Chapter 2 Reports in Different Fields

I. Mechanical & Vehicle Engineering

1 Engineering research hotspots and engineering research focus

1.1 Development trends of engineering research hotspots

The top 10 engineering research hotspots in mechanical and vehicle engineering (hereinafter referred to as the mechanical field) include mechanical engineering, naval architecture and ocean engineering, aerospace science and technology, armament science and technology, power and electrical equipment engineering and technology, transportation engineering, and other subjects (Table 1.1.1). Traditional research in mechanical engineering has focused on "Large-scale robot tactile sensors and implementations," "Neural network model and fuzzy logic," "Vibration isolation system," "Piezoelectric energy harvesting," "Fluid–solid coupling simulation," "Instability and dynamics of a gas turbine combustor," "Shape memory alloy," and "Nonlinear vibration modes in mechanical engineering." "Process design and self-adaptive control of additive manufacturing" and "Supersonic flow and aerodynamics" are emerging hotspots. Table 1.1.2 shows the annual publication of core papers involved in all hotspots in 2011–2016. The number of studies on "Process design and self-adaptive control for additive manufacturing" has significantly increased.

(1) Large-scale robot tactile sensors and implementations

A robot obtains external information through tactile sensors to perceive the external environment. Currently, tactile sensors are divided into two categories: the first category uses pressure sensing unit to detect the force, detect the vector of contact force at a single point, and form a multi-point array (e.g., an array sensor composed of many strain foils); and the second category uses an elastomer as contacting part of the sensor, and deformation occurs when the elastomer is subjected to force. Large robots have high stiffness and output power; as such, the output force in their interaction with the environment is large. To achieve accurate operation, robots should be equipped with tactile sensors with precise sensing capability. Currently, research on single-dimensional force sensor has

Table 1.1.1 Top 10 engineering research hotspots in mechanical and vehicle engineering

No.	Engineering research hotspots	Core papers	Citation frequency	Average citation frequency	Mean year	Proportion of consistently cited papers	Patent-cited publications
1	Large-scale robot tactile sensors and implementations	49	1536	31.35	2012.35	12.2%	0
2	Process design and self-adaptive control of additive manufacturing	33	610	18.48	2013.82	12.1%	0
3	Supersonic flow and aerodynamics	41	697	17.00	2013.61	7.3%	0
4	Neural network model and fuzzy logic	47	1600	34.04	2011.64	8.5%	0
5	Vibration isolation system	35	786	22.46	2013.37	8.6%	0
6	Piezoelectric energy harvesting	39	1578	40.46	2012.51	28.2%	0
7	Fluid-solid coupling simulation	45	1442	32.04	2012.84	8.9%	0
8	Instability and dynamics of a gas turbine combustor	35	1105	31.57	2013.03	17.1%	0
9	Shape memory alloy	41	1287	31.39	2013.17	24.4%	2
10	Nonlinear vibration modes in mechanical engineering	32	646	20.19	2013.69	6.3%	0

Table 1.1.2 Annual number of core papers belonging to each of the top 10 engineering research hotspots in mechanical and vehicle engineering

No.	Engineering research hotspots	2011	2012	2013	2014	2015	2016
1	Large-scale robot tactile sensors and implementations	17	11	13	4	3	1
2	Process design and self-adaptive control of additive manufacturing	2	3	7	9	11	1
3	Supersonic flow and aerodynamics	3	8	7	10	10	3
4	Neural network model and fuzzy logic	24	16	7	0	0	0
5	Vibration isolation system	3	8	7	8	8	1
6	Piezoelectric energy harvesting	10	14	5	5	5	0
7	Fluid-solid coupling simulation	9	13	3	16	4	0
8	Instability and dynamics of a gas turbine combustor	7	8	6	6	7	1
9	Shape memory alloy	8	4	10	14	2	3
10	Nonlinear vibration modes in mechanical engineering	5	1	7	7	10	2

matured. However, detecting forces in three-dimensional directions and even multidimensional directions is necessary to perceive the interaction between the robot and the environment. The main research focuses are the optimization of flexible structures and the design of base materials. Research and development of flexible multidimensional tactile sensors are important but difficult to achieve.

(2) Process design and self-adaptive control of additive manufacturing

Metal additive manufacturing techniques are categorized according to heat source into laser, electron beam, and arc methods. Laser engineering net shaping based on powdered materials, selective laser melting, and selective electron beam melting are used in the field of aerospace, biological medicine, and molding. These processes can solve complex, integrated, and personalized manufacturing difficulties that come with traditional manufacturing techniques. However, these processes exhibit limitations in forming large parts at a rapid speed and low cost because of their complex laser and electron beam control, high cost, difficult powder preparation, easy contamination, and low formation efficiency. Wire arc additive manufacture (WAAM) uses arc as energy beam; moreover, parts are accumulated by multiple welds, with uniform chemical composition and high density. The local atmosphere does not limit the forming dimension. The efficiency of WAAM can reach kilograms per hour or even higher. The wire material exhibits less pollution and lower cost than the powder material and thus can be used in low-cost high-efficiency additive manufacturing of large aerospace components. In addition, arc is easier to achieve than laser and electron beam. The wire materials can be more easily transported and collected than the powdered materials and have significant potential in the space metal additive manufacturing field. Compared with laser and electron beam techniques, the part used in arc additive manufacturing technique possesses a rough surface, low dimensional accuracy, and coarse and big interior tissues. In-situ integration with cutting, forging, and other traditional processes is the development direction of this technology and one of the research hotspots in this field to improve the accuracy and performance of structures.

(3) Supersonic flow and aerodynamics

Supersonic flow plays an important role in the design of supersonic civil and military airplanes and is affected by a number of key technical issues related to supersonic aerodynamics. An advanced aerodynamic layout design of supersonic jet can be obtained by exploring the type of boundary transition and control measures under supersonic flow; such design can be used to determine the effect of shock wave/boundary layer interference on aerodynamic layout design, clarify the perturbation modes of supersonic flow and the evolutionary characteristics of the interaction of shock waves, and understand the structure characteristics of coherent vortex in supersonic turbulent boundary layer and the generation and propagation mechanism of aerodynamic noise. Research on the characteristics of the translot jet field can optimize the mixing process of fuel, reveal the physical mechanism of the combustion stability of scramjet engine, and improve the applications of scramjet technology and scramjet engine in engineering practices. Transverse slot jet flow plays an important role in the overall thermal protection of aircraft and the internal cooling of scramjet engine. However, unsteady aerodynamic issues (e.g., flow separation and reattachment) are prone to occur under supersonic flow due to the disturbance of shock wave and the effects of supersonic shear layer and turbulence. These issues can be addressed through the following: explore new theory and mechanism; conduct advanced experimental technology research; develop efficient numerical simulation methods; emphasize the interaction mechanism between the jet field and the main flow field; systematically understand the effect of the comprehensive coupling of shock wave, expansion wave, shear layer, and boundary layer on the mixed characteristics of jet media and mainstream moving media; and finally grasp shock wave impinging and the relationship between the resulting flow separation and peak heat flow.

(4) Neural network model and fuzzy logic

Fuzzy neural network control is an intelligent control technology that combines fuzzy control and neural network. Fuzzy logic is similar to the thinking mode of humans and is used for systematic qualitative analysis and reasoning with fuzzy rules; this tool requires strong understanding and processing ability of natural language. Fuzzy logic can solve the fuzzy information problem, which is difficult to accurately quantify in a control system. Neural network is similar to the human brain, which is made up of neurons. Neural network, which exhibits self-learning ability, can adjust the weight matrix to complete the nonlinear mapping between input and output. With the rapid development of computer science, neural network and fuzzy logic can be combined while maintaining their respective advantages. However, a mathematical model is difficult to establish when many variables and strong coupling factors exist in a nonlinear system. Compared with traditional control methods, this intelligent control method can effectively improve the intelligence level of a system and improve the quality of control. The rapidly rising deep learning technology has introduced new vitality into the artificial neural network because of the development of hardware technology. Fuzzy neural network has become the frontier and significant research direction for intelligent control technology.

Future research will focus on designing a network structure, fuzzy rules, and optimized learning algorithm on a fuzzy neural network. The intersection of fuzzy theory and neural network enables theoretical and technological breakthroughs for completing each system by combining with other advanced machine learning methods. Hence, fuzzy neutral network technology is further integrated with advanced control and large data analysis methods. This technology will play an increasingly important role in the reform of intelligent manufacturing, smart grids, and other new industrial fields.

(5) Vibration isolation system

The main method for vibration isolation is to install a vibration isolation device or adopt vibration isolation technology between vibration source and transmission path. This kind of device plays a role in vibration isolation and is referred to as a vibration isolation system. A research hotspot and challenge both at home and abroad is to satisfy the strict requirements for the working environment of the processing of ultra-precision instruments and the performance indices of remote sensing equipment and the high-precision optical equipment on the satellite as the high resolution satellites in orbit (especially the strict requirements for micro vibration and ultra-low frequency vibration, ultra-low frequency, and high-performance isolation vibration system). With the traditional linear passive vibration isolation system, research of high-performance vibration isolation system is difficult because of two major contradictions, namely, difficulty in considering the system carrying capacity and the ultra-low isolation frequency and inability to consider the suppression of the peak of resonance frequency domain and the improvement of vibration isolation in the high frequency domain. The nonlinear vibration isolation technology and the active and semi-active vibration isolation technology are the main approaches used to fabricate vibration high-performance isolation systems, such as vibration isolation device with high static and low dynamic rigidity, nonlinear vibration isolation system, and nonlinear magnetic vibration isolator based on damper, and so on. A device with negative stiffness is introduced in linear vibration isolation system to design a low-frequency vibration isolation system with high static and low dynamic stiffness and ensure the bearing capacity of the system while maintaining ultra-low frequency vibration isolation. Nonlinear vibration isolation systems based on non-viscous damper can effectively inhibit vibration amplitude in the resonance frequency domain and the occurrence of jumping. Moreover, this system does not influence the vibration isolation characteristics in the high-frequency domain. A wide spectrum of effective vibration isolation systems can be achieved using intelligent materials and active control technology.

(6) Piezoelectric energy harvesting

In recent years, research on the conversion of vibration energy into electrical energy in the environment has attracted significant attention. When the piezoelectric material deforms under external force, the polarized charge will appear on the surface to form an electric field with high energy density. A device that uses piezoelectric effect to generate energy is called a piezoelectric energy collector; this device is characterized by simple structure, small calorific value, lack of electromagnetic interference, easy miniaturization, low carbon content, and environment friendliness.

Key technologies of piezoelectric energy harvesting mainly include study on high-performance piezoelectric materials and design of intelligent piezoelectric energy harvesting structure with low-power consumption, and simple and efficient energy harvesting circuit. The self-powered device based on piezoelectric energy harvesting has been applied for inspection of traffic infrastructures and wireless medical equipment, monitoring of indoor environment, and detection of tire pressure. Moreover, the conversion of human kinetic energy into electrical energy and the achievement of energy supply of wearable electronic devices have attracted significant attention because of their broad market prospect.

(7) Fluid–solid coupling simulation

Fluid–solid coupling refers to the interaction between solid and liquid media. Fluid–solid coupling simulation mainly investigates the coupling dynamic behavior between the solid and fluid. Fluid–solid coupling simulation is involved in the nonlinear behavior of fluid, the nonlinear constitutive equations of solid materials, and the nonlinearity of the fluid–solid coupling interface. Therefore, simulation of fluid–solid coupling is a frequent nonlinear dynamic problem. The coupling can be analyzed using numerical algorithms and simulation of the force transfer between the fluid and solid sub domains. With the development of fluid–solid coupling (e.g., arterial vascular simulation and parachute aerodynamics simulation), accurately solving large deformation, strong nonlinearity, multi-scale, spatio-temporal coupling, and multi-phase fluid-solid structure coupling is necessary. Highly precise and efficient fluid–solid coupling model and numerical algorithms have become research hotspots at home and abroad. For the fluid–solid coupling problem, uniform and non-uniform mesh generation techniques and space–time simulation techniques have good prospects for development. Fluid–solid coupling method considering time and space has a significant application prospect for improving the accuracy and efficiency of the solution.

(8) Instability and dynamics of a gas turbine combustor

Combustion instability is one of the most important research topics in the field of combustion and is widely investigated in internal combustion engines, aircraft engines, gas turbines, and other combustion phenomena. Instability induces flame discontinuity, local extinction, propagation velocity, and shock of flame surface to show cycle changes, decreased combustion efficiency, deteriorated pollutant emission and mechanical damage, and other hazards. Research on the combustion instability mechanism and its inhibition approaches must be improved to avoid hazards caused by combustion instability, expand the scope of work of advanced combustion mode, improve efficiency, and reduce emissions. Between China and other countries, the main gaps in designing and manufacturing gas turbines and its combustion chamber include the design, processing, and high-temperature resistant composite technology.

(9) Shape memory alloy

Shape memory alloy exhibits shape memory effect and pseudo elasticity (i.e., hyperelasticity) due to its thermoelastic martensitic transformation. Since their discovery in the 1960s, shape memory alloys, such as nickel titanium alloys, have been widely used in aviation, aerospace, biomedical, and other fields. The major unsolved problems in research on shape memory alloys include the following: ① thermomechanical coupling–cyclic deformation characteristics, including temperature dependence in the deformation of shape memory alloys, speed (frequency) dependence in the deformation process of pseudo elastic shape memory alloys, evolution law of thermal mechanical behavior under cyclic loading, and local effects of stress-induced martensitic transformation; ② numerical simulation of the mechanical behavior of shape memory alloys with complex structure and complex load (non-proportional load); and ③ fatigue and fracture characteristics, including crack formation and expansion under cyclic phase transformation, effect of thermal mechanical coupling on fatigue fracture behavior, and stability and macroscopic fatigue criteria under high cycle fatigue loading. In this regard, experimental and theoretical studies on shape memory alloys at micro, meso, and macro scales must be conducted to establish a multi-physical field coupling model, reveal the underlying mechanism, and simulate and predict the mechanical behavior of shape memory alloys.

(10) Nonlinear vibration modes in mechanical engineering

Nonlinear phenomena are ubiquitous in engineering applications and considerably change the dynamic behavior of structures. Research hotspots at home and abroad include dynamics analysis and solving method, experimental test, system nonparametric identification, modal parameter identification, model updating, uncertainty analysis, and other engineering problems on nonlinear mechanical system. Modal theory is the core of linear vibration theory. Nonlinear modal theory is proposed to determine a simple and efficient method for solving multidimensional nonlinear systems (e.g., linear modes). In addition, the concept of modal theory is extended to nonlinear systems. Specifically, nonlinear mode is the extension of linear mode and is the basis for simplifying nonlinear systems. The modes of the linear system are determined, and nonlinear modes may produce bifurcations to increase the number of modes of the nonlinear system beyond the degree of freedom of the system. Scholars have developed direct solutions to nonlinear vibration modes, subspace iteration, and model reduction methods for nonlinear systems. These methods provide an efficient solution for dynamic study on bifurcation, jumping, modal coupling, force relaxation, and flutter. However, quantitative analysis of many influencing factors is difficult due to the complexity of the dynamic characteristics of nonlinear systems. Therefore, uncertainty analysis methods (e.g., Bayesian method) must be combined to address limitations on studying model identification, parameter identification, model updating, model reduction, and skeleton curve stability identification. Thus far, a complete system has not been established yet.

1.2 Understanding of engineering research focus

1.2.1 Large-scale robot tactile sensors and implementations

Large robots possess high stiffness, output power, and output force in their interaction with the environment. Tactile sensors with precise sensing capability are frequently required to achieve accurate operation. Research on one-dimensional force sensors has matured. However, to perceive the interaction between the robot and its environment, robot tactile sensors should detect the vertical pressure on the surface and the shear force in the horizontal direction. For example, when a robot holds an object, the tangential force must be perceived with the positive pressure. When a robot touches an object with irregular surface, the three-dimensional or even multi-dimensional force must be determined. The development of three-dimensional force tactile sensors has become an important research field on intelligent robot technology. To obtain three-dimensional force tactile sensations, scholars have used pressure-sensitive film resistors, platinum/titanium films, anisotropic carbon nanotubes, flexible capacitors, carbon black/silicone rubber, and other base materials for covering the cross structure. The main research work focuses on the optimization of flexible structures and the design of base materials.

(1) 3D shape tactile sensor with high sensitivity

A robot obtains external information through tactile sensors to perceive the external environment. Tactile sensors are categorized into two groups. The first group uses a pressure sensing unit to detect the force and the vector of contact force at a single point and form a multi-dot array (e.g., an array sensor composed of many strain foils). The second group uses an elastomer as the contacting part of the sensor, and deformation occurs when the elastomer is subjected to force. Therefore, the size and distribution of contact force are calculated by detecting the shape and deformation of the elastomer. The generalized tactile is a general term for contact, sliding, pressure perception, and so on. In addition, tactile in the narrow sense refers to the force perception on the contact surface. Three-dimensional tactile shape refers to the tactile sensation that can perceive the shape of the object being touched. Indirect perception is mainly achieved based on changes in the amount of correlated sensing in the contact sliding process. In the current research, changes in light reflection after subjecting the fiber material to stress are used as basis to achieve a 3D tactile shape.

(2) Flexible tactile sensor

Research on flexible tactile sensor has become a hotspot in the field of robot tactile sensor, with emphases on the development and research of multi-dimensional flexible tactile sensors. Multi-dimensional flexible tactile sensors are flexible, similar to the human skin, and can attach to the surface of objects to sense and measure multidimensional information. These flexible sensors can attach to carriers with different surface shapes and roughness to rapidly and accurately sense and obtain outside information. Flexible tactile sensors fabricated with new sensitive materials and manufacturing processes exhibit flexibility and malleability, which will be increasingly similar to those of the human skin. Future research must focus on providing flexible tactile sensors with multidimensional force measurement ability.

(3) Tactile array sensor

A large amount of perceptual information, including spatial pressure and temperature distribution, can be obtained by integrating tactile sensors in large arrays. In practical applications, most tactile array sensors possess flexible structures. For making artificial skin, tactile array sensors should not only be flexible but must also be capable of measuring contact pressure on any surface of a carrier. Accordingly, tactile array sensors must partially or fully cover the surface of an actuator. However, tactile array sensors exhibit certain limitations. First, some sensing elements of tactile sensors are rigid. A rigid sensor is implanted in the flexible material used as medium to transmit tactile information. The tactile sensor itself is inflexible, and the degree of curvature is limited. Thus, obtaining other accurate continuous distribution information is difficult. Second, the sensing element of another kind of tactile array sensor is flexible. However, this sensor can only measure one-dimensional tactile information. As such, scholars aim to research and develop tactile array sensors by using capacitance, PVDF, optical wave guidance, and other technologies. The present study mainly focuses on the flexibility, multidimensional aspects, and large-scale design of array sensors.

(4) Evaluation of grasping quality based on physics

Robust grasp is the most desirable attribute of robots. Stable grasping is the basis of the physical interaction between a robot gripper and the environment and is a foundation to achieve high-order grasping motion. The tactile information in the robot grasping process can be used to evaluate the quality of robot grip and provide regulatory information for real-time grasp of a robot gripper. Abundant tactile information is the basis of the robot gripper to enable grasping and flexible operation. Tactile theory and technology research can provide impetus for eventual reappearance of hand operations and perception through robotic systems. Robot grasping quality is mainly evaluated using closeness, operability, and stability of grasping.

The top three countries or regions with the highest number of core papers in engineering research on "Large-scale robot tactile sensors and implementations" are the USA (17), Germany (11), and Switzerland (6). Countries or regions with top three average citation frequency include Switzerland (48.83), Spain (45.00), and Italy (42.25) (Table 1.2.1). Among the top 10 countries or regions producing core engineering papers, Germany–Spain and England–Italy exhibit high cooperation (Figure 1.2.1). The institutions with top two publication numbers of core engineering papers are Tech Univ Munich (4), Czech Tech Univ (4), Willow Garage Inc (3), RoyalInst Technol (3), and Columbia Univ (3). Moreover, the institutions with top three average citation frequency are ETH (97.50), Univ Zaragoza (65.00), and Univ Genoa (60.00) (Table 1.2.2). Among the top 10 institutions with the highest number of publications, the Italian Inst Technol and Univ Sheffield exhibits high cooperation (Figure 1.2.2). Countries or regions with top three publication number of core papers are Spain (3), the USA (3), and Sweden (2) (Table 1.2.3). The main institutions producing core papers are the Royal Inst Technol (2), Univ Bristol (2), and Carnegie Mellon Univ (1) (Table 1.2.4).

1.2.2 Vibration isolation system

The performance indices of high-resolution satellites, high-precision optical equipment, and so on; and the isolation and elimination of micro vibration are challenging and hot issues that should be addressed to satisfy the strict requirements for the working environment of processing and testing of ultra-precision equipment. Scholars, both at home and abroad, have focused on the previously neglected micro vibration problem of spacecraft caused by moving parts (e.g., reaction wheel, thrustor, solar panels, momentum wheel, refrigerator, antenna drive mecha-

Table 1.2.1 Major producing countries/regions of core papers on the engineering research focus "Large-scale robot tactile sensors and implementations"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	USA	17	34.69%	383	29.28%	22.53	4	0
2	Germany	11	22.45%	340	25.99%	30.91	3	0
3	Switzerland	6	12.24%	293	22.40%	48.83	0	0
4	England	5	10.20%	129	9.86%	25.80	1	0
5	Spain	4	8.16%	180	13.76%	45.00	1	0
6	Italy	4	8.16%	169	12.92%	42.25	3	0
7	Japan	4	8.16%	63	4.82%	15.75	1	0
8	Czech	4	8.16%	53	4.05%	13.25	0	0
9	Sweden	3	6.12%	94	7.19%	31.33	2	0
10	Denmark	2	4.08%	59	4.51%	29.50	1	0

Table 1.2.2 Major producing institutions of core papers on the engineering research focus "Large-scale robot tactile sensors and implementations"

No.	Institution	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	Tech Univ Munich	4	8.16%	211	16.13%	52.75	1	0
2	Czech Tech Univ	4	8.16%	53	4.05%	13.25	0	0
3	Willow Garage Inc	3	6.12%	123	9.40%	41.00	1	0
4	Royal Inst Technol	3	6.12%	94	7.19%	31.33	2	0
5	Columbia Univ	3	6.12%	60	4.59%	20.00	0	0
6	ETH	2	4.08%	195	14.91%	97.50	0	0
7	Univ Zaragoza	2	4.08%	130	9.94%	65.00	0	0
8	Univ Genoa	2	4.08%	120	9.17%	60.00	2	0
9	Italian Inst Technol	2	4.08%	105	8.03%	52.50	1	0
10	Univ Sheffield	2	4.08%	105	8.03%	52.50	1	0

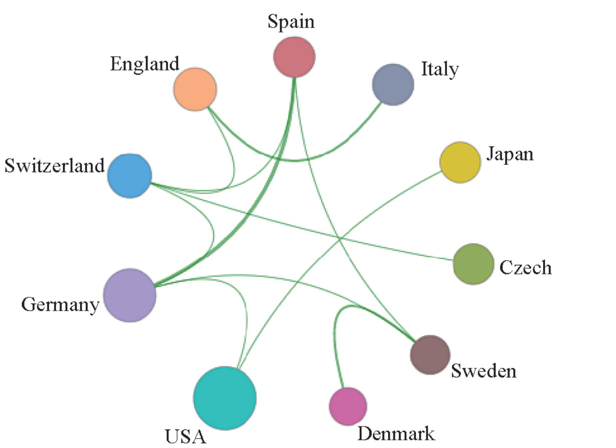

Figure 1.2.1 Collaboration network of the major producing countries or regions of core papers on the engineering research focus "Large-scale robot tactile sensors and implementations"[1]

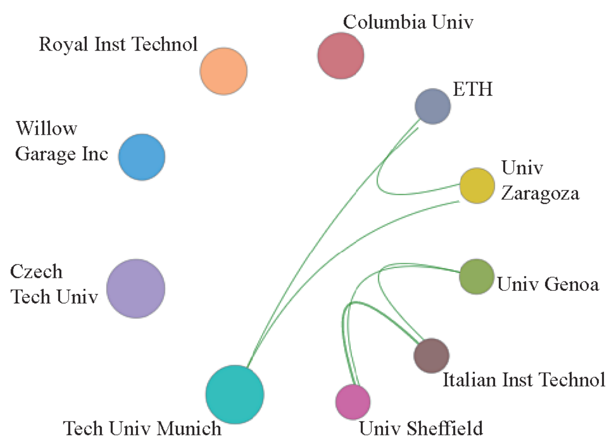

Figure 1.2.2 Collaboration network of the major producing institutions of core papers on the engineering research focus "Large-scale robot tactile sensors and implementations"

[1] In the figure, the nodes refer to the countries or regions, the size of the nodes refers to number of papers, the connecting line between nodes refers to papers published based on research cooperation, and the thickness of the connecting line indicates the number of papers based on research cooperation. These are the same in full text.

Table 1.2.3 Major producing countries or regions of core papers that are cited by core papers on the engineering research focus “Large-scale robot tactile sensors and implementations”

No.	Country/Region	Number of core papers cited by core papers	Proportion	Mean year
1	Spain	3	18.75%	2014.33
2	USA	3	18.75%	2013.00
3	Sweden	2	12.50%	2014.00
4	Germany	2	12.50%	2014.50
5	England	2	12.50%	2015.50
6	Denmark	1	6.25%	2014.00
7	Italy	1	6.25%	2015.00
8	Japan	1	6.25%	2013.00
9	Czech	1	6.25%	2015.00

Tab 1.2.4 Major producing institutions of core papers that are cited by core papers on the engineering research focus “Large-scale robot tactile sensors and implementations”

No.	Institution	Number of core papers cited by core papers	Proportion	Mean year
1	Royal Inst Technol	2	9.52%	2014.00
2	Univ Bristol	2	9.52%	2015.50
3	Carnegie Mellon Univ	1	4.76%	2013.00
4	Columbia Univ	1	4.76%	2014.00
5	German Aerosp Ctr DLR	1	4.76%	2015.00
6	Google Inc	1	4.76%	2013.00
7	Italian Inst Technol	1	4.76%	2015.00
8	Karlsruhe Inst Technol	1	4.76%	2014.00
9	MPI Intelligent Syst	1	4.76%	2014.00
10	Toyota Motor Co Ltd	1	4.76%	2013.00

nism, and other components) to progressively increase the point accuracy and point stability of spacecraft. Normal work will be affected once micro vibration resulting from the moving parts is converted into sensing elements (e.g., MW infrared sensor, laser communication equipment and space telescope, and high-precision equipment). As the core equipment of semiconductor science and technology industry, lithography is a typical representative of ultra-precision equipment. The machining accuracy of this equipment can reach the nanometer level. Micro vibration factors, which can be ignored in traditional processing and testing equipment, will have a fatal effect on the accuracy of lithography. Therefore, the inhibition of micro vibration has become one of the major bottlenecks in the development of high-resolution and high-precision spacecraft and ultra-precision equipment.

Micro vibration is mainly characterized by small amplitude, wide frequency band, and difficult controllability. The frequency of micro vibration ranges from extremely low to thousands of Hertz. Vibration energy ranges from several Hertz to hundreds of Hertz and is difficult to decay. Low-amplitude micro vibration possesses a complex propagation mechanism of mechanical structure and is thus difficult to remove from the vibration source. Nonlinear vibration isolation technology and active and semi-active vibration isolation technology are the main techniques used to suppress micro vibration; these technologies include high-static and low-dynamic stiffness (HSDLS) vibration isolation device, nonlinear vibration isolation system, active/semi-active isolation system, and so on.

(1) High-static and low-dynamic stiffness (HSDLS) vibration isolation device

The HSDLS vibration isolation device has a wide application prospect for solving the limitations of system carrying capacity and ultra-low isolation frequency. Quasi zero stiffness isolator (or the vibration isolation system with high-static and low-dynamic stiffness) formed by the parallel connection of positive and negative stiffness elements has become a hotspot in the field of global engineering. An elastic element with positive stiffness generally refers to vertical spring, and many forms of negative stiffness regulators exist. Quasi zero stiffness isolator is composed of the positive stiffness elastic element and the negative stiffness regulating mechanism in parallel. The positive stiffness elastic element is used to bear the main load. The negative stiffness regulating mechanism is used to counteract the stiffness of the positive stiffness elastic element and increase the likelihood of leading the stiffness of the system at the static equilibrium position to zero. The quasi zero stiffness vibration isolator has high static stiffness and low dynamic stiffness. High static stiffness can improve the bearing capacity of the isolator and reduce static displacement, whereas low dynamic stiffness can reduce the natural frequency of the system and obtain a wider isolation frequency band than the linear isolator.

(2) Nonlinear vibration isolation system

Advanced nonlinear isolation methods based on nonlinear damper and nonlinear stiffness technology have excellent isolation performance and high reliability. For example, vibration isolation, which can be used in low frequency and/or wide frequency ranges, has a significant application potential in the ultra-low frequency vibration isolation field. For designing a traditional linear passive vibration isolation system, a contradiction exists between the damping ratio and the high frequency attenuation capability. This contradiction can be solved through nonlinear damping technology. The design that uses nonlinear damping model to limit the amplification of resonance and improve the attenuation ability of high frequency vibration has become the focus of current research. This nonlinear damping vibration isolation system can provide a large damp in the case of slight amplitude vibration. This system not only can effectively control the resonance amplification factor at the resonance peak but also provide improved vibration isolation effect in the high frequency range. The vibration isolation performance of nonlinear damping is superior to that of linear damping in the wide frequency range. Combining nonlinear stiffness vibration isolation system (e.g., HSDLS vibration isolation system) may play an important role in the design of ultra-low frequency vibration isolator with high performance.

(3) Active/semi-active vibration isolation system

Active/semi-active vibration isolation technology can be used to effectively inhibit the micro vibration of spatial structure and ultra-precision instruments; this technology particularly solves the vibration isolation problem in the low frequency range and is characterized by low energy consumption and cost. In active vibration isolation, actuators and sensors are commonly used to provide control force and feedback signals, respectively. Active feedback of control can be used to regulate the stiffness and damping of the system. This mechanism can isolate vibration in the low frequency domain. Compared with passive vibration isolation systems, active vibration isolation systems are more advantageous in terms of the vibration isolation in the low frequency domain and resonance region and have a wide application prospect in the vibration isolation design of ultra-precision instruments. However, if micro vibration isolation in the low frequency domain is completely achieved using active vibration isolation technology, then the reliability of the system may be reduced. Semi-active vibration isolation technology, which combines the advantages of passive vibration isolation and active control, can demonstrate improved vibration isolation performance than the passive or active vibration isolation system. The technology can be effectively used to isolate the micro vibration of orbital spacecrafts in narrow-band, wide-band, and low frequency range. This technology is an effective method for suppressing micro vibration in space engineering.

Countries or regions with top three publication numbers of core papers in engineering research focusing on “Vibration isolation system” are China (26), England (9), Korea (2), Brazil (2), and the USA (2). Countries or regions with top three average citation frequency are Korea (38.50), Brazil (36.50), and India (33.00) (Table 1.2.5). Among countries/ regions with top three publication number, China and England exhibit high cooperation (Figure 1.2.3). Institutions with top two publication number of core papers are Hong Kong Polytech Univ (6), Univ Southampton (5), Natl Univ Def Technol (5), and Tongji Univ (5). Institutions with top three average citation frequency are Univ Bristol (39.50), Univ Ulsan (38.50), and UNESP Ilha Solteira (36.50) (Table 1.2.6). Among the institutions with top ten publication number, Hong Kong Polytech Univ–Tongji Univ and Beihang Univ–Sci Technol Inertial Lab exhibit high cooperation (Figure 1.2.4). In 2011–2016, 26 core papers are related to engineering research focusing on "Vibration isolation system" published in China. Institutions with many published papers in Mainland China cover the National University of Defense Technology, Tongji University, Shanghai Jiao Tong University, Beijing University of Aeronautics and Astronautics, and so on. Countries or regions with top three publication number of core papers cited by core papers are China (15), England (2), Iran (1), and the USA (1) (Table 1.2.7). The main institutions producing core papers cited by core papers are Tongji Univ (4), Hong Kong Polytech Univ(4), and Beihang Univ (3) (Table 1.2.8).

1.2.3 Supersonic flow and aerodynamics

Supersonic flow plays an important role in the design of supersonic civil and military airplanes and is affected by a number of key technical issues related to supersonic aerodynamics. This paper aims to achieve the following: explore the type of boundary transition and control measures under supersonic flow (mainly the first mode unstable wave and transverse mode wave), determine the effect of shock wave/boundary layer interference on aerodynamic layout design, clarify the perturbation modes of supersonic flow and the evolutionary characteristics of the interaction of shock waves, understand the structural characteristics of coherent vortex in supersonic turbulent boundary layer and the generation and propagation

Table 1.2.5 Main producing countries or regions of core papers on the engineering research focus "Vibration isolation system"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	China	26	74.29%	401	58.88%	15.42	2	0
2	England	9	25.71%	242	35.54%	26.89	1	0
3	Korea	2	5.71%	77	11.31%	38.50	1	0
4	Brazil	2	5.71%	73	10.72%	36.50	0	0
5	USA	2	5.71%	49	7.20%	24.50	0	0
6	India	1	2.86%	33	4.85%	33.00	0	0
7	Iran	1	2.86%	13	1.91%	13.00	0	0

Table 1.2.6 Main producing institutions of core papers on the engineering research focus "Vibration isolation system"

No.	Institution	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	Hong Kong Polytech Univ	6	17.14%	91	13.36%	15.17	1	0
2	Univ Southampton	5	14.29%	149	21.88%	29.80	1	0
3	Natl Univ Def Technol	5	14.29%	89	13.07%	17.80	1	0
4	Tongji Univ	5	14.29%	57	8.37%	11.40	1	0
5	Shanghai Jiao Tong Univ	4	11.43%	84	12.33%	21.00	0	0
6	Beihang Univ	4	11.43%	44	6.46%	11.00	0	0
7	Sci Technol Inertial Lab	3	8.57%	28	4.11%	9.33	0	0
8	Univ Bristol	2	5.71%	79	11.60%	39.50	0	0
9	Univ Ulsan	2	5.71%	77	11.31%	38.50	1	0
10	UNESP Ilha Solteira	2	5.71%	73	10.72%	36.50	0	0

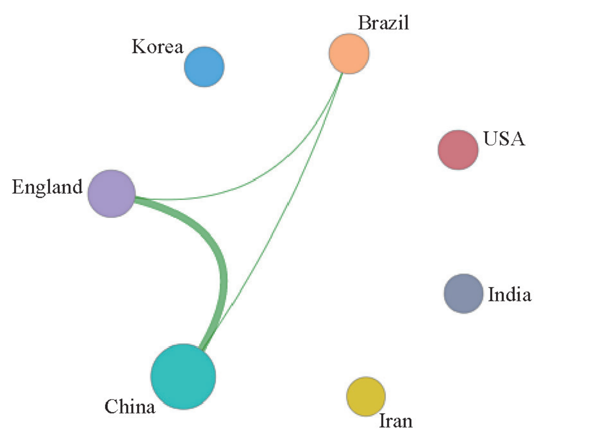

Figure 1.2.3 Collaboration network of the major producing countries or regions of core patents on the engineering development focus “Vibration isolation system”

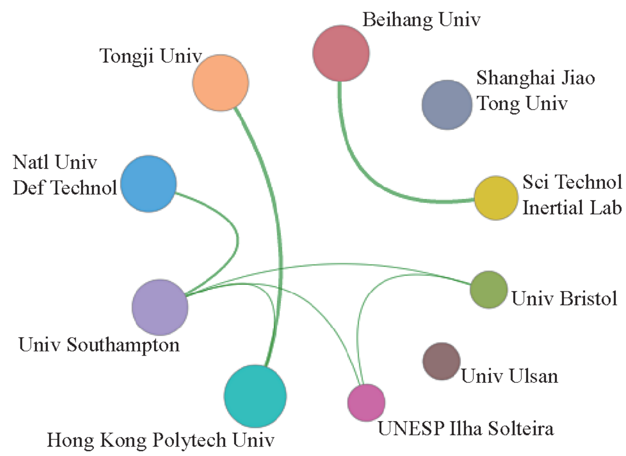

Figure 1.2.4 Collaboration network of the major producing institutions of core patents on the engineering development focus “Vibration isolation system”

Table 1.2.7 Major producing countries or regions of core papers that are cited by core papers on the engineering research focus “Vibration isolation system”

No.	Country/Region	Number of core papers cited by core papers	Proportion	Mean year
1	China	15	78.95%	2014.27
2	England	2	10.53%	2014.00
3	Iran	1	5.26%	2014.00
4	USA	1	5.26%	2014.00

Tab 1.2.8 Main producing institutions of core papers that are cited by core papers on the engineering research focus “Vibration isolation system”

No.	Institution	Number of core papers cited by core papers	Proportion	Mean year
1	Tongji Univ	4	13.79%	2014.75
2	Hong Kong Polytech Univ	4	13.79%	2014.75
3	Beihang Univ	3	10.34%	2015.00
4	Natl Univ Def Technol	3	10.34%	2013.00
5	Sci Technol Inertial Lab	2	6.90%	2015.00
6	Shanghai Jiao Tong Univ	2	6.90%	2013.50
7	Beijing Univ Technol	1	3.45%	2015.00
8	Harbin Inst Technol	1	3.45%	2015.00
9	Harvest Technol	1	3.45%	2014.00
10	HRL Labs	1	3.45%	2014.00

mechanism of aerodynamic noise, investigate the new principle and technology of temperature reduction and noise reduction, and achieve advanced aerodynamic layout design for supersonic jets.

(1) Characteristics of translot jet-flow field

Translot jet flow refers to that the jet-flow direction is parallel to the main direction of movement; a condensing agent is also used in jet flow to reduce the temperature of object surface and change the structure of the flow field.

Translot jet flow plays an important role in the overall thermal protection of aerocraft and internal cooling of detached engines. Unsteady aerodynamic problems (e.g., flow separation and reattachment under supersonic flow) are prone to occur due to the effect of shock wave interference, supersonic shear layer, and turbulence. Moreover, the relative velocity between the jet flow field and the supersonic main flow leads to a complex vortex structure in the shear layer, thereby producing strong acoustic radiation. Hence, scholars must explore new theories and mechanisms, conduct advanced experimental technology research, and develop efficient numerical simulation methods. This paper emphasizes the interaction mechanism between the jet field and the main flow field; systematically understands the effect of the comprehensive coupling of shock wave, expansion wave, shear layer, and boundary layer on the mixing characteristics of jet-flow medium and mainstream moving medium; and determines the relationship between shock wave effect, flow separation, and peak thermal flow.

(2) Characteristics of lateral jet-flow field

If Ma > 3.0, significantly increasing the propulsion thermal efficiency of gas turbine through isobaric combustion and turbofan engine is difficult. Ramjet engine is pressurized by geometry changes to meet the pressure demand in the combustion chamber. The simple structure, light weight, and improved performance of this engine under high flight Mach number have gained increased research attention at home and abroad.

In scramjet engines, the residence time of supersonic flow is extremely short. Achieving a rapid mixture between fuel and air to promote highly efficient and stable combustion in the chamber while minimizing the total pressure loss as much as possible is the most fundamental technical challenge in the design of super-combustion engine. Lateral jet flow is a common fuel injection method that exhibits deep penetration and good mixing efficiency. Study on the characteristics of lateral jet-flow field not only can optimize the mixing process of fuel but also reveal the physical mechanism of combustion stability of scramjet for early application of scramjet technology and engine scramjet in the engineering field.

Countries or regions with top three publication numbers of core papers on the engineering research focus "Supersonic flow and aerodynamics" are China (25), England (8), the USA (5), and Iran (5). Countries or regions with top three average citation frequency are England (21.38), Egypt (19), and Turkey (16) (Table 1.2.9). Among the countries or regions with top 10 publication number, China and England exhibit high cooperation (Figure 1.2.5). Institutions with top three publication number of core papers are Natl Univ Def Technol (21), Univ Leeds (6), and Univ Michigan (5). Institutions with top three average citation frequency are Univ Leeds (22.67), Mil Tech Col (19), and Univ Sheffield (19) (Table 1.2.10). Among top ten institutions, Natl Univ Def Technol and Univ Leeds exhibit high cooperation (Figure 1.2.6). In 2011–2016, 25 core papers related to engineering studies focusing on "Supersonic flow and aerodynamics". The institutions with other publication number are National University of Defense Technology and Harbin Institute of Technology.

Table 1.2.9 Major producing institutions of core papers on the engineering research focus "Supersonic flow and aerodynamics"

No.	Country/Region	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	China	25	60.98%	383	67.43%	15.32	3	0
2	England	8	19.51%	171	30.11%	21.38	1	0
3	USA	5	12.20%	72	12.68%	14.40	1	0
4	Iran	5	12.20%	50	8.80%	10.00	1	0
5	Japan	4	9.76%	50	8.80%	12.50	0	0
6	Scotland	2	4.88%	25	4.40%	12.50	0	0
7	Sweden	2	4.88%	12	2.11%	6.00	0	0
8	Egypt	1	2.44%	19	3.35%	19.00	0	0
9	Turkey	1	2.44%	16	2.82%	16.00	0	0
10	France	1	2.44%	9	1.58%	9.00	0	0

Countries or regions with top three publication number of core papers cited by core papers are China (19), Iran (4), and England(3) (Table 1.2.11). The main institutions producing core papers cited by core papers are Natl Univ Def Technol (18), Babol Univ Technol (3), and Univ Leeds (3) (Table 1.2.12).

2 Engineering development hotspots and engineering development focus

2.1 Development trends of engineering development hotspots

The top 8 engineering development hotspots in the field of mechanical and vehicle engineering include mechanical engineering, naval architecture and ocean engineering, aerospace science and technology, armament science and technology, power and electrical equipment engineering and technology, transportation engineering, and other subjects (Table 2.1.1). Among which, "Sensor technology," "Advanced semiconductor technology and equipment," "Power system of electric vehicles," "New propulsion systems," "Imaging technology," "Design and manufacturing of high-efficiency, and low-emission engines" are further development of traditional research; "Surgical robot and key functional components," and "Unmanned vehicles" are emerging hotspots. All core patents involved in these hotspots in 2011–2016 are disclosed in Table 2.1.2.

Table 1.2.10 Major producing institutions of core papers on the engineering research focus "Supersonic flow and aerodynamics"

No.	Institution	Core papers	Proportion of core papers	Citation frequency	Proportion of citation frequency	Average citation frequency	Consistently cited papers	Patent-cited publications
1	Natl Univ Def Technol	21	51.22%	333	58.63%	15.86	3	0
2	Univ Leeds	6	14.63%	136	23.94%	22.67	1	0
3	Univ Michigan	5	12.20%	72	12.68%	14.40	1	0
4	Babol Univ Technol	4	9.76%	39	6.87%	9.75	1	0
5	Tohoku Univ	3	7.32%	35	6.16%	11.67	0	0
6	Harbin Inst Technol	2	4.88%	31	5.46%	15.50	0	0
7	Univ Glasgow	2	4.88%	25	4.40%	12.50	0	0
8	Islamic Azad Univ	2	4.88%	17	2.99%	8.50	1	0
9	Mil Tech Coll	1	2.44%	19	3.35%	19.00	0	0
10	Univ Sheffield	1	2.44%	19	3.35%	19.00	0	0

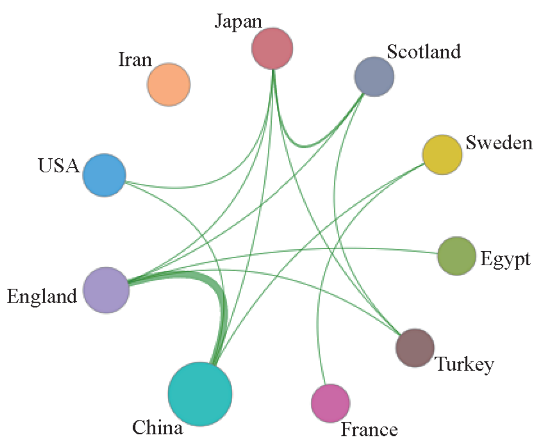

Figure 1.2.5 Collaboration network of the major producing countries or regions of core papers on the engineering development focus "Supersonic flow and aerodynamics"

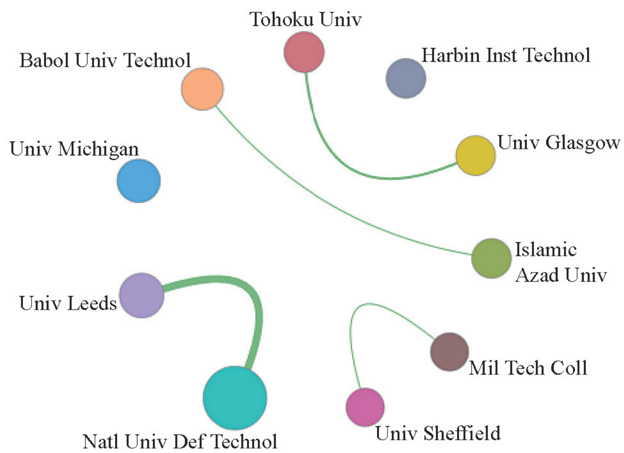

Figure 1.2.6 Collaboration network of the major producing institutions of core papers on the engineering development focus "Supersonic flow and aerodynamics"

Table 1.2.11 Major producing countries or regions of core papers that are cited by core papers on the engineering research focus "Supersonic flow and aerodynamics"

No.	Country/Region	Number of core papers cited by core papers	Proportion	Mean year
1	China	19	63.33%	2014.05
2	Iran	4	13.33%	2014.50
3	England	3	10.00%	2013.00
4	USA	2	6.67%	2013.00
5	Malaysia	1	3.33%	2016.00
6	Sweden	1	3.33%	2016.00

Table 1.2.12 Major producing institutions of core papers that are cited by core papers on the engineering research focus "Supersonic flow and aerodynamics"

No.	Institution	Number of core papers cited by core papers	Proportion	Mean year
1	Natl Univ Def Technol	18	52.94%	2014.00
2	Babol Univ Technol	3	8.82%	2014.67
3	Univ Leeds	3	8.82%	2013.00
4	Islamic Azad Univ	2	5.88%	2014.50
5	Univ Michigan	2	5.88%	2013.00
6	Amirkabir Univ Technol	1	2.94%	2014.00
7	China Aerodynam R&D Ctr	1	2.94%	2015.00
8	Harbin Inst Univ	1	2.94%	2016.00
9	Isfahan Univ Technol	1	2.94%	2015.00
10	Lund Univ	1	2.94%	2016.00

Tab 2.1.1 Top 8 engineering development hotspots in mechanical and vehicle engineering

No.	Engineering research hotspots	Published patents	Citation frequency	Average citation frequency	Mean year
1	Sensor technology	259	3 122	12.05	2012.10
2	Advanced semiconductor technology and equipment	750	32 405	43.21	2012.30
3	Unmanned vehicles	88	3 070	34.89	2013.20
4	Surgical robot and key functional components	118	4 877	41.33	2012.86
5	The power system of electric vehicle	695	13 000	18.71	2011.80
6	New propulsion system	507	2 048	4.04	2012.79
7	Imaging technology	214	7 409	34.62	2012.07
8	Design and manufacture of high efficiency, and low-emission engines	440	2137	4.86	2012.88

(1) Sensor technology

A sensor is a device that converts acquired information into another form in accordance with certain laws of specific phenomenon in physics, chemistry, or biology. Sensor technology has been increasingly used in aerospace, transportation, machinery manufacturing, petrochemical, technical supervision and testing, and other technical fields. The focuses of sensor technology development include the

Table 2.1.2 Annual number of core patents belonging to each of the Top 8 engineering development hotspots in mechanical and vehicle engineering

No.	Engineering research hotspots	2011	2012	2013	2014	2015	2016
1	Sensor technology	103	68	59	22	3	4
2	Advanced semiconductor technology and equipment	289	185	124	79	58	15
3	Unmanned vehicles	103	145	155	127	88	37
4	Surgical robot and key functional components	29	23	21	28	15	2
5	The power system of electric vehicle	330	220	114	22	6	3
6	New propulsion system	87	158	123	65	61	13
7	Imaging technology	91	61	31	22	6	3
8	Design and manufacture of high efficiency, and low emission engines	97	90	93	105	37	18

development of general technology for sensors and special technology in the industrial field. The innovative applications of sensors in the medical treatment, environmental monitoring, large-scale infrastructure, intelligent manufacturing, smart grid, wearable devices, and other fields will become new research hotspots. Sensors should be miniaturized, possess integrated and modular structures, and exhibit wide range, high-precision and high-reliability detection performance, strong anti-interference ability, and long service life to satisfy engineering requirements for development of sensor technology. Moreover, to meet the needs of long-term monitoring, achieving energy self-sufficiency of sensors is also the future trend of sensor technology.

(2) Advanced semiconductor technology and equipment

Semiconductor processing technology faces numerous technological change points, such as reduction in feature size and introduction of new materials and structures. New requirements and challenges have been proposed for semiconductor manufacturing technology. The feature size reduction in integrated circuits requires the implementation of ultrafine graphics processing, precise control of graph shape, and control of the shape, surface, energy, status, and multiple other factors. Ultrafine shape processing requires extreme ultraviolet lithography equipment with shorter wavelength. Moreover, other technical equipment should be used in combination for shape, surface roughness, energy, status, and others. With the improvement of the integration of large-scale circuits, new requirements for packaging technology have been proposed. 3D encapsulation technology based on through-silicon via has attracted considerable attention. With the introduction of a new structure, unnecessary shape damage should be avoided while the 3D high aspect ratio structure is precisely controlled; with the introduction of new materials, performance should be improved while the impact on process integration is avoided. In recent years, the rapid increase mobile consumer electronics on the internet has markedly promoted the growth of the semiconductor market.

(3) Unmanned vehicles

An unmanned vehicle is a mobile platform that does not require a person to drive within the vehicle. At present, unmanned vehicles have covered land, air, and water. Land unmanned vehicles, including wheeled and crawler types, are used in the field of explosive removal, reconnaissance, and others. Unmanned aerial vehicles include fixed-wing, rotor-wing, and flapping-wing unmanned aerial vehicle and others, which have been applied in disaster rescue and observation. Unmanned underwater vehicles include unmanned surface vehicles, unmanned underwater vehicles, and others, which have been preliminarily used in underwater rescue and detection. Unmanned vehicles are developing from teleoperation to autonomous control. Autonomous control of unmanned vehicles involves the design of unmanned vehicles, environmental perception, mapping, positioning, navigation, obstacle avoidance, and numerous techniques. For technical security and reliability, autonomous control should also cover condition monitoring, fault diagnosis, and maintenance. With the large-scale applications of unmanned vehicles in the future, autonomous control of unmanned vehicles will be developed from personal intelligence to swarm intelligence.

(4) Surgical robot and key functional components

A surgical robot refers to a special robot that replaces or assists doctors in performing surgical procedures. Its key functional components refer to the precise mechanism, hardware, and software needed for the completion of the whole operation process. Based on the degree of opening of the surgical space, the two categories of robotic surgery are open and closed. The former includes orthopedic surgery, and the latter category includes various endoscopic surgeries. The development hotspots for orthopedic surgery include computer-aided design and the manufacture of preoperative artificial prosthesis, intraoperative pose detection, 3D navigation, instrument support and guidance, visual observation, and others. Personalized prosthesis design, accurate implant placement, and the integration of surgical procedures are important trends in the development of orthopedic surgical robots. For endoscopic surgeries, the development hotspots include tissue anastomat, endoscopic instrument controller, multifunctional scalpel, stereoscopic vision, haptic feedback, wireless monitoring of tissue and instrument status, and others. Minimally invasive, multi-functional integration is an important trend in the development of endoscopic surgical robots and endoscopic surgical instruments.

(5) Power system of electric vehicle

Electric vehicles refer to vehicles that are propelled by an electric motor or traction motor; these vehicles include road and rail vehicles, surface or underwater ships, airplanes, space vehicles, and others. Batteries are a core technical difficulty of electric vehicles. Lithium batteries will dominate the power battery market in the short term. Fuel cells, metal–air batteries, solid-state cell, ultra-capacitor battery composite power supplies, and several new systems and technologies will be the focus of competition for major manufacturers in the future. The application of motor and electronic control technology in electric vehicles has been approved, but the technical maturity is far from meeting the requirement. In the future, the core technology of drive motors and the chain of industry system will be integrated, and high-performance, high-efficiency, and lightweight motor system and electric drive components will be developed with the help of the third-generation large energy gap power semiconductors. The charging infrastructure system is an important obstacle to the popularity of electric vehicles. Moreover, high-efficiency, intelligent energy management technology and advanced vehicle control technology directly determine the performance indicators of electric vehicles. The electric vehicle will be an electric industrial model that is integrated with the new industry, new energy, and new information.

(6) New propulsion system

Electric propulsion refers to a propulsion method in which the electric energy is produced by the prime motor unit first; then, the motor drives the propeller, jet propulsion, and other propulsion systems. At present, the development trend of marine electric propulsion equipment is using an alternating current electric propulsion device to replace the direct current electric propulsion device, as well as the AC and DC electric propulsion device, developing superconducting electric propulsion, developing submarine fuel cell propulsion system instead of lead acid battery, and developing integrated full electric propulsion system. The pump-jet propulsor, a rotary combined type hydrodynamic propeller, consists of an axisymmetric annular duct, as well as rotating and stationary cascades within the duct, with good cavitation resistance. The propeller is widely used in ships and is an important component in determining ship performance. High efficiency, good energy saving, strong cavitation resistance, low vibration and noise, simple structure, and strong reliability are the important directions of propeller development.

(7) Imaging technology

Eighty percent of the information is acquired by humans through vision. Imaging and image processing technologies, which are widely used in the industry, agriculture, medical treatment, aeronautics and astronautics, military affairs, and other important fields, have always been research hotspots and present an important foundation of the information age. The current hotspots of the imaging technology include high-resolution imaging technology in a complex service environment, high resolution remote sensing imaging, and seabed imaging. Among these technologies, sonar technology based on multibeam seabed imaging is an important development direction in the future. The current hotspots in image processing include contour detection, image segmentation and bottom information extraction, and others. Meanwhile, with the development, deep learning has markedly improved the results of traditional methods. In recent years, this approach has gained considerable success in the recognition, understanding, and target detection of various types of images.

(8) Design and manufacture of high-efficiency, and low-emission engines

This section mainly focuses on micro-turbine engines with the power of less than several hundred kilowatts. Being characterized by small size, light weight, high horsepower, high supercharging ratio, simple structure, micro-turbine engines are mainly used in distributed power supply, standby power supply, micro turbine-fuel cell combined power generation, alternative power for traditional piston type diesel engine, and others. Moreover, certain micro-turbine engines are used for aviation. At present, micro-turbine electric generator is a hotspot. Domestic light micro-turbine is still in its infancy in design technology and market development. The key technical problems cover structural design of turbine blades, manufacturing technology of blades and impellers, and blade materials. The outlet temperature of small and micro-turbine engine exceeds 1800 K. The turbine still does not cool. Therefore, only composite ceramic-based material can be used. Nanocoating technology is also a current technical hotspot. It should be also a thermal barrier coating, with high temperature resistance and low heat dissipation. And, it can improve the thermal efficiency of the whole machine. Another function of nanocoating is wear resistant, satisfying the rotation speed of the working axle of the turbine engine up to 10 000 turns.

2.2 Understanding of engineering development focus

2.2.1 Sensor technology

With the rapid development of science and technology, sensor technology is being widely used in aerospace, transportation, machinery manufacturing, petrochemical, technical supervision and testing, and other technical fields. At present, the focuses of sensor technology development include the development of general technology for sensor itself and that of special technology in the industrial field. The former includes sensor materials and manufacturing technique, sensor detection principle, and so on, whereas the latter mainly includes the development of composite perception sensor in the medical and health field and sensors for extreme conditions in the automotive and energy fields.

(1) Sensor materials and manufacturing technique

The performance of sensing and conversion element in sensor determines the performance of the sensor to a considerable extent. The refinement of processing technique is becoming more important in sensor fabrication. Numerous new sensors can be fabricated through micro-electro mechanical systems (MEMS). The substrate, the sensing element, and the auxiliary material can be packaged into various standard semiconductor packages by means of MEMS technology. The sensing element, processing circuit, amplifier circuit, and communication circuit are all arranged on the common substrate; thus, the power dissipation of the MEMS sensor is reduced with miniaturized structure. With a folding beam structure, the sensor can increase shear strength and effectively reduce encapsulation stress.

(2) The principle of sensor detection

Most sensors use some special properties of certain materials to obtain information. Among them, the mechanical and magnetic properties of materials are research hotspots for new sensors. Development directions of force sensor include high sensitivity, working in a harsh environment, wider dynamic range, and shorter response time. The development directions of magnetic sensors include high sensitivity, temperature stability, anti-interference, integration, and low power consumption. On the basis of signal detection, the micro-mechanical pressure sensor is divided into two types, namely, piezo-resistive and capacitive. High-precision measurement can be achieved in an environment with temperature fluctuation through forming a bridge circuit consisting of numerous sensing elements.

(3) Development of composite perception sensor in medical and health field

Medical sensors and wearable devices perform an increasingly important role in improving the quality of life, as well as improving the comfort and convenience of people. Sensors in these fields are developing rapidly, and various types of sensors are emerging. The position monitoring and energy supply of medical sensors is an important research direction, and driving force control for medical devices is a development focus. Wearable devices generally contain multiple types of sensors for measuring heart rate, temperature, sleep, blood pressure, and so on. Pressure sensors are applied in electronic skin and instrument prostheses. With the development of sensor manufacturing technologies, wearable sensors are becoming smaller and more easily fit together with skin or human tissue, and can more sensitively acquire changes in the monitoring indices.

(4) Development of sensors in the field of vehicles, energy, and operation in harsh working environments

Safety and energy conservation are difficult problems in the fields of automobile and energy. Charging control for electric vehicles, monitoring of battery life cycle, and monitoring in power transmission depend on the important role of the sensor. Multidimensional sensing technology can effectively prevent and reduce accidents in the automotive and energy fields. The use of a new type of sensor ensures high-accuracy measurement results. Moreover, reduction of error and fault of sensors is crucial in the field of automobile safety. In charging automobiles, the application of sensors needs to be combined with charging control methods to achieve energy saving.

(5) Current situation and future development trend

Sensors have been widely used in automobiles, industrial automation, aerospace technology, military engineering, environmental detection and other fields. A variety of new sensors are emerging, and innovations and applications in medical treatment, environmental monitoring, large-scale infrastructure, health monitoring, intelligent manufacturing, smart grid, wearable devices, and other fields will become future hotspots. With miniaturization, integration and modularization structure, wide range, high precision and reliability, strong anti-interference, and long life, new engineering requirements are proposed for the development of sensor technology. The future developmental trend in sensor technology also includes meeting the requirements of long-term monitoring and achieving energy self-sufficiency of sensors.

In development focuses of “Sensor technology,” the three countries or regions with the highest numbers of core patent disclosure are the USA (87), Japan (60), and China (41). The three countries or regions with the top average citation frequency are the USA (14.61), China (13.02), and the Netherlands (11.83), as shown in Table 2.2.1. Among the top 10 countries or regions in terms of patent disclosure numbers, the USA has cooperated with China, Germany, France, and the Netherlands (Figure 2.2.1). The top three institutions in terms of amounts of core patent disclosure are BOSC (13), FRSE (7), and SHIH (7) respectively. The top three institutions in average citation frequency are BERT (19.33), FRSE (16.29), and TOKE (14.5) (Table 2.2.2). Among the top 10 institutions, NXPS cooperated with AMSI more frequently (Figure 2.2.2). In 2011–2016, a total of 41 core patents related to the development focus of “Sensor technology” were disclosed in China, and the institution frequently disclosed patents in China mainland is Zhejiang University.

Table 2.2.1 Major producing countries or regions of core patents on the engineering development focus “Sensor technology”

No.	Country/Region	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	USA	87	33.59%	1271	40.71%	14.61
2	Japan	60	23.17%	648	20.76%	10.80
3	China	41	15.83%	534	17.10%	13.02
4	Germany	35	13.51%	314	10.06%	8.97
5	France	8	3.09%	50	1.60%	6.25
6	Switzerland	6	2.32%	44	1.41%	7.33
7	Korea	6	2.32%	52	1.67%	8.67
8	The Netherlands	6	2.32%	71	2.27%	11.83
9	Canada	4	1.54%	41	1.31%	10.25
10	UK	4	1.54%	8	0.26%	2.00

Tab 2.2.2 Major producing institutions of core patents on the engineering development focus “Sensor technology”

No.	Institution	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	BOSC	13	5.02%	97	3.11%	7.46
2	FRSE	7	2.70%	114	3.65%	16.29
3	SHIH	7	2.70%	81	2.59%	11.57
4	TOKE	6	2.32%	87	2.79%	14.50
5	INFN	5	1.93%	44	1.41%	8.80
6	NXPS	5	1.93%	45	1.44%	9.00
7	HONE	4	1.54%	45	1.44%	11.25
8	UYZH	4	1.54%	46	1.47%	11.50
9	AMSI	3	1.16%	31	0.99%	10.33
10	BERT	3	1.16%	58	1.86%	19.33

Note: BOSC stands for Bosch Group); FRSE stands for Freescale Semiconductor Inc; SHIH stands for Seiko Epson Corp; TOKE stands for Toshiba KK; INFN stands for Infineon Technologies AG; NXPS stands for NXP Semiconductors BV; HONE stands for Honeywell International Inc; UYZH stands for Zhejiang University; AMSI stands for Ams AG; BERT stands for Bertec Corporation.

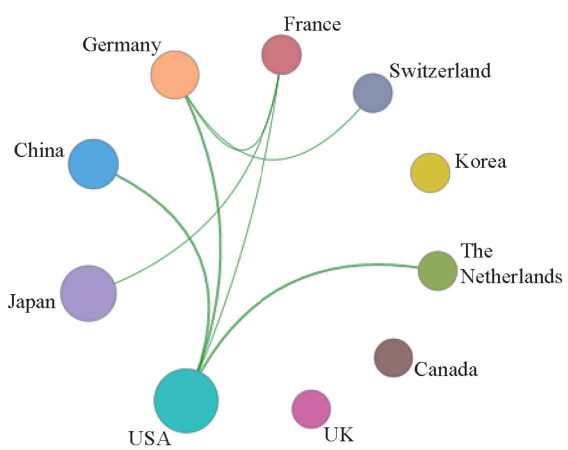

Figure 2.2.1 Collaboration network of the major producing countries or regions of core patents on the engineering development focus “Sensor technology”

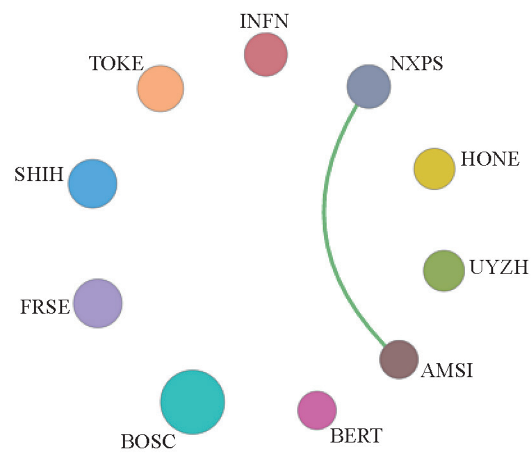

Figure 2.2.2 Collaboration network of the major producing institutions of core patents on the engineering development focus “Sensor technology”

2.2.2 Design and manufacture of high-efficiency, and low-emission engines

The design and manufacturing technologies for high-efficiency, low-emission engines are mainly directed against large-scale gas turbine engine and mini turbine engine. Mini-turbine engines are characterized by small size, light weight, huge power, high supercharging ratio, and simple structure. At present, the perspective on ground gas turbine technology is mainly based on several ongoing or unfinished projects with outstanding value, as verified by long-term air and ground fuel and relevant discipline development planning in western countries. The selection of these projects is still based on high efficiency, energy saving, low pollution, low cost, high reliability, and so on. A brief description is as follows.

(1) High parameter, high performance

Fourth- and fifth-generation aero gas turbines, T_4 = 1800–2000 K, $\pi_c \geq 30$, will be used as a prototype engine. The outlet temperature of the ground gas turbine can reach 1527 °C to 1727 °C, $\pi_c \geq 30$, and the corresponding performance will be improved.

(2) Development of heat-resisting materials

Existing super alloys are no longer applicable to meet the requirements of high operating temperature of turbine. Therefore, non-metallic super high-temperature materials, including ceramics and their composites reinforced with carbon, as well as carbon composites, will be adopted as hot end-components.

(3) Design of highly active cooling method

Combined cooling with gas film, convection current, and impact, which is currently employed by turbine blades and combustion chambers, remains applicable. As a next-generation coolant, steam has been tested on individual gas turbines. Steam cooling saves 10%–20% cooling air and improves thermal efficiency and power. However, it is only applicable to the ground combined cycle gas turbine. Ground sealing technology is the key to prevent steam leakage.

(4) Advanced design and manufacturing technology for the turbine

The aims of the aero-turbine compressor is to improve the blade design method and increase the supercharging rate, whereas those of the turbine are high efficiency, large enthalpy drop, and high temperature resistance. The results will continue to be absorbed and adopted by ground gas turbines and inject new vitality into ground gas turbines.

(5) Low pollution combustion technology

At present, most aviation and ground gas turbines adopt dry low NO_x combustion chambers, including radial and axial staged combustion chambers, sequential reheat combustion chambers, and oil–poor premixed pre-evaporation combustion chambers, which may be continuously promoted in the future. Moreover, the catalytic combustion chamber and the long-researched oil-rich combustion-quench–oil-poor combustion chamber may be adopted in the future to achieve ultra-low NO_x combustion. A currently adopted, effective desulfurization technology in integrated gasification combined cycle and the coal-fired PFBC gas turbine–steam turbine combined cycles can be adopted in the future to reduce SO_2 emission.

(6) New thermodynamic cycle and total energy system

At present, separate complex cycles or complex cycles involved in combined cycles have been adopted. Moreover, new combined cycles, such as steam (water) injection combined cycle, integrated gasification combined cycle in the coal-fired combined cycle, the coal-fired–fluidized bed combined cycle under constant and high pressure, have been employed. In the future, the IGCC and pressurized fluidized bed combined cycle will be ideal and extensively used. Other cycles will be adopted with their technical maturation.

(7) Design and manufacturing technology of micro and ultra-micro gas turbine

Centralized high power gas turbine generation and distributed micro-turbine power supply have become the two harnesses for the future power supply of vehicles. At present, the main technical keys are innovations of air-cooled bearing, high-speed micro motor, fluid viscosity, heat transfer, and combustion mechanism in small size. In the future, more attention will be focused on the development and application of this technology.

The top three countries or regions in terms of the number of core patent publications on "Design and manufacture of high-efficiency, and low-emission engines" are the USA (231), France (75), and the United Kingdom (58); the

Tab 2.2.3 Major producing countries or regions of core patents on the engineering development focus "Design and manufacture of high-efficiency, and low-emission engines"

No.	Country/Region	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	USA	231	52.50%	1230	57.56%	5.32
2	France	75	17.05%	336	15.72%	4.48
3	UK	58	13.18%	176	8.24%	3.03
4	China	23	5.23%	107	5.01%	4.65
5	Germany	18	4.09%	77	3.60%	4.28
6	Japan	12	2.73%	69	3.23%	5.75
7	Canada	11	2.50%	80	3.74%	7.27
8	The Netherlands	7	1.59%	21	0.98%	3.00
9	Austria	2	0.45%	10	0.47%	5.00
10	Belgium	2	0.45%	10	0.47%	5.00

Tab 2.2.4 Major producing institutions of core patents on the engineering development focus “Design and manufacture of high-efficiency, and low-emission engines”

No.	Institution	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	RORO	63	14.32%	201	9.41%	3.19
2	UNAC	58	13.18%	219	10.25%	3.78
3	GENE	43	9.77%	156	7.30%	3.63
4	SNEA	40	9.09%	196	9.17%	4.90
5	SUNH	31	7.05%	132	6.18%	4.26
6	EADS	22	5.00%	79	3.70%	3.59
7	HONE	17	3.86%	113	5.29%	6.65
8	SFRA	10	2.27%	60	2.81%	6.00
9	BOEI	9	2.05%	75	3.51%	8.33
10	MOTU	9	2.05%	34	1.59%	3.78

Note: RORO stands for Rolls-Royce Limited; UNAC stands for United Technologies Corp; GENE stands for General Electric Company; SNEA stands for Snecma; SUNH stands for Hamilton Sundstrand Corp; EADS stands for Airbus Helicopters; HONE stands for Honeywell International Inc; SFRA stands for Turbomeca; BOEI stands for Boeing Company; MOTU stands for MTU Aero Engines AG.

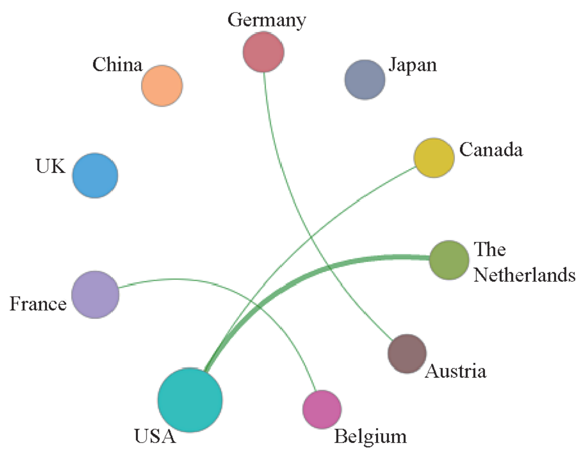

Figure 2.2.3 Collaboration network of the major producing countries or regions of core patents on the engineering development focus “Design and manufacture of high-efficiency, and low-emission engines”

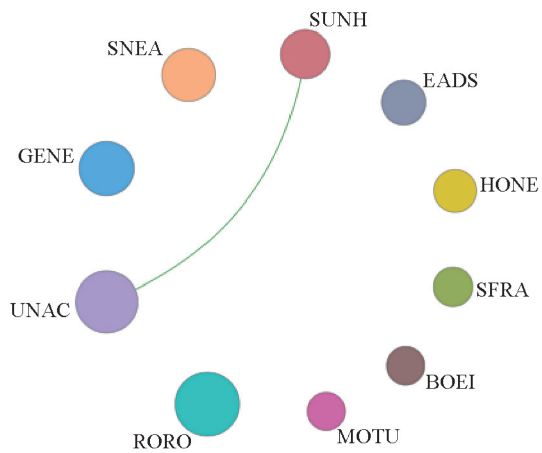

Figure 2.2.4 Collaboration network of the major producing institutions of core patents on the engineering development focus “Design and manufacture of high-efficiency, and low-emission engines”

top three countries or regions for the average citation frequency are Canada (7.27), Japan (5.75), and the USA (5.32) (Table 2.2.3). Among the top 10 countries or regions for publication amount, the USA closely cooperated with the Netherlands (Figure 2.2.3). The three institutions with the highest number of core patent publications are RORO (63), UNAC (58), and GENE (43). The top three institutions in average citation frequency are BOEI (8.33), HONE (6.65), and SFRA (6) (Table 2.2.4). Among the top 10 institutions in publication amount, UNAC cooperated with SUNH more frequently (Figure 2.2.4). From 2011–2016, 23 core patents related to the development focus of “Design and manufacture of high-efficiency, and low-emission engine” are disclosed in China, and no institution is listed in the Top 10.

2.2.3 Unmanned vehicles

An unmanned vehicle is a mobile platform that does not require a person to drive within a vehicle. Land unmanned vehicles includes wheeled and crawler-type vehicles. Unmanned aerial vehicles include fixed-wing unmanned aerial vehicles, rotor-wing unmanned aerial vehicles, flapping-wing unmanned aerial vehicles, and others. Finally, unmanned underwater vehicles include unmanned surface vehicles, unmanned underwater vehicles, and others. Autonomous control of unmanned vehicles involves the design of unmanned vehicles, environmental perception, mapping, positioning, navigation and obstacle avoidance, status monitoring, fault diagnosis and maintenance, and numerous techniques.

(1) Bionic design of basic machine

At present, several problems in unmanned vehicles include low ratio of load weight to self-weight and low energy efficiency, among others. The basic approach to solving these problems is through learning from nature, that is, by analyzing the movement mechanism, force mechanism, and energy adjustment mechanism of animals adapting to the nature. The construction of a driver with high energy density, high dynamic response, high strength, and high energy structure, and the establishment of a multi-objective, multi-level, and multi variable design method based on motion-force-energy cooperation are the focuses of future research.

(2) Intelligent system for unmanned vehicles

Analysis of biological control behavior from the perspective of bionics, the establishment of the overall structure of information processing, logic analysis, decision selection, and system control have gradually become the research focuses in intelligent systems for unmanned vehicles. On the basis of animal behavior and movement characteristics, researchers have developed and designed reactive intelligence, deliberative intelligence, deliberative/reactive complex intelligence, and other autonomous intelligent control systems for unmanned vehicles. With the development of artificial intelligence technology, intelligent systems based on symbolic classification, intelligent systems based on depth learning and open distributed intelligent systems have attracted increasing attention.

(3) Control method for unmanned vehicles

The problem of autonomous control for unmanned vehicles is a high-dimensional hybrid system control problem. Owing to the complexity of the running environment and the diversity of the moving mode, the autonomous control system for unmanned vehicles must be polymorphic and complex, and different states should be able to be switched smoothly. Traditional kinematics-based planning and control evolved to motion-dynamic planning and control; therefore, analysis of force–position–posture cooperation planning and control will be the basic technical approach to design the autonomous control system for unmanned vehicles.

(4) Positioning and navigation

Positioning and navigation are the bases of the autonomous motion of unmanned vehicles. The positioning and navigation procedure for unmanned vehicles can be divided into three links, namely environmental modeling, positioning, and path planning, and the technical key is environmental modeling. Accurate positioning and navigation technology is based on satellite positioning and navigation information to realize multi-sensor information fusion, as well as local global seamless positioning navigation by forming a local environment map by combining inertial, visual, lidar, and other sensing information. For meeting the practical needs of unmanned vehicles, the positioning navigation technology should be developed from the structured environment space to the outdoor free environment. Therefore, the development of an all-weather high-precision sensor for environmental identification modeling is a development hotspot.

(5) Active obstacle avoidance

Active obstacle avoidance is an important problem in autonomous movement of unmanned vehicles. With the development of unmanned vehicles for practical use, unmanned vehicles need to cope with dynamic obstacles and highlight obstacles during high-speed moving in complex environments. Therefore, the development of obstacle avoidance technology focuses on improving dynamic obstacle recognition ability and dynamic decision-making ability. Recognition of dynamic obstacles, motion intentions, and motor parameters should be added on the basis of traditional geometric recognition to improve the accuracy and credibility of obstacle identification. Then, smooth path replanning is carried out in real time.

(6) Automatic parking

Automatic parking is achieved through two approaches: one is by increasing the automatic parking function in the vehicle itself, and another is by adding infrastructure in the parking lot and using autonomous parking chassis to move and park the vehicle. For the automatic parking technology against autonomous parking chassis, the emphasis of its application development is on the omnidirectional, rapid movement of large-inertia objects, automatic parking efficiency, and multi-machine cooperative scheduling. Aiming at automatic parking technology of the vehicle itself, the emphasis of its development lies in adaptability to parking spaces, reliability, and high parking efficiency because of the variety of parking spaces in urban traffic.

(7) Autonomous driving

Autonomous driving refers to the application of computer control instead of a person to accomplish the vehicle motion control task. At present, autonomous driving technology exhibits a breakthrough, but its security and reliability still hardly meet actual application requirements. Autonomous driving for unmanned vehicles includes environmental perception and pathway planning. In the future, autonomous driving needs to adapt an environmental perception mode of multi-sensor information fusion for a real-time analysis and integration of redundant information so as to ensure the safe driving of unmanned vehicles with richer environmental information. The types and amounts of vehicles will markedly increase in the future. Autonomous driving systems should offer multi-machine coordination and self-optimization to construct the intelligent traffic network through establishing a multi vehicle communication mechanism.

(8) Condition monitoring and fault diagnosis

Autonomous control for unmanned vehicles can perform condition monitoring, fault diagnosis, performance reduction, and health prediction when a failure occurs. Condition monitoring includes two parts, namely, monitoring of surrounding environment condition and monitoring of the running condition. Among these functions, recognition and extraction of environmental information and time-varying complex environment are the research focus. The main challenges in monitoring the running state of the vehicle are multi-sensor information fusion, quantization of the vehicle's running state, failure/fault criteria, and accurate fault location. Future research and development will focus on multi-fault intelligent diagnosis and preventive maintenance technology. With the development of artificial intelligence technology, intelligent condition monitoring and fault diagnosis technology based on learning will be a future development direction.

(9) Swarm intelligence

Multi-platform/multi sensor information fusion, design of efficient universal communication interface, and open control architecture are focuses of cluster intelligent technology research. With the development of bionic research, the self-organization mechanism, which draws lessons from nature, provides new ideas for the research on swarm intelligence technology. Based on the study of bionics and swarm intelligence algorithm, the swarm intelligence technology for unmanned vehicles will further achieve large scale and autonomy. Moreover, swarm intelligence technology is developed from conspecific unmanned vehicles to a variety of different unmanned vehicles to assist in accomplishing complex tasks. Thus, the technology has attracted research attention.

Table 2.2.5 Major producing countries or regions of core patents on the engineering development focus "Unmanned vehicles"

No.	Country/Region	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	USA	70	79.55%	2666	86.84%	38.09
2	Japan	6	6.82%	90	2.93%	15.00
3	Germany	4	4.55%	185	6.03%	46.25
4	China	3	3.41%	101	3.29%	33.67
5	UK	2	2.27%	17	0.55%	8.50
6	Canada	1	1.14%	17	0.55%	17.00
7	Israel	1	1.14%	4	0.13%	4.00
8	Korea	1	1.14%	9	0.29%	9.00
9	Taiwan of China	1	1.14%	30	0.98%	30.00

The top three countries or regions in number of core patent publication for "Unmanned vehicles" are the USA (70), Japan (6), and Germany (4). The top three countries or regions in average citation frequency are Germany (46.25), the USA (38.09), and China (33.67) (Table 2.2.5). Among the top 10 countries in terms of publication amount, the USA and Germany have substantially cooperated (Figure 2.2.5). The top three institutions in number of core patent publication are FORD (15), GOOG (15), and Flextronics (6), and the institutions with top 3 average citation frequency are GOOG (49.47), BOSC (46.25), and Flextronics (41.83) (Table 2.2.6). Among the 10 institutions in terms of publication amount, HONE and EMS Technologies cooperated more substantially (Figure 2.2.6). In 2011–2016, three core patents related to one development focus, that is, "Unmanned vehicles", are disclosed in China. Of which, 2 patents are from Shenzhen Dajiang.

Table 2.2.6 Major producing institutions of core patents on the engineering development focus "Unmanned vehicles"

No.	Institution	Published patents	Proportion of published patents	Citation frequency	Proportion of citation frequency	Average citation frequency
1	FORD	15	17.05%	432	14.07%	28.80
2	GOOG	15	17.05%	742	24.17%	49.47
3	Flextronics	6	6.82%	251	8.18%	41.83
4	BOSC	4	4.55%	185	6.03%	46.25
5	HONE	3	3.41%	14	0.46%	4.67
6	EMS Technologies	2	2.27%	6	0.20%	3.00
7	Shenzhen Dajiang	2	2.27%	63	2.05%	31.50
8	TOYT	2	2.27%	18	0.59%	9.00
9	TTTA	2	2.27%	17	0.55%	8.50

Note: FORD stands for Ford Inc; GOOG stands for Google Inc; Flextronics stands for Flex International Ltd; BOSC stands for Bosch Group; HONE stands for Honeywell International Inc; EMS Technologies stands for EMS Technologies Inc; TOYT stands for Toyota Motor Corp; TTTA stands for Jaguar Land Rover Ltd.

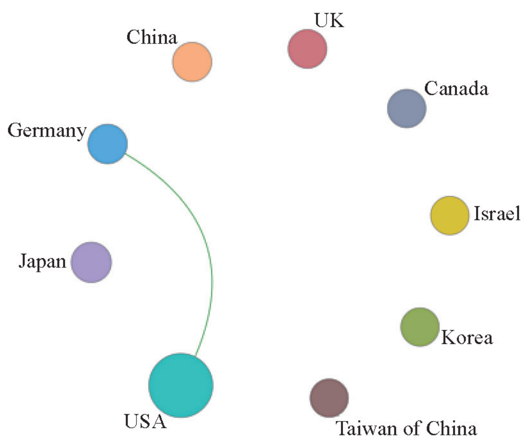

Figure 2.2.5 Collaboration network of the major producing countries or regions of core patents on the engineering development focus "Unmanned vehicles"

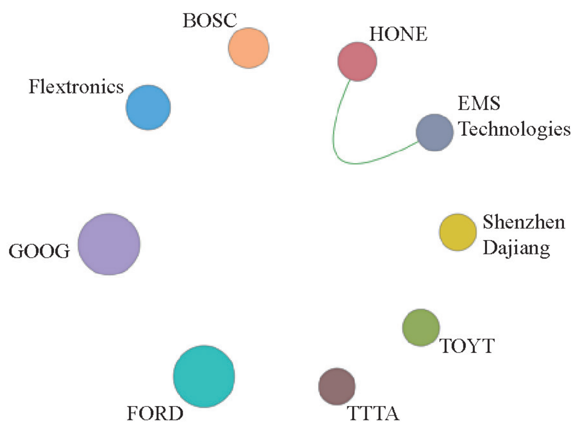

Figure 2.2.6 Collaboration network of the major producing institutions of core patents on the engineering development focus "Unmanned vehicles"

Project Participants

Field Group

Leaders of the Field Group:

DUAN Zhengcheng, GUO Dongming

Other Members:

SHI Tielin, LI Renfu, ZHAO Yingjun, WANG Shaorong, CHENG Yuansheng, XIA Qi, XIA Liang, SUN Bo, CHEN Xixi

Report Writers

SHI Tielin, ZHAO Yingjun, XIONG Caihua, WU Xinjun, LUO Xin, LI Renfu, CHENG Xiaobei, HUANG Yongan, HU Xianluo, LIU Yinshui, WEI Qingsong, XIA Qi, XIA Liang, SUN Bo, LI Li