, it is possible to increase the intelligence and stability of the automobile brake system in addition to their safety.

This paper first introduces the definition, characteristics and development history of mechatronics technology, and tells the development of mechatronics technology in a more comprehensive way. Then, through the structure of the drive system, the matching principle of the motor, the control principle and the related algorithm, the principle of the mechatronics drive system is analyzed at a deeper level. Finally, the application potential, potential defects and future development direction are analyzed from many aspects.

2. Development analysis of mechatronics technology

2.1. Definition and characteristics of mechatronics technology

Mechatronics is created by fusing the first and second halves of the words "Mechanics" and "Electronics". The term "mechatronics" initially debuted in a 1971 supplement to the Japanese magazine Mechanical Design, and it was accepted by all walks of life in Japan around 1976 [1]. Mechatronics technology has experienced unprecedented growth and widespread acceptance due to the rapid advancement and extensive implementation of computer technology. As a result, the term is now commonly used. Furthermore, the development of mechatronics has endowed machines with human-like characteristics and intelligence.

Mechatronics technology integrates various technologies such as mechanical, electrical, electronic, microelectronics, information, sensor, interface, and signal conversion. This comprehensive technology finds extensive application in modern automated production equipment, which can be attributed to its close association with mechatronics.

2.2. Development history of mechatronics technology

The development of mechatronics can be divided into three stages. The first stage was in the 1960s and before, and this stage was called the primary stage. The term "mechatronics" first appeared in a 1971 supplement of the Japanese magazine Mechanical Design. At the time, mechatronics was always thought of as an amalgamation of electronics and mechanical. Additionally, because electronic technology development had not yet reached a certain stage, the integration of mechanical and electronic technology could not have been fully explored, and the developed products could not have been widely advertised, research and development were still largely in a spontaneous state [2].

The second stage took place in the 1970s and 1980s, a time when communication, control, and computer technologies all blossomed, setting the groundwork for mechatronics development [3]. Among these, information technology has developed, and microprocessor performance has increased, leading to the adoption of these technologies by more modern mechatronics devices. The mechanical-electronic system has been extensively employed in exhaust control, altitude control, and vibration control since the emergence of the microcomputer as a major technology in the aviation system. At the same time, China has gradually begun to carry out research and application in mechatronics, relatively speaking, it started late, so in the face of competition in the global economic market, China is facing a grim situation in this field.

Mechatronics technology started to advance towards a new level of intelligence in the late 1990s, and it entered a phase of in-depth development. At this time, mechatronics now incorporate communication technology, and networked mechatronics operated by computers that are intimately linked with technologies like remote control and virtual reality multimedia are becoming more and more common. A new branch of mechatronics has been developed as a result of the development of micro-machining technology, which has been combined with semiconductor technology, traditional mechatronics, and other technologies [2]. Artificial intelligence, neural networks, optical fiber, and other technologies have made significant advancements as a result, giving mechatronics technology a more expansive development direction and space. The development of mechatronics from all aspects has entered the stage of in-depth research. These research and the increasing development of technology have prompted mechatronics to steadily enter the 21st century. The development history of mechatronics is shown in Fig. 1 below.

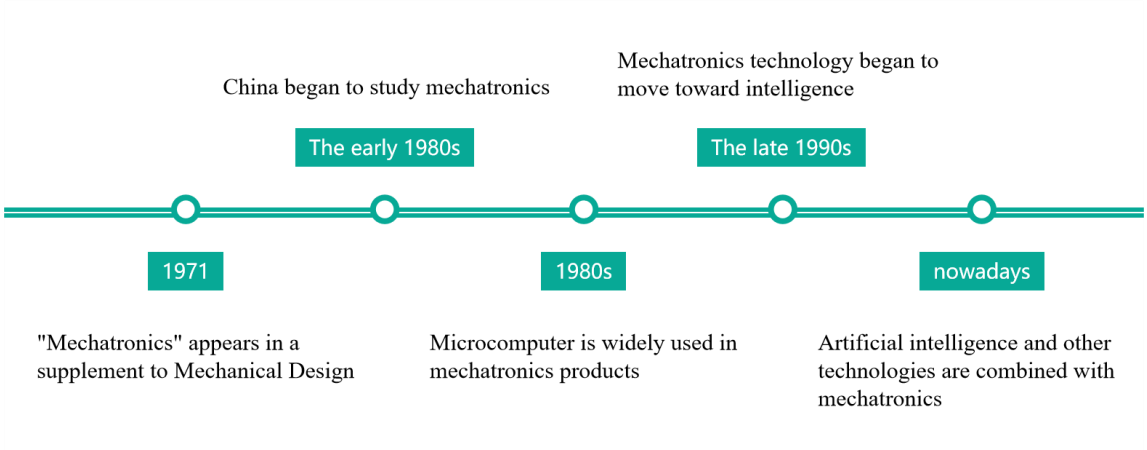


Fig. 1 The development history of mechatronics (Photo/Picture credit: Original)

3. Principle analysis of mechatronics drive system

3.1. Components of the drive system

3.1.1 Traditional actuation form

The conventional drive form is shown in Fig. 2, in which the clutch, transmission, main reducer, differential, drive shaft, and drive axle are retained while the engine of the conventional car is directly replaced by an electric motor.

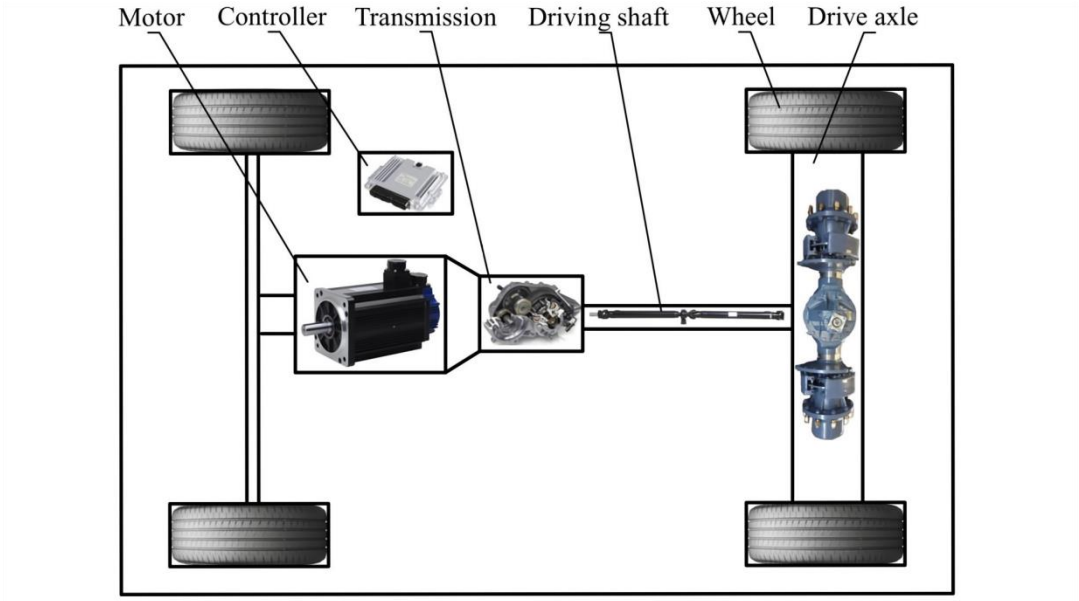


Fig. 2 Traditional drive system form of electric vehicle (Photo/Picture credit: Original)

Its working principle is also similar to the traditional car, the clutch is used to control the power cut off or connected, the transmission plays the role of deceleration and torque increase, because the motor speed range is relatively wide, so the transmission can be simplified accordingly [4]. This design is primarily used in early electric vehicles, saving on research and development costs while also being appropriate for modifying the original vehicle. However, due to its complicated and bulky structure, occupies a large space, and low efficiency, it is unable to fully exploit the benefits of motor drive.

3.1.2 Driving axle Mechatronics actuation form

The driving axle Mechatronics actuation form is depicted in the Fig. 3, this drive system has two kinds: coaxial type and dual type.

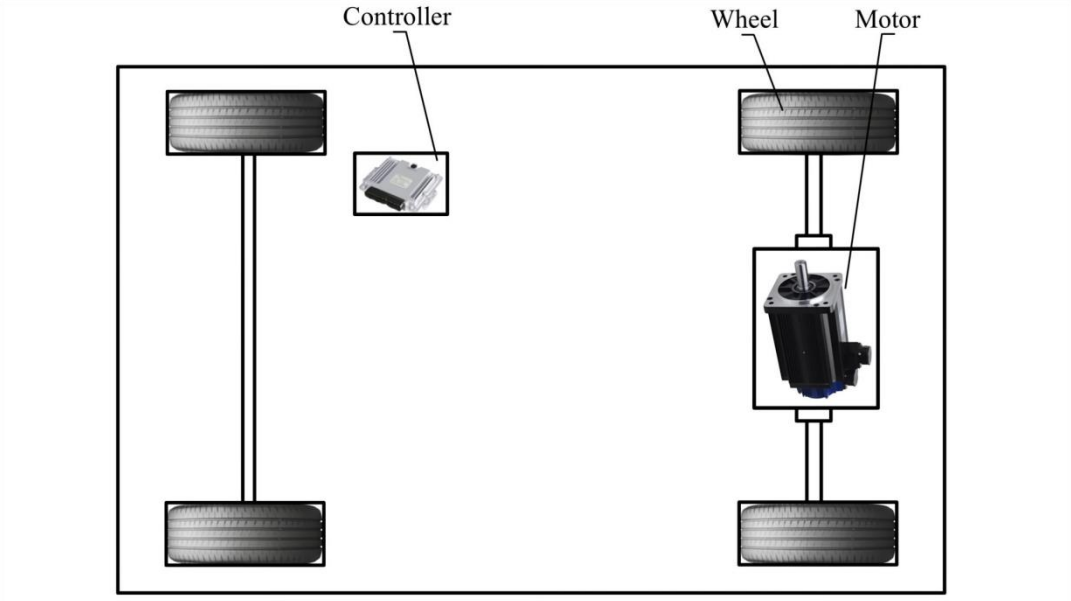


Fig. 3 Mechatronics drive system form of of electric vehicle (Photo/Picture credit: Original)

The coaxial drive system only needs one drive motor, which is hollow and has a mechanical differential and planetary reducer installed at one end of the motor output shaft [4]. The left and right two motors in the dual drive system are driven by the electronic differential directly through the axle wheel, this drive form is similar to the hub motor drive form, but the motor power can be substantial. When the car turns, the coaxial drive system uses the mechanical differential, and the dual drive system is realized by the electronic differential [4]. The mechatronics drive system, which consists of a motor and drive axle, is more space-efficient and has a more compact structure. It also has a high transmission efficiency, is lightweight and small, and is versatile and interchangeable [5]. The motor's performance requirements are higher, though. If properly developed, this driving form has a promising future and may even produce more power than a fuel-powered vehicle.

3.2. Motor selection and matching principle

Pure electric vehicles experience frequent starts, stops, and changes in acceleration and deceleration while driving, necessitating a drive motor with higher torque response characteristics and a wider speed range to meet the needs of the car's efficient and stable operation under various driving conditions [5]. It is necessary to analyze the working characteristics of the motor [5-7].

3.2.1 Choice of motor power

The main power source of pure electric vehicles is the drive motor, so the power of the drive motor must meet the power needs of pure electric vehicles in various operating conditions. The parameter matching mainly includes the rated power, peak power and maximum torque of the motor. If the rated power is selected too small the motor often runs in the overload state, shortening the service life of the motor. On the contrary, the motor will run in the underload state for a long time, reducing the efficiency of the motor. Therefore, it is very important to choose the rated power of the motor reasonably.

The maximum speed at which the car is expected to travel is often used to determine the initial power of the motor, which essentially reflects its ability to accelerate and climb hills. When the car travels at the highest speed U on a good level road surface, subject to rolling resistance and air resistance, the rated power of the motor cannot be less than the total resistance power, that is:

$$P_n \geq \left(\frac{C_D A U_{max}^3}{76140} + \frac{mgfU_{max}}{3600}\right)/\eta \quad (1)$$

In the formula, m is the vehicle mass; f is rolling resistance coefficient; U_{max} is maximum speed; A is the windward area; C_D is the air resistance coefficient; η is the motor transmission efficiency, generally 0.92.

3.2.2 Electric motor speed selection

(1) The rated speed of the motor is determined at the conventional speed, that is:

$$n_N = \frac{i_0 u_N}{0.377r} \tag{2}$$

In the formula, is the speed ratio of the transmission; u_N is the rated speed of the motor (r/min); r is the radius of wheel (m).

(2) The maximum speed of the drive motor should ensure the demand of the car at the maximum speed. Generally, the motor speed corresponding to the maximum speed of the electric vehicle is 90% to 95% of the maximum speed, and 90% is generally taken [8], that is:

$$n_{max} = \frac{i_0 u_{max}}{0.377r}/0.9 \tag{3}$$

3.2.3 Choice of motor torque

(1) Rated torque is determined by the rated power and rated speed of the motor, that is:

$$T_n = \frac{9554P_n}{n_N} \tag{4}$$

(2) The maximum gradient required by the electric vehicle determines it's the highest torque, that is:

$$F_t = F_f + F_w + F_i \tag{5}$$

$$\frac{T_{max} i_0 \eta}{r} = mgsin\alpha_{max} + mgcos\alpha_{max} + \frac{C_D A}{21.15} v_g^2 \tag{6}$$

In the formula, F_f is the rolling resistance, F_w is the air resistance, F_i is the slope resistance, α_{max} is the maximum slope, v_g is the ramp travel speed.

3.2.4 Motor selection

According to the above motor parameter matching principle, combining the basic parameters of electric vehicle, battery and motor and substituting them into the corresponding formula, the parameters of the motor can be obtained. In this way, the power performance of electric vehicles can be calculated according to the power performance requirements of various electric vehicles, and different types of motors can be selected.

3.3. Motor control principle and related algorithm

Motors can be classified based on their power supply as DC motors and AC motors. They can be further categorized into DC motors, asynchronous motors, and synchronous motors based on their structure and working principles. Additionally, motors can be differentiated as drive motors and control motors based on their purpose. Another classification criterion is the running speed, which can classify motors into high-speed, low-speed, constant-speed, and speed-regulated motors.

As a kind of drive motor, permanent magnet synchronous motor (PMSM) has more advantages in performance such as efficiency, power density and torque density, compared with other drive motors, so the application of permanent magnet synchronous motor in mechatronics drive system and electric vehicle is of great practical significance [8]. Therefore, this section mainly introduces the motor control principle and related algorithms of permanent magnet synchronous motor.

3.3.1 Structure of PMSM

The composition of a permanent magnet synchronous motor includes the stator, rotor, and end cover. To reduce iron consumption during motor operation, the stator is made of laminated sheets. It is equipped with a three-phase AC winding known as the armature. The rotor can be either solid or

laminated, and it contains permanent magnet material. Depending on the position of the permanent magnet material on the rotor, there are two structural forms of permanent magnet synchronous motors: protruding type and built-in type.

The built-in rotor's magnetic circuit structure can be radial, tangential, or hybrid. The distinction between these types depends on the relationship between the direction of magnetization of the permanent magnet and the rotor's rotation direction. The placement of the permanent magnet inside the rotor allows for the surface of the rotor to be designed as a pole piece. Copper or cast aluminum can be placed in the pole piece to facilitate starting and damping, resulting in good steady-state and dynamic performance.

Moreover, the asymmetry of the built-in rotor magnetic circuit generates reluctance torque during operation, which enhances the motor's gravimetric specific power and overload capacity. This structural design also simplifies the achievement of weak magnetic expansion speed.

3.3.2 Working principle of PMSM.

The magnetomotive force produced by a three-phase A.C. circuit flowing into a permanent magnet synchronous motor's stator's three-phase symmetric winding is a rotating force with constant amplitude. This rotational magnetomotive force is known as a circular rotational magnetomotive force because its trajectory forms a circle due to its constant amplitude. Its size is exactly 1.5 times the maximum value of the single-phase magnetomotive force, that is:

$$F = \frac{3}{2}F_{\varphi l} = \frac{3}{2} \cdot 0.9k \cdot \frac{NI}{P} \tag{7}$$

In the formula, F is the circular rotating magnetomotive force ($T \cdot m$), $F_{\varphi l}$ is the maximum value of single-phase magnetomotive force ($T \cdot m$), k is the fundamental wave winding coefficient, P is the pole pair, N is the number of windings per coil, I is the root-mean-square value of the current flowing through the coil.

In order to facilitate the later design of the magnetic field orientation controller, the permanent magnet synchronous motor in the synchronous rotating coordinate system is often selected in engineering, and its voltage equation, that is [9-10]:

$$\begin{cases} u_d = R_s i_d + \frac{d}{dt}(L_d i_d) - \omega_e L_q i_q \\ u_q = R_s + \frac{d}{dt}(L_q i_q) + \omega_e L_d i_d + \omega_e \psi_f \end{cases} \tag{8}$$

Its magnetic linkage equation, that is:

$$\begin{cases} \psi_d = L_d i_d + \psi_f \\ \psi_q = L_q i_q \end{cases} \tag{9}$$

Its Electromagnetic torque equation, that is:

$$T_e = \frac{3}{2} p_n i_q \left[i_d (L_d - L_q) + \psi_f \right] \tag{10}$$

In the formula, $u_{d,q}$ is the voltage of the PMSM, $i_{d,q}$ is the electric current, $L_{d,q}$ is the inductance, $\psi_{d,q}$ is the magnetic linkage, p_n is the number of poles of a permanent magnet.

4. Application potential analysis

4.1. Electric vehicle drive field

With the progress of science and technology, the concept of mechatronics is gradually integrated into every design of automobiles. The main body of the drive system is the universal joint, the differential, the viscous coupler and the synchronizer. Among them, the universal joint can effectively solve the performance problems of the car during the driving process, especially on the bumpy road. When the vehicle is driving on an uneven or non-linear road surface, the differential will rotate the

first two driving wheels of the vehicle at different speeds to prevent the vehicle from sliding. When the car needs a liquid viscous transmission device that transmits a large amount of power during the driving process, the viscous coupler can meet these purposes [11].

The operation of the drive system needs to be based on the occurrence of emergency. After the application of mechatronics technology in the design of the drive system, it can help each system to accept the information transmitted by the control central system and analyze the information according to the information processing function of the drive system, and finally react. Under the role of mechatronics technology, the compatibility and efficiency of the drive system will be improved [12].

With the advancement of technology, the future drive system will become more and more reliable, and the energy consumption will be lower and lower. The wide application of these cutting-edge technologies has greatly improved people's driving experience and promoted the vigorous development of the automobile industry.

4.2. Electric vehicle power generation field

4.2.1 Efficient energy conversion and intelligent energy management

Electric vehicles adopt mechatronics technology, integrating sensors, battery management systems and control algorithms, which can realize real-time monitoring and optimal control of charge and discharge status, and effectively convert electrical energy into mechanical energy. Therefore, it helps to improve the energy efficiency of electric vehicles, increase driving range, reduce energy consumption, extend battery life and save charging time.

4.2.2 multi-energy integration and feedback brake energy recovery

The mechatronics technology makes the feedback brake energy recovery system run efficiently and helps to realize multi-functional integration and collaborative work. At the same time, electric vehicles can be integrated with other renewable energy systems, such as solar and wind. Through mechatronics technology, a variety of energy sources can be successfully converted and shared, converting braking energy into electricity, which is stored in the battery to drive the car, thereby improving energy efficiency and sustainability.

4.2.3 Autonomous driving and intelligence

The application of mechatronics technology in autonomous driving and intelligence is also one of the important directions of the development of electric vehicles. By integrating sensors, control systems, and motors, higher levels of autonomous driving capabilities can be achieved. At the same time, mechatronics technology can also support the intelligent management of electric vehicles, such as remote monitoring, diagnosis and maintenance.

5. Potential defects and future development

5.1. Potential defect

The mechatronics drive system is composed of mechanical and electronic components, and the electronic components are sensitive to environmental conditions, and the harsh environment will reduce the performance and life of electronic components, and even lead to component failure. If the system fails, because the mechanical and electrical parts are closely integrated, the failure of one component may affect the operation of the entire system, and a failure of the system may also cause the fault to spread to other parts, and the difficulty of maintenance will be greatly improved.

Mechatronics drive systems are more expensive than traditional mechanical drive systems because they require additional components including electronic components, sensors, controllers, and more complex design and manufacturing processes. In addition, mechatronics drive systems are often designed for specific applications and are difficult to customize and flexibly adjust. If changes need

to be made to the system or to adapt to new requirements, large-scale modifications or redesigns may be required, which may result in additional time and cost.

5.2. Future development direction

With the coordinated development of mechatronics technology and artificial intelligence, the future mechatronics drive system will be more intelligent, and the control will be improved [13]. The system can adjust the motion control parameters in real time by collecting and analyzing a large number of sensor data and combining with intelligent algorithms to adapt to different working conditions and needs. Thanks to the use of intelligent algorithms and machine learning techniques, the system will be able to independently learn and optimize motion control strategies, which will also improve the effectiveness and performance of the system. At the same time, due to the application of new materials, improvements in sensor technology and advanced manufacturing processes, the mechatronics drive system will have higher performance and higher precision. High resolution position sensor and precise motion control algorithm will make the system realize more accurate position control and motion trajectory tracking.

Due to the continuous improvement of people's requirements for energy saving and space utilization, the mechatronics drive system will also develop in the direction of lightweight and compact design, and the technology has high application value in biomedicine, national defense and other fields [14]. The new material and structural design will reduce the weight and volume of the system, while improving the stiffness and stability of the system. This will help the system achieve greater output power and higher efficiency in a limited space.

Future mechatronics drive systems will also focus on efficient energy management and sustainable development [15]. The use of advanced energy recovery technologies, renewable energy and environmentally friendly materials will reduce energy waste and harm to the environment, improve the energy efficiency of the system and avoid resource waste. In addition, the application of intelligent energy management algorithms will enable the system to adjust the supply and consumption of energy according to the actual demand to achieve the optimal allocation of energy. Mechanical and electrical products can be connected to each other, avoiding a lot of resource waste, but also to achieve the reuse of resources, reduce costs. At the same time, the energy consumption and emissions in the use of the system will be more effectively managed and controlled, reducing the harm to the environment, which also makes the concept of green environmental protection has been well implemented.

6. Conclusion

In this paper, the principle of mechatronics drive system is analyzed in depth, and its application potential and development direction in different directions are prospected. Through the description of the paper, it can be concluded that in-depth understanding of mechatronics technology, the composition of the drive system, the matching principle of the motor, the control principle and related algorithms are crucial to master the working principle of the mechatronics drive system. And it can bring great potential for the development of electric vehicles in all fields. At present, there are still some problems in the research of mechatronics drive system, such as the challenges of system stability, reliability and cost. In order to promote its further development, it is also necessary to solve these problems and continuously improve the relevant technology. In the future, mechatronics will face new development directions and challenges, and it is necessary to focus on innovation, improve the performance and reliability of the system, explore new application areas, and more effectively combine with other technologies in order to achieve a wider range of applications.

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