VI. Environmental & Light Textile Engineering

1 Engineering research fronts

1.1 Development trends in the top 10 engineering research fronts

The top 10 engineering research fronts in the field of environmental and light textile engineering (hereafter referred to as environmental engineering), which includes the subfield of environmental science, environmental engineering, meteorological science, marine science engineering, food science and engineering, textile science and engineering, and light industry technology and engineering, are summarized in Table 1.1.1. The annual number of core papers for individual research fronts between 2012 and 2017 is summarized in Table 1.1.2.

(1) Transport and transformation mechanisms of contaminants under multi-media and multi-interface

The transport of contaminants refers to the spatial migration and the process of enrichment, diffusion, and disappearance of contaminants into the environment. The transformation of contaminants indicates a change in the form of pollutants, or a conversion into another substance, through physical, chemical, or biological processes. Environmental systems consist of multiple media and have different environmental interfaces. Therefore, the transport of contaminants between media leads to contamination and the transformation at the interface of the media determines the level of pollution.

The research focuses on the transport, transformation, distribution, and fate behavior of carbon, nitrogen, phosphorus, sulfur, heavy metals, and organic contaminants in water–gas, water–soil, gas–soil and their biological interfaces, as well as their mechanisms for impacting the environment and ecosystems. Due to the multi-media, multi-interface, multi-component, and multi-fluid characteristics of the environmental system, the transport and transformation process of contaminants in the system is extremely complicated; while qualitatively describing this process is relatively easy, quantitatively describing it is challenging. The primary research directions include the distribution and

Table 1.1.1 Top 10 engineering research fronts in environmental and light textile engineering

No.	Engineering research front	Core papers	Citations	Citations per paper	Mean year	Percentage of consistently-cited papers	Patent-cited papers
1	Transport and transformation mechanisms of contaminants under multi-media and multi-interface	483	22 579	46.75	2013.24	–	–
2	The mechanisms of combined air pollution	182	12 610	69.29	2014.02	–	–
3	The health effects of air pollution	1 119	68 394	61.12	2013.49	–	–
4	Performance and mechanism of decontamination technologies based on environmental nanocomposites	11	291	26.45	2016.27	27.3%	0.00
5	High-resolution ocean circulation models	29	655	22.59	2014.48	27.6%	0.00
6	Ocean acidification	38	1 852	48.74	2013.66	15.8%	0.00
7	Weather and climate predictability and model development	14	731	52.21	2014.14	14.3%	0.00
8	Mechanism of food nutrition metabolism based on intestinal microbiomics	20	2 112	105.60	2013.10	–	–
9	Intelligent wearable materials	152	6 221	40.93	2015.01	16.4%	0.02
10	Deep treatment of dyeing and finishing effluents	14	402	28.71	2016.07	14.3%	0.00

Table 1.1.2 Annual number of core papers published for the top 10 engineering research fronts in environmental and light textile engineering

No.	Engineering research front	2012	2013	2014	2015	2016	2017
1	Transport and transformation mechanisms of contaminants under multi-media and multi-interface	175	138	79	68	18	5
2	The mechanisms of combined air pollution	31	28	58	39	24	2
3	The health effects of air pollution	324	287	258	157	74	19
4	Performance and mechanism of decontamination technologies based on environmental nanocomposites	0	0	0	2	4	5
5	High-resolution ocean circulation models	7	2	5	4	7	4
6	Ocean acidification	9	9	11	4	5	0
7	Weather and climate predictability and model development	1	3	4	5	1	0
8	Mechanism of food nutrition metabolism based on intestinal microbiomics	8	5	4	3	0	0
9	Intelligent wearable materials	9	17	28	33	40	25
10	Deep treatment of dyeing and finishing effluents	0	0	0	4	5	5

fate behavior of contaminants in environmental media, the transport and transformation mechanisms of contaminants in multi-media, the control and influence that micro-interfaces exert on pollutant transport and transformation, and the process simulation of pollutant transport and transformation in complex systems.

Traditional research on environmental pollution and control has been primarily limited to the properties of media. Scientists in the environmental field are often distinguished according to the studied medium. With a deepening of the concept of the environmental system, the study of pollution in a single medium (i.e., water, gas, soil, or organisms) is considered to be incapable of solving complex environmental problems. Future research of environmental pollution, and how to effectively control it, will increasingly move beyond the inertial thinking of transferring contaminants from one medium to another. Instead, by comprehensively considering water, gas, and soil pollution problems, the transport process of contaminants between the media and their transformation mechanism at the interface will be studied in depth, which will enable an accurate depiction and effective control of environmental pollution.

(2) The mechanisms of combined air pollution

"Combined air pollution" refers to a complicated air pollution system in which a variety of pollutants from various sources have coupling interactions between multiple interfaces under certain atmospheric conditions (temperature, humidity, illumination, etc.). Such a system features an increase in both the oxidizing capacity of the atmosphere and fine particulate matter (PM) concentrations, as well as a reduction in atmospheric visibility. Alongside China's rapid economic growth and urbanization, urban and regional air quality has deteriorated rapidly, characterized at first by high concentrations of sulfur dioxide (SO_2) and PM resulting from coal-dominated energy production and consumption. This was followed by a significant increase in nitrogen oxides (NOx) and volatile organic compounds (VOCs) triggered by an increase in vehicle use. These primary pollutants and secondary pollutants, which are generated by the complex reactions of primary pollutants in the atmosphere, interact with the weather and climate systems, leading to a higher level and a wider range of pollution that eventually results in the reduction of visibility, frequent occurrence of haze, and formation of regional air pollution. The main research topics in this field include: revealing the key chemical and physical processes that cause the combined air pollution complex, establishing a theoretical system of combined air pollution, and developing new principles for the monitoring and source apportionment of atmospheric pollutants. The research on air pollution complex will provide a more scientific basis for solving global air pollution problems and climate issues.

(3) The health effects of air pollution

The complex and extensive effects of air pollution on human health have become a pressing issue facing the development of global society. The Global Burden of Disease (GBD) identifies air pollution among the leading risk factors for the global disease burden, responsible for 3.1% of disability-adjusted life years alone. Air pollution is a complex and ubiquitous mixture of pollutants including airborne PM, heavy metal elements, and VOCs. A significant amount of epidemiological and pathophysiological data support the claim that air pollution, especially particles with respirable aerodynamic diameters less than 10 µm (PM_{10}) and 2.5 µm ($PM_{2.5}$), increases respiratory disease (such as asthma, chronic obstructive pulmonary disease, and lung cancer) and cardiovascular and cerebrovascular diseases (such as myocardial infarction, heart failure, and stroke). The elderly, pregnant women, babies, and people with similar diseases are more susceptible to the adverse effects of air pollution. Therefore, it is important to address China's human health issues by improving atmospheric conditions through a wide range of studies and comprehensive analyses of the impact of air pollution on human health.

(4) Performance and mechanism of decontamination technologies based on environmental nanocomposites

Nanomaterials refer to materials that have at least one dimension with a size of 1–100 nm. Nanomaterials have exhibited huge advantages in the efficient purification and treatment of pollutants (e.g., adsorption and catalytic degradation) due to their large specific surface area and high reactivity, and thus, have been important to the development of new technologies for environmental protection and remediation. However, technological bottlenecks, including aggregation, deactivation, and poor operability, have significantly limited the practical application of these materials. Fabrication of nanocomposites via the immobilization of nanoparticles is a promising strategy to address these problems. For example, nanosized metal oxides (e.g., Fe and Mn oxides) have satisfactory capabilities in removing contaminants such as heavy metals from water. Meanwhile, carbonaceous materials (e.g., graphene and carbon nanotubes) and porous materials (e.g., zeolites, clay minerals, and activated carbon) are promising hosts for nanoparticles due to their suitable conductivity, confinement, and supporting effects. In recent years, scientists around the world have developed various types of environmental nanocomposites for decontamination.

The environmental nanocomposites reported recently in prominent research papers include various types such as nano metal oxides–chitosan, nano ZnO–montmorillonite, nano Mn-oxide–activated carbon, Co-impregnated carbon nanotubules, nano CuO–zeolite, and nano metal oxides–porous resins. The corresponding decontamination processes mainly include the adsorptive removal of aqueous contaminants (e.g., heavy metals, As, F, and P) from water, catalytic degradation of organic pollutants, and desulfurization of gasoline. Currently, research of decontamination technologies based on environmental nanocomposites is generally limited to lab-scale explorations, with limited instances of full-scale application. To promote environmental nanotechnologies moving from lab investigation to practical application, it is necessary to further develop novel nanocomposites with millimeter-sized hosts, upgraded operability, and sustainable reusability.

(5) High-resolution ocean circulation models

High-resolution ocean circulation models that include multiple temporal and spatial scale physical processes are a primary method for investigating and predicting ocean multi-scale dynamic processes in the marine environment. In recent years, with the development of ocean circulation modeling and the improvement of computing power, ocean numerical models have been able to simulate large-scale circulations more accurately and also have the capability to characterize ocean mesoscale processes. However, current ocean circulation models are unable to effectively simulate key dynamic processes in the ocean's mesoscale to small-scale, because of the relatively slow progress in theoretical research and the absence of a deep understanding of the dynamics of these scales. With regard to bottlenecks and frontier issues, the primary research directions and development trends include: developing a ultra-high-resolution ocean circulation model that utilizes high-resolution ocean observation, promoting theoretical innovation in small and mesoscale ocean dynamics, and enhancing the capability to simulate small and mesoscale dynamic processes and marine environment through the improvement of parameterization schemes based on physical processes; and further developing technologies for the data assimilation of satellite remote sensing observations and field measurements based on the high-resolution ocean circulation model, to reduce the models simulation error for marine environment elements with assimilating observation data, and to improve the forecast accuracy of the ocean circulation models in multi-scale processes and environmental elements.

(6) Ocean acidification

The dramatic rise of anthropogenic CO_2 emissions has led to ocean acidification, an increase in the acidity (pH) of seawater resulting from the increased absorption of CO_2 by oceans and changes in the terrestrial inputs and oceanic upwelling caused by climate change. Presently, global oceans are experiencing their fastest rate of acidification in 55 million years. Based on the current, increasing rate of anthropogenic CO_2 emission, it is estimated that the pH of the ocean surface will drop by 0.3–0.4 (to a pH of about 7.8) by 2100, an acidification increase of 1–1.5 times the level found in 1800. To assess the harm and risk associated with ocean acidification, the main research directions of ocean acidification include the following. ① Research will be conducted on the causes, processes, and reaction mechanisms of ocean acidification, the relationship between ocean acidification and biogeochemical variations in the ocean, and the parameter changes and modeling analysis of ocean acidification. ② Sensitive organisms that are vulnerable to ocean acidification will be targeted in research to study the effects of ocean acidification on the early life process, evolutionary adaptation, and pathological response of calcifying organisms. ③ Additionally, representative species, such as coral and algae, will be selected in the early research stages. ④ Finally, research will be conducted to trace the earth's history and investigate past climate change and acidification events through geological mineral research.

Ocean acidification is a topic at the forefront of international marine research. In addition to the research topics mentioned above, there are also a number of other trends in this field. ① Research is gradually expanding from directly affected, vulnerable organisms to other species such as large mammals. ② Research methods in the field are upgrading from simple laboratory research to near in situ containment tests with advanced technical equipment. ③ The research contents are shifting from early life stages, such as breed and larval growth, to life processes, physiological responses, functional behaviors, and gene expression. ④ The research scope of the assessment is expanding from the individual to the group level and multi-level response. ⑤ The study area is expanding beyond coastal areas to the open ocean and even the deep sea. ⑥ The study parameters are developing from a single pH test to a multi-factor joint test and a synergistic effect analysis.

(7) Weather and climate predictability and model development

The accuracy of short-term weather forecasting and medium- and long-term climate predictions is important to many people and is a key frontier in the field of atmospheric science. Presently, numerical models are the main tool for weather forecasting and climate prediction. The European Centre for Medium-Range Weather Forecasts (ECMWF), the UK, and the USA possess the world-class forecasting systems and models. The horizontal resolution of the high-resolution global model of the ECMWF is currently 9 km; the resolution of the global ensemble prediction system has been increased to 18 km, which can be used for ensemble prediction 15 days in advance. The ECMWF's model also leads the way in short- and medium-term forecasting techniques for global atmospheric circulation and severe weather. For example, Hurricane Sandy in October 2012 was successfully forecasted 15 days in advance. The UK (through its Met Office) is currently the only country in the world that has developed and implemented a unified weather and climate model (i.e., using the same model system framework for short- and medium-term global and regional weather forecasts, extended forecasts, month to seasonal predictions, and 100-year climate projections). The USA's global numerical weather prediction technology, which successfully forecasted the winter snowstorm that struck New York City in 2015, is ranked third in the world.

Based on GRAPES, a unified global and regional framework for numerical weather forecasting, China has independently improved and developed relevant technologies such as data assimilation, model dynamic physics, and ensemble forecasting. It has also established a comprehensive GRAPES technical system to achieve numerical deterministic and ensemble predictions over China with a regional resolution of 3 km and global resolutions of 10–25 km, narrowing the gap with advanced international systems.

(8) Mechanism of food nutrition metabolism based on intestinal microbiomics

The intestine, which contains many kinds of microbes, is an important organ for digestion, immunity, and nerve perception within the human body. In recent years, studies have found that the intestinal microbiome is closely related to various diseases of the human body. There has been a worldwide surge in research examining how the use of probiotics and other dietary measures can improve intestinal health by regulating intestinal microbes. To gain a better understanding of human nutrition and health, it is important to clarify the effects of dietary structure and its components on intestinal micro-ecology. It is also necessary to fully understand the regularity and mechanism of dietary nutrients affecting the occurrence and development of metabolic diseases mediated by intestinal microorganisms, establish the relationship between intestinal micro-ecological changes and human health status, predict the risk of metabolic diseases associated with different dietary compositions, and to design new dietary combination formulas and treatment strategies based on risk analysis.

(9) Intelligent wearable materials

The research of intelligent wearable materials aims to manufacture and process flexible materials into functional and intelligent electronic devices. These devices can sense changes in their external environment; the information processor evaluates the signal produced by a given change and then the driver adjusts the state of the material to adapt to the external environment. Through this process, these materials may eventually achieve self-diagnosis, self-adjustment, self-repair, and other functions. The materials used for manufacturing require high-speed electron mobility, good electrical conductivity, practical mechanical properties, safety features, and environmental stability. Appropriate material selection and manufacture processes are key to achieving these goals. Intelligent wearable materials have enormous potential across a wide range of applications, including intelligent electronic clothing, wearable computer clothing, wireless remote sensing and communication clothing, and leisure and entertainment clothing, etc.

(10) Deep treatment of dyeing and finishing effluents

The dyeing and finishing industries are on the list of the top dischargers of industrial effluents. The wastewater generated by dyeing and finishing processes is characterized by a complex composition, high organic content, high salt content, and significant discoloration. The emergence of newer generations of dyes and functional finishing agents has aggravated the bio-degradability of dyeing and finishing wastewater. Conventional biochemical and physicochemical treatment of these effluents is insufficient for lowering the chemical oxygen demand and chromaticity to the standard levels for discharge or reuse. Therefore, efficient and cost-effective techniques for the deep purification of dyeing and finishing wastewater must be developed urgently. Treatment by catalytic oxidation, which breaks down organic pollutants in wastewater to small non-toxic molecules or CO_2 and water through a catalyst that takes advantage of light, electricity or green oxidants, has emerged as a promising method in the field.

The catalytic oxidation treatment of wastewater is a collective term that includes electrochemical oxidation, Fenton oxidation, photocatalytic oxidation, and catalytic ozone (O_3) oxidation, all of which have certain limitations. Therefore, future developments in this field will center on addressing these corresponding limitations and integrating existing technologies for improved performance. Specifically, these include the development of highly-efficient, low-cost, and exudation-resisted electrode materials, conveniently-recyclable supported photocatalysts that utilize a broader range of the electromagnetic spectrum, pretreatment and new designs of photoreactors for improved efficiency in catalysis, the development of multiphasic O_3 catalyzed oxidation, and integrated treatment techniques that take advantage of two or more existing oxidative methods, such as electrochemical + O_3 and photochemical + $O_{3.}$

1.2 Interpretations of three key engineering research fronts

1.2.1 The health effects of air pollution

In recent years, China has faced serious environmental problems as a result of air pollution. The complexity of air pollution also causes severe health problems; in 2013, the International Agency for Research on Cancer officially listed air pollution as a primary carcinogen. An estimated 92% of the world's population live in areas with air quality that exceeds certain healthy limits. Approximately 3 million deaths each year are related to air pollution and nearly 90% of them occur in low- and middle-income countries. Air pollutants mainly include respirable particulate matter ($PM_{2.5}$, PM_{10}, etc.), SO_2, NO_x, O_3, carbon monoxide (CO), and VOCs.

A number of epidemiological and pathophysiological studies have shown that air pollution is correlated with cardiovascular diseases, respiratory diseases, and some cancers. Among the different air pollutants, aerosol particles smaller than 2.5 μm pose the greatest risk to human health because they are small enough to be inhaled deeply into the lungs and, in some cases, enter the bloodstream. Any harmful substances carried by the particles, such as bacteria, viruses, or heavy metals, can then be absorbed by the human body.

Nations are increasingly regarding the impact of air pollution on human health as a key area for research. Presently, research on this topic is mainly focused on the relationship between atmospheric pollutant concentration and exposure-response, the acute and chronic health effects of atmospheric pollutants, and genotoxic and non-genotoxic pathogenesis, among other aspects. However, due to the lack of long-term systematic monitoring and data accumulation, the academic study of the impacts of air pollution on human health in China still has much room for further development compared to that of western countries.

A review of 1119 core papers on the health effects of air pollution revealed that these studies were cited as many as 68 394 times, with a per paper citation frequency of 61.12—mostly from 2012 to 2015 (Table 1.1.1). Almost all 1119 core studies were conducted in the USA and China, and the citations per paper for both countries are 71.26 and 84.89, respectively (Table 1.2.1). Harvard University and the University of California, Berkeley, are the 2 major producers of the core papers, publishing 7.42% and 6.88% of the papers which were cited 11 212 and 9938 times, respectively.

When analyzing the engineering research front of "the health effects of air pollution", the top three countries or regions that published the highest number of core papers are the USA (556), China (228), and the UK (168); the top 3 countries or regions with the highest average citations are Switzerland (149.60), Germany (139.42), and the Netherlands (134.87) (Table 1.2.1). Among these countries or regions, China, and the USA extended the highest level of cooperation to each other, followed by the UK, Canada, and Germany (Figure 1.2.1).

The 3 institutions that published the highest number of core papers are Harvard University (83), the University of California, Berkeley (77), and Peking University (53), and the top 3 cited institutions per core paper are the University of British Columbia (197.93), Health Canada (195.91), and Fudan University (195.18) (Table 1.2.2). The institutions with the highest number of published papers in China include Peking University, the Chinese Academy of Sciences, and Fudan University (Table 1.2.2). The University of California, Berkeley has the largest cooperation with Health Canada and Peking University has significant cooperation with the Chinese Academy of Sciences, Fudan University, and the University of British Columbia (Figure 1.2.2).

The major research institutions with regard to citing core papers include the Chinese Academy of Sciences, Peking University, and Tsinghua University in China; Harvard University, the University of Washington, the University of California, Berkeley, and Columbia University in the USA; and the Imperial College of Science, Technology and Medicine in the UK (Table 1.2.3 and Table 1.2.4).

Table 1.2.1 Countries or regions with the greatest output of core papers on the "health effects of air pollution"

No.	Country/Region	Core papers	Percentage of core papers	Citations	Percentage of citations	Citation per paper
1	USA	556	49.69%	39 618	57.93%	71.26
2	China	228	20.38%	19 356	28.30%	84.89
3	UK	168	15.01%	17 229	25.19%	102.55
4	Canada	130	11.62%	13 335	19.50%	102.58
5	Italy	106	9.47%	8 740	12.78%	82.45
6	Germany	102	9.12%	14 221	20.79%	139.42
7	Spain	92	8.22%	11 044	16.15%	120.04
8	France	90	8.04%	10 580	15.47%	117.56
9	Netherlands	86	7.69%	11 599	16.96%	134.87
10	Switzerland	72	6.43%	10 771	15.75%	149.60

Table 1.2.2 Institutions with the greatest output of core papers on the "health effects of air pollution"

No.	Institution	Core papers	Percentage of core papers	Citations	Percentage of citations	Citations per paper
1	Harvard Univ	83	7.42%	11 212	16.39%	135.08
2	Univ Calif Berkeley	77	6.88%	9 938	14.53%	129.06
3	Peking Univ	53	4.74%	3 292	4.81%	62.11
4	Univ Utrecht	50	4.47%	8 923	13.05%	178.46
5	US EPA	47	4.20%	8 512	12.45%	181.11
6	Hlth Canada	43	3.84%	8 424	12.32%	195.91
7	Chinese Acad Sci	43	3.84%	3 074	4.49%	71.49
8	Univ British Columbia	42	3.75%	8 313	12.15%	197.93
9	Ctr Res Environm Epidemiol CREAL	42	3.75%	2 830	4.14%	67.38
10	Fudan Univ	40	3.57%	7 807	11.41%	195.18

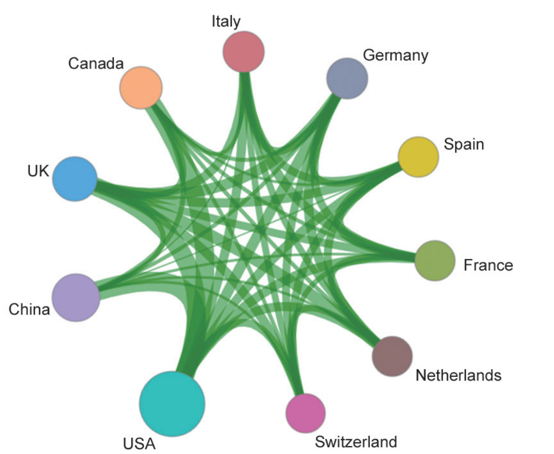

Figure 1.2.1 Collaboration network among major countries or regions in the engineering research front of "the health effects of air pollution"

In summary, China is gradually taking the global lead in research on the topic of "the health effects of air pollution." Therefore, the country should continue to invest in this research area and promote research that will accelerate the progression that will allow it to remain at the forefront of the field

1.2.2 High-resolution ocean circulation models

Marine environment forecasting forms the basis of human maritime activities which in turn drive the development of ocean circulation models. Since the 1990s, progress made in ocean observation, data assimilation, and high-performance computer technology has enabled high-resolution ocean circulation models to develop rapidly to meet an increasing

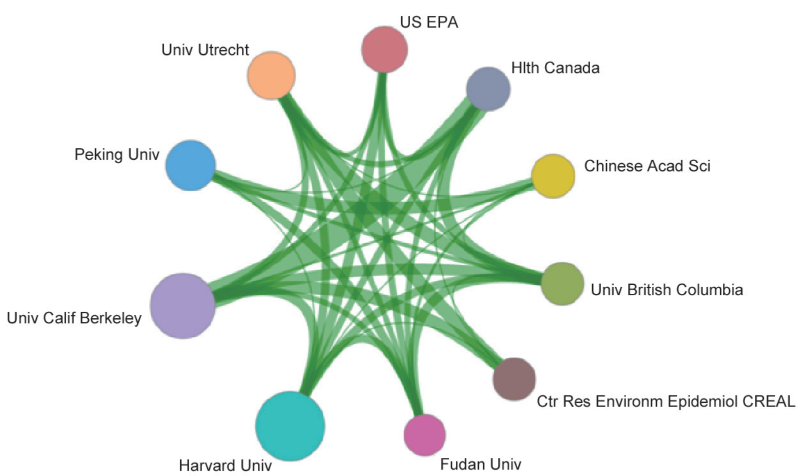

Figure 1.2.2 Collaboration network among major institutions in the engineering research front of "the health effects of air pollution"

Table 1.2.3 Countries or regions with the greatest output of citing papers on the "health effects of air pollution"

No.	Country/Region	Citing papers	Percentage of citing papers	Mean year
1	USA	1 852	31.13%	2014.38
2	China	890	14.96%	2014.66
3	UK	752	12.64%	2014.48
4	Germany	445	7.48%	2014.64
5	Canada	412	6.93%	2014.52
6	Australia	368	6.19%	2014.65
7	Netherlands	327	5.50%	2014.55
8	Italy	315	5.30%	2014.54
9	Spain	298	5.01%	2014.51
10	Switzerland	290	4.87%	2014.55

Table 1.2.4 Institutions with the greatest output of citing papers on the "health effects of air pollution"

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	Harvard Univ	278	18.42%	2014.40
2	Chinese Acad Sci	217	14.38%	2014.81
3	Univ Washington	180	11.93%	2014.56
4	Univ London Imperial Coll Sci Technol & Med	139	9.21%	2014.05
5	Univ Calif Berkeley	137	9.08%	2014.15
6	Peking Univ	119	7.89%	2014.45
7	Columbia Univ	114	7.55%	2014.65
8	Univ British Columbia	111	7.36%	2014.81
9	Univ Utrecht	110	7.29%	2014.31
10	Tsinghua Univ	104	6.89%	2014.63

demand for global operational ocean forecasting. A number of internationally renowned ocean circulation models have been generated, including HYCOM, POM, ROMS, NLOM, HAMSOM, LICOM, NEMO, and MOM. Ocean circulation involves multi-scale dynamic processes ranging from large-scale circulation over thousands of kilometers to small-scale turbulent mixing over centimeters, and interactions and coupling between these multi-scale processes. Nonlinear interactions between different scales lead to the mass and energy transferring in multi-scale dynamic space. Although high-resolution ocean numerical models have been able to simulate large-scale circulation structures relatively accurately and have a certain ability to characterize the ocean mesoscale process, there is still a lack of theoretical research to provide an in-depth understanding of small-scale dynamic processes and their interactions in the ocean. The dynamic frames and mixed parameterization schemes of current mainstream circulation models determine that the mesoscale energy in models tends to reverse cascade, which cannot accurately describe the forward cascade and dissipation of mesoscale energy. This is one of the main bottlenecks that currently restricts the development of marine environmental forecasting and it is an international frontier for developing high-resolution ocean circulation models.

In view of these bottlenecks and frontier issues, the primary research directions and development trends at present include: carrying out in-depth research on ocean mesoscale processes and promoting theoretical innovation with regard to marine dynamics and parameterization schemes for physical processes by developing ultra-high-resolution ocean circulation models combined with high-resolution satellite remote sensing and field observation. The simulation and forecasting capability of ocean mesoscale dynamic processes and marine environment is also improved by the progress of the parameterization schemes of ocean circulation models. Currently, this work is primarily undertaken by the global ultra-high-resolution circulation model of the Jet Propulsion Laboratory in the USA and NASA's Surface Water and Ocean Topography satellite program. On the other hand, there is also a need to further develop data assimilation technologies based on satellite remote sensing and field observation. Assimilating the observation data by using the three-dimensional variation, multi-scale coupling and other technologies could reduce the error happened in calculation of marine environmental elements. This work is primarily undertaken by the global HYCOM data assimilation model jointly developed by Florida State University, the Naval Postgraduate School, and the University of Miami.

Table 1.2.5 shows the main output countries or regions of the core papers published in the research front "high-resolution ocean circulation models." It is evident that the USA ranks first in the proportion of both the number of papers published and citation frequency and there is a large gap between the other countries. This indicates that the USA holds significant research advantages in this field. China has a small number of core papers in this area, ranked eighth; however, it is worth noting that it ranks second in citation frequency with 31. In terms of the cooperative networks of major output countries or regions (Figure 1.2.3), there is extensive cooperation and exchange among the USA, Australia, Canada, and the UK, while China only cooperates with the USA.

Table 1.2.6 is the main output organization of core papers in the engineering fronts. The top 10 institutions in terms of the number of core papers produced are predominantly concentrated in the USA, while the Chinese research institutions do not appear in the top 10. According to the major inter-agency cooperation network (Figure 1.2.4), four institutions, the University Michigan, the University of

Table 1.2.5 Countries or regions with the greatest output of core papers on "high-resolution ocean circulation models"

No.	Country/Region	Core papers	Percentage of core papers	Citations	Percentage of citations	Citations per paper
1	USA	24	82.76%	560	85.50%	23.33
2	UK	9	31.03%	237	36.18%	26.33
3	Australia	6	20.69%	160	24.43%	26.67
4	France	4	13.79%	71	10.84%	17.75
5	Canada	4	13.79%	89	13.59%	22.25
6	Japan	1	3.45%	30	4.58%	30.00
7	China	1	3.45%	31	4.73%	31.00

Table 1.2.6 Institutions with the greatest output of core papers on "high-resolution ocean circulation models"

No.	Institution	Core papers	Percentage of core papers	Citations	Percentage of citations	Citations per paper
1	Univ Michigan	8	27.59%	152	23.21%	19.00
2	Univ Calif San Diego	5	17.24%	128	19.54%	25.60
3	Univ Southampton	5	17.24%	173	26.41%	34.60
4	Woods Hole Oceanog Inst	5	17.24%	191	29.16%	38.20
5	MIT	3	10.34%	29	4.43%	9.67
6	USN	3	10.34%	96	14.66%	32.00
7	Univ New S Wales	3	10.34%	131	20.00%	43.67
8	Portland State Univ	3	10.34%	41	6.26%	13.67
9	Naval Res Lab	3	10.34%	30	4.58%	10.00
10	Bangor Univ	3	10.34%	30	4.58%	10.00

California, San Diego, the U.S. Naval Research Laboratory, and Bangor University, have cooperative relationships with each other. Three institutions, the University of Southampton, Woods Hole Oceanography Institute, and the University of New South Wales, also have cooperative relationships.

China ranks fourth in terms of citation frequency of its core papers (Table 1.2.7). There is still a significant gap between China and the USA, the leader in the category. The Ocean University of China and Chinese Academy of Sciences rank sixth and seventh, respectively, in the rankings of institutions from which core papers were cited (Table 1.2.8). Institutions in the USA still occupy the majority of the institutional rankings.

It is evident that the USA is a world leader in the field, not only in terms of the development of "high-resolution global ocean circulation models", but also with regard to its cooperation with other countries. In contrast, China is still following in this field; to overcome this China should strengthen exchange and cooperation with other countries and institutions, continue to increase research investment, and promote research in the innovative fields that will enable it to become a world leader.

1.2.3 Intelligent wearable materials

As electronic information systems have become indispensable to our daily lives, intelligent wearable materials have received significantly more attention in the engineering field. They are the combination of electronic components and textiles, but their properties are vastly different: the former is hard

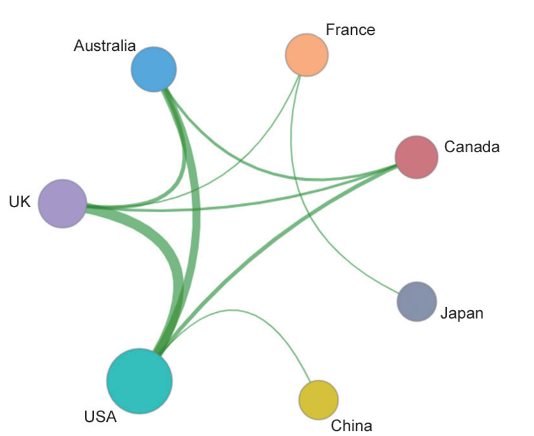

Figure 1.2.3 Collaborative network among major countries or regions in the engineering research front of "high-resolution ocean circulation models"

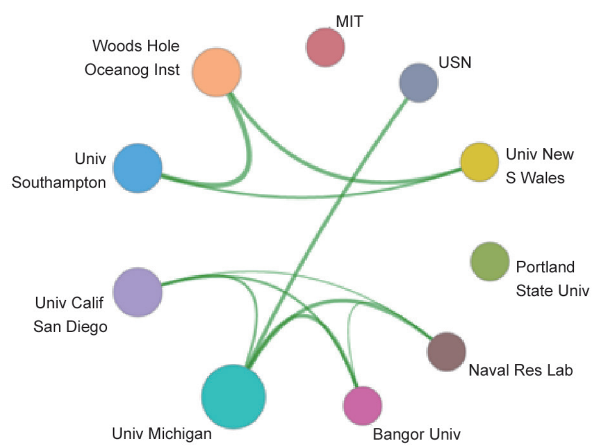

Figure 1.2.4 Collaborative network among major institutions in the engineering research front of "high-resolution ocean circulation models"

Table 1.2.7 Countries or regions with the greatest output of citing papers on "high-resolution ocean circulation models"

No.	Country/Region	Number of cited core publications	Percentage of cited core publications	Mean year
1	USA	196	41.09%	2015.48
2	France	59	12.37%	2015.46
3	UK	55	11.53%	2015.15
4	China	41	8.60%	2015.61
5	Australia	35	7.34%	2015.26
6	Japan	28	5.87%	2015.75
7	Germany	24	5.03%	2015.04
8	Canada	24	5.03%	2015.17
9	Norway	8	1.68%	2014.63
10	Sweden	7	1.47%	2015.57

and brittle and the latter is flexible. Functional and intelligent wearable textiles sense changes in the external environment. The information processor judges the signal produced by a given change and the driver then adjusts the state of the material to adapt to the external environment and ultimately achieve self-diagnosis, self-adjustment, and self-repair, among other functions.

(1) One-dimensional flexible conductive material

One-dimensional flexible conductive material, an important component of fiber-based intelligent wearable materials, requires high-speed electronic mobility, good conductivity, practical mechanical properties, safety features, and environmental stability. Appropriate material selection and manufacture processes are key to achieving these goals. Presently, fiber-based flexible conductive materials primarily include conductive polymers, metal oxides, and carbon materials. The most promising technology in the manufacturing process is textile technology, followed by nano-coating technology.

(2) One-dimensional flexible energy storage device

In addition to exploring the function of wearable flexible textiles, researchers also pay attention to energy storage devices, such as supercapacitors and flexible batteries, especially for advanced nanotechnology, that make it feasible to directly integrate electronic devices into fibers. However, it is also a significant challenge to integrate one-dimensional fibers into three-dimensional clothing that can maintain their performance when in use. Therefore, the design of intelligent wearable components should be considered in terms of material preparation, manufacturing technology, and device structure.

(3) Intelligent wearable materials applications

The applications of intelligent wearable materials mainly include electronic components, wearable electronic devices, and other applications. Electronic components include optical fiber transistors, fabric antennas, electronic connectors, and fiber circuits. Wearable electronic devices include sensors and sensor networks, wearable energy converters, wearable energy storage, etc. Other applications include electronic intelligent protective clothing, electronic intelligent monitoring clothing, wearable computer clothing, wireless remote sensing and communication clothing, and leisure and entertainment clothing, etc.

The research front of “intelligent wearable materials” is mainly undertaken in China, the USA, and Iran (Table 1.2.9). These three countries are responsible for more than 81% of the core papers published in this field across the world, with most of this activity concentrated over the last three years. The top five research institutes relating to this front are the Institute for Color Science and Technology, Nanyang Technological University, the Chinese Academy of Sciences, Xi’an Jiaotong University, and the National University of Singapore (Table 1.2.10).

China and the USA occupy the top two positions in the research front, and China, which has cooperative relationships with many other countries, is at the forefront (Figure 1.2.5). Among

Table 1.2.8 Institutions with the greatest output of citing papers on “high-resolution ocean circulation models”

No.	Institution	Number of cited core publications	Percentage of cited core publications	Mean year
1	Univ Calif San Diego	40	17.24%	2015.60
2	Woods Hole Oceanog Inst	34	14.66%	2015.29
3	Univ Washington	23	9.91%	2015.43
4	MIT	23	9.91%	2015.74
5	Univ Southampton	22	9.48%	2014.82
6	Ocean Univ China	20	8.62%	2015.50
7	Chinese Acad Sci	19	8.19%	2015.95
8	Univ Michigan	18	7.76%	2015.22
9	Natl Oceanog Ctr	17	7.33%	2015.41
10	CALTECH	16	6.90%	2015.94

Table 1.2.9 Countries or regions with the greatest output of core papers on “intelligent wearable materials”

No.	Country/Region	Core papers	Percentage of core papers	Citations	Percentage of citations	Citations per paper
1	China	82	53.95%	3 678	59.12%	44.85
2	USA	25	16.45%	925	14.87%	37.00
3	Iran	19	12.50%	465	7.47%	24.47
4	Singapore	15	9.87%	790	12.70%	52.67
5	Australia	9	5.92%	344	5.53%	38.22
6	Russia	4	2.63%	85	1.37%	21.25
7	UK	4	2.63%	63	1.01%	15.75
8	Saudi Arabia	3	1.97%	181	2.91%	60.33
9	South Korea	3	1.97%	151	2.43%	50.33
10	Japan	3	1.97%	88	1.41%	29.33

Table 1.2.10 Institutions with the greatest output of core papers on “intelligent wearable materials”

No.	Institution	Core papers	Percentage of core papers	Citations	Percentage of citations	Citations per paper
1	Inst Color Sci & Technol	16	10.53%	403	6.48%	25.19
2	Nanyang Technol Univ	9	5.92%	454	7.30%	50.44
3	Chinese Acad Sci	9	5.92%	453	7.28%	50.33
4	Xi’an Jiao Tong Univ	7	4.61%	197	3.17%	28.14
5	Natl Univ Singapore	6	3.95%	336	5.40%	56.00
6	MIT	6	3.95%	244	3.92%	40.67
7	Harbin Engn Univ	5	3.29%	114	1.83%	22.80
8	Huazhong Univ Sci & Technol	5	3.29%	605	9.73%	121.00
9	Joint Ctr Energy Storage Res	5	3.29%	216	3.47%	43.20
10	Monash Univ	4	2.63%	175	2.81%	43.75

the major institutions, MIT and Joint Ctr Energy Storage Res cooperate more than others (Figure 1.2.6).

Among major countries/regions, China ranks first in the output of citing papers on this front (Table 1.2.11). And among major institutions, Chinese Academy of Sciences ranks first in the output of citing papers on this front (Table 1.2.12).

2 Engineering development fronts

2.1 Development trends in the top 10 engineering development fronts

The top 10 engineering development fronts in this field, which are summarized in Table 2.1.1, include the subfields of environmental science, environmental engineering, meteorological science, marine science engineering, food science and engineering, textile science and engineering, and light industry technology and engineering. The number of patents issued between 2012 and 2017 related to these individual topics is summarized in Table 2.1.2.

(1) New energy and clean energy technologies

New energy and clean energy refer to solar energy, wind energy, geothermal energy, ocean energy, bioenergy, small hydropower, and nuclear energy, as opposed to conventional fossil-fuel energy and large- and medium-sized hydropower. Countries around the world are actively promoting the development and utilization of these various forms of clean energy. The main difficulties in solar and wind energy

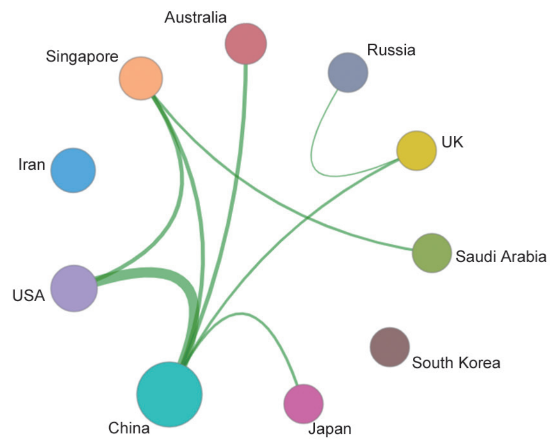

Figure 1.2.5 Collaborative network among major countries or regions in the engineering research front of "intelligent wearable materials"

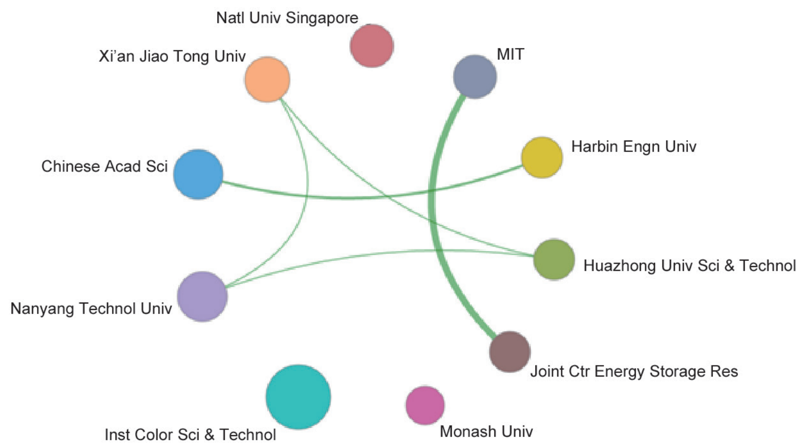

Figure 1.2.6 Collaborative network among major institutions in the engineering research front of "intelligent wearable materials"

Table 1.2.11 Countries or regions with the greatest output of citing papers on "intelligent wearable materials"

No.	Country/Region	Citing papers	Percentage of citing papers	Mean year
1	China	1 765	55.49%	2016.27
2	USA	433	13.61%	2015.95
3	South Korea	207	6.51%	2016.13
4	Iran	168	5.28%	2016.26
5	India	152	4.78%	2016.16
6	Singapore	118	3.71%	2015.38
7	Australia	110	3.46%	2015.97
8	Germany	80	2.51%	2016.19
9	UK	79	2.48%	2016.22
10	Saudi Arabia	69	2.17%	2016.03

applications are low energy conversion efficiencies, high costs, short life spans, and challenges in energy storage. The development of solar thermal conversion key materials and spectrally selective absorption coatings is a key technical

Table 1.2.12 Institutions with the greatest output of citing papers on “intelligent wearable materials”

No.	Institution	Citing papers	Percentage of citing papers	Mean year
1	Chinese Acad Sci	181	28.33%	2016.08
2	Nanyang Technol Univ	58	9.08%	2015.59
3	Natl Univ Singapore	54	8.45%	2015.15
4	Tsinghua Univ	53	8.29%	2016.28
5	Inst Color Sci & Technol	53	8.29%	2016.15
6	Huazhong Univ Sci & Technol	50	7.82%	2016.26
7	Tongji Univ	49	7.67%	2016.31
8	Shanghai Jiao Tong Univ	49	7.67%	2016.00
9	Cent S Univ	47	7.36%	2016.26
10	Xi’an Jiao Tong Univ	45	7.04%	2016.67

Table 2.1.1 Top 10 engineering development fronts in environmental and light textile engineering

No.	Engineering development front	Published patents	Citations	Citations per paper	Mean year
1	New energy and clean energy technologies	1 519	58 880	38.76	2013.07
2	Remediation technology for organic pollution in soils	780	1 116	1.43	2015.47
3	Sewage and wastewater resources energy recovery technology	47	18	0.38	2015.79
4	Air pollution control technology	252	2 848	11.30	2013.05
5	Automatic monitoring technology of remote sensing radar	149	5 083	34.11	2013.53
6	Automatic monitoring and early-warning system for disasters	302	4 931	16.33	2013.69
7	Autonomous underwater vehicles	1 000	6 517	6.52	2014.27
8	E-innovation of monitoring techniques for pesticide residues	1 000	1 100	1.10	2015.40
9	Smart wearable textiles	1 000	17 056	17.06	2014.47
10	Ecological leather	1 745	618	0.35	2015.98

Table 2.1.2 Annual number of core patents published for the top 10 engineering development fronts in environmental and light textile engineering

No.	Engineering development front	2012	2013	2014	2015	2016	2017
1	New energy and clean energy technologies	664	404	227	149	52	23
2	Remediation technology for organic pollution in soils	43	47	88	133	192	267
3	Sewage and wastewater resources energy recovery technology	2	5	0	6	15	19
4	Air pollution control technology	23	30	34	33	27	40
5	Automatic monitoring technology of remote sensing radar	44	32	40	19	11	3
6	Automatic monitoring and early-warning system for disasters	75	77	60	53	30	7
7	Autonomous underwater vehicles	100	122	138	166	174	192
8	E-innovation of monitoring techniques for pesticide residues	37	40	156	117	107	354
9	Smart wearable textiles	79	111	190	151	181	219
10	Ecological leather	0	0	76	489	566	614

barrier to improving the utilization of solar energy. As the core of wind power generation systems, wind turbines have experienced many breakthroughs with regard to overcoming technical problems, which has had an extremely positive impact on the wind power industry. The related research, design, and manufacturing of wind turbines are the primary, future research directions. The development of renewable biomass energy has become an important resource for reducing environmental pollution and the gap between energy supply and demand. A major focus for the future is developing efficient and economical technology related to biomass gasification and liquefaction, biogas, bioethanol, and biohydrogen production, and to promote their development.

(2) Remediation technology for organic pollution in soils

China is in short supply of arable land and soils in certain regions are severely polluted with heavy metals and organic pollutants. Compared with heavy metals, organic pollution is widespread and complicated—pollutants such as PAHs affect the safety of agricultural products and the continuous utilization of land resources. Thus, it is important to develop remediation technology for organic pollution in soils.

Remediation technology for organic pollution, which includes physical, chemical, and biological remediation, was introduced in the 1970s and rapidly developed in the 1980s. Common physical remediation technologies, such as vapor extraction, thermal desorption, and incineration, were suitable for pollutants with high or semi volatility. Chemical remediation technologies oxidize the organic pollutants using Fenton's reagent or potassium permanganate, or enhance the solubility of organic pollutants in the liquid phase through surfactants that are applied to decompose non-volatile or non-degradable pollutants. Biological remediation technologies are used to degrade, absorb, or accumulate pollutants by using indigenous microorganisms and adding bacterial strains or plants. Because of the coexistence of different types of pollutants, integrated remediation techniques are required to address the soil pollution at growing industrial sites.

Although the soil remediation industry has been rapidly developing in recent years, China is still lacking advanced techniques, equipment, and innovative technology. Searching for economical, efficient, and environmentally-friendly soil remediation technology is a clear priority for the future.

(3) Sewage and wastewater resources energy recovery technology

Sewage and wastewater resources energy recovery technology enables the recycling and utilization of biological energy sources and nutrient substances. Sewage and wastewater contain valuable resources; however, current water treatment technology that focuses on removing pollutants fails to effectively harness the energy embedded in these resources. The concept of sewage treatment is currently being transformed from pollutant removal to resource energy recovery, and sewage treatment plants will also become energy recovery plants. The development of this key technology includes the following aspects. ① Advanced treatment and safe and efficient use technologies for reclaimed water. Develop new physicochemical, biochemical, and highly-efficient coupling technologies to create an advanced and super-advanced sewage treatment technology system that utilizes emerging pollutant removal technology, and highly advanced technology for treatment of high-quality reclaimed water. ② Energy self-sufficient technology for sewage treatment. Develop low carbon processes that utilizes a number of technologies: aerobic granular sludge, anaerobic membrane bioreactor, and anaerobic ammonia oxidation technology; thermal hydrolysis and gasification of sludge, anaerobic sludge digestion and related biogas recovery, and purification and technology; and combined heat and power generation, including fuel cells and micro gas turbines. ③ Sewage treatment and resource recovery technology. Study the method and potential of resource recovery in the sewage treatment process, with a focus on the recovery of phosphorus, cellulose, biodiesel, and Polyhydroxyalkanoic acids. ④ Operation management and strategy optimization technology for the next generation of sewage treatment plants. Determine the precise control factors and integrate technological advances such as the Internet of things to realize the self-perception and self-management of sewage treatment plants, realize energy-savings, reduce consumption, and optimize operation and control efficiency. Further, to achieve resource recycling, energy self-sufficiency, and environmental friendliness, recovery technology for sewage and wastewater resources will be a development focus in the water treatment field.

(4) Air pollution control technology

The onset of rapid industrialization since the middle of the last century has led to an increased discharge of pollutants that has caused air pollution to become a serious threat to human health. This has attracted significant efforts around the world to control air pollution through a series of strategies and technologies. Atmospheric pollution mainly includes harmful gases produced by industrial production, harmful substances discharged from automotive engine fuels, and naturally formed gaseous pollutants or fine particulate matter that pose a hazard to human health—with the first two items currently representing the main sources of air pollution. Air pollution control involves particle pollution control technology, gas pollutant control technology, and automobile exhaust control technology. It can be further divided into power plant boiler flue gas emission control, industrial boiler and furnace flue gas emission control, typical toxic and harmful industrial waste gas purification, vehicle exhaust emission control, typical indoor and public air pollutants purification, non-organized emission source control, monitoring and decision-making support for complex air pollution, and clean production, among others. From a clean energy perspective, foreign countries have developed and controlled automotive exhaust pollution by actively reforming fuel and combustion structures and developing efficient exhaust treatment devices. At the same time, many countries are also studying and developing specific pollutant reduction and control technologies for industrial production, such as technology to reduce mercury emissions from coal combustion. China is gradually attaching importance to the development of such technology. At present, the related development front mainly includes two parts: the separation and treatment of industrial waste gas and the treatment of exhaust gas from engines. With regard to industrial waste gas treatment, the emphasis is currently on the coordinated disposal of a variety of pollutants, integrated treatment, and deep removal. For automobiles, the development of exhaust purification technology is a key focus.

(5) Automatic monitoring technology of remote sensing radar

The application of remote sensing and radar in meteorological science mainly includes the collection, transmission, and processing of echo data, using the theory of scattering, refraction, and attenuation of radar waves in the atmosphere to study cloud and precipitation physics, detecting weather systems of various scales and clear-sky atmospheric echoes, the quantitative measurement of precipitation, and providing warnings of severe weather. The research work of radar meteorology is divided into three main areas: the study of atmospheric kinematics and dynamics under clear and cloudy conditions using Doppler measurements; the measurement of rainfall and the identification of various water condensate; and the study of precipitation and atmospheric thermal structure with a focus on kinetic-kinematics. At present, remote sensing radar data has been widely used in short-term disaster weather monitoring. However, with the increased frequency of extreme disaster weather events, the automatic monitoring technology of remote sensing radar and the level of radar and sounding intelligence must be developed further. It is necessary to improve the observation layout of weather radars while considering its widespread use for water conservancy, civil aviation, and the military, and to supplement and improve the technology by utilizing the existing, new-generation weather radar stations, with an emphasis on monitoring blank and disaster-prone areas.

(6) Automatic monitoring and early-warning system for disasters

This research, related to meteorology, is a development of traditional research fronts. In recent years, an increasing number of meteorological disasters have occurred, causing significant economic and property damage. Automatic disaster monitoring and early warning systems have become an important aspect of disaster risk mitigation. Presently, the main research focuses include making breakthroughs in the comprehensive meteorological disaster database, mechanisms of meteorological disaster, rapid assessment technology, prediction technology of disaster factors, dissemination early warning information, and the risk management of meteorological disasters. Focusing on different types of disasters, including rainstorms, floods, hurricanes, haze, droughts, and extreme high and low temperatures, will enable the establishment of a comprehensive meteorological disaster database based on large-scale data technology. It will enable researchers to better understand the characteristics, occurrence, development conditions, and disaster-causing mechanisms of meteorological disasters, and to make breakthroughs in remote sensing and rapid identification techniques. In addition, better techniques for meteorological disaster risk prevention, control, and management will be established to achieve disaster prevention and reduction by conducting automatic monitoring and providing early warnings of floods, droughts, earthquakes, surge storms, geological hazards, forest fires, and other disasters. Therefore, developing the fastest and most effective remote sensing methods and techniques, technologies for large data processing of meteorological satellite remote sensing and ground-based meteorological radar, and establishing a comprehensive, national early warning system for meteorological disasters that possesses strong visualization and high security, are the focuses for the disaster mitigation field.

(7) Autonomous underwater vehicles

Ocean underwater observations rely on measurements by sensors and probes to obtain various observation parameters. To conduct real-time or near-real-time underwater detection on a large scale, sensors need to be equipped in autonomously controllable underwater vehicles, including autonomous underwater vehicles (AUVs), autonomous or remotely controlled underwater vehicles, hybrid-driven underwater vehicles, underwater gliders, or wave gliders. The AUV is an integrated, unmanned, non-cable, underwater vehicle equipped with multiple technologies, such as artificial intelligence, detection and identification, information fusion, intelligent control, and system integration, among others. Observation of the underwater environment using AUVs is an increasingly popular area of international research and a key development trend in the field of marine engineering and technology. The main technical directions include improving the movement of AUVs, studying the action constraints of ocean currents on their autonomous behaviors, and studying the cooperative observation and integrative control of multiple vehicles.

Due to the non-cable, remote connection, AUVs can operate at great distances from the launch ship. However, AUVs are restricted by their navigation capabilities, control system, and endurance. Therefore, key breakthrough technologies will focus on developing intelligent navigation systems with strong reliability, high integration, and comprehensive compensation and correction ability, improving the shelf-adaption of control systems, and developing high-efficiency and high-density energy sources for the vehicles.

(8) E-innovation of monitoring techniques for pesticide residues

Traditional qualitative and quantitative methods for monitoring the residues of pesticide chemical pollutants are based on using the corresponding material standards as a reference. However, the world is now firmly in the information age and is increasingly transforming material standards into electronic standards. Generally speaking, by establishing a unique electronic ID for each pesticide, it is possible to realize the electronic and informationization of pesticide residues for detection technology so that traditional, physical monitoring methods can be replaced with electronic ones. A technological leap-forward has also been achieved by moving from traditional targeted detection to the non-targeted screening of pesticide residues. The effectiveness of this method is unparalleled by traditional chromatography or mass spectrometry. Coming decades will mark an epoch of progress for the detection technology of the residues of pesticide chemical pollutants, as technology currently in its infancy is expected to be widely available in 10 or 20 years.

(9) Smart wearable textiles

Smart wearable textiles are textiles that have electronics and interconnections integrated into them, providing a physical flexibility and size that cannot be achieved with other existing electronic manufacturing techniques. Components and interconnections are intrinsic to the fabric and are thus less visible. Smart wearable textiles can more easily adapt to rapid changes in the computational and sensing requirements of any specific application. Wearable systems will be characterized by their ability to automatically recognize the activity and behavioral status of their user, as well as their external environment. In this field, significant attention has been paid to materials and their manufacturing processes; various innovative technologies are emerging which aim to achieve an effective balance between flexibility, ergonomics, low power consumption, integration, and eventually, autonomy.

From an engineering perspective, smart wearable textiles require the knowledge integration of a range of subfields, including textile engineering, materials science, electricity, and control. At present, the main research focuses are one-dimensional flexible conductive yarn, one-dimensional flexible energy storage material, and smart wearable clothing such as flexible sensors, electronic and smart protective clothing, and electronic and smart monitoring clothes.

(10) Ecological leather

Manufacturing more ecologically friendly leather and fur is the most important strategic objective for the domestic and international leather industry. Chrome tanning is currently the most dominant tanning technique in the leather industry because of its excellent properties; however, there are significant environmental impacts associated with the wastewater and solid waste this technique produces. Therefore, it is vitally important to develop a chrome-free, ecological tanning technique to address the problem of chrome pollution caused by leather manufacturing. This is currently a primary research focus of the leather industry.

The main research areas and targets essential to developing chrome-free ecological leather and fur include: ① developing a series of ecological, organic tanning agents to replace conventional chrome tanning agents, and establishing the corresponding application technology with a complete understanding of the mechanisms and structure of organic tanning agents and their potential impacts; ② developing a series of amphoteric re-tanning agents and fatliquoring agents that have a high binding capability and compatibility with the organic tanning system used for ecological leather, and establishing the corresponding application technology based on a complete understanding of the influence of the molecular structure and the charge property regulation of amphoteric dyeing and finishing materials; ③ establishing ecological evaluation methods and standards for multi-component, complex systems that are capable of evaluating the impacts of tanning agents, dyeing and finishing materials, and leather and fur manufacturing processes and products; ④ establishing an integrated ecological leather industry chain by solving the balance problems in leather manufacturing and shortcomings in the industrial chain connection.

Ultimately, technological breakthroughs that will drive the future development of the leather industry will involve exploring new tanning agents, dyeing and finishing materials for manufacturing ecological leather within an integrated industry chain, and establishing ecological evaluation methods and standards for the corresponding leather products.

2.2 Interpretations of three key engineering development fronts

2.2.1 Remediation technology for organic pollution in soils

Remediation technology for organic pollution has developed significantly since the 1970s. Common remediation technologies include phytoremediation, microbial remediation, vapor extractions, thermal desorption, mixed-surfactants enhanced solubilization-washing, chemical oxidation-reduction, fixation-stabilization, electrodynamics remediation, and soil replacement. Of these technologies, physical remediation techniques have the advantage of being highly efficient but are not suitable for large-scale application due to its high cost. Additionally, the oxidant and surfactants used in chemical remediation may cause secondary pollution and further ecological risks. Therefore, bioremediation and cooperated remediation techniques have attracted more attention. The soil remediation industry in China has experienced rapid development and continuous innovation in recent years; to continue this development, it is essential to explore mobile, modularized, highly efficient, and economical soil remediation technologies and equipment that possesses proprietary intellectual property rights.

As shown in Table 2.2.1, China has issued 766 core patents related to remediation technology for organic pollution in soils over the past six years, which comprises 98% of the 780 issued patents issued in this field. As the trends in patent publication between China and the USA reveal, the soil remediation industry in China began 20 years later than in many developed countries. Soil remediation technology in the country developed rapidly as the number of related patents increased exponentially and is driven forward by world-leading R&D investment. In comparison, remediation technology has been well established in developed countries since the 1990s and the number of patents issued has gradually decreased in recent years. Meanwhile, the citation frequency of issued patents on remediation technology was 1.33—much lower than that in the USA and Canada. This statistic also reveals a lack of original techniques, innovation, and influence in the field of remediation technology for organic pollution in soils.

The top 10 patents output institutions were all from China, with 5 universities and research institutions and 5 companies represented (Table 2.2.2). The Qingdao University of

Technology has the largest number of issued patents, with 19 patents focused on the remediation of oil pollution and the combined pollution of heavy metal and organic pollutants. BCEG Environmental Remediation Co., Ltd., established in 2008, Jiangsu Suntime Environmental Remediation Co., Ltd., established in 2010, and Beijing Dingshi Environmental Engineering Co., Ltd. established in 2002, ranked second, third, and fourth respectively, and focused on equipment for ex-situ remediation. Institute of Applied Ecology at Chinese Academy of Science in Shenyang ranked fifth, specializing in the surfactant enhanced, phyto-microbial remediation of organic contaminated soils. Additionally, Zhejiang University, Institute of Soil Science at the Chinese Academy of Science, and Changzhou University ranked sixth, eighth, and tenth, respectively. As shown in Figure 2.2.1, there are no partnership among main countries/regions. As shown in Figure 2.2.2, there was no partnership between the universities, research institutions, and companies. The industry-university-research collaboration still faces significant challenges.

The issued patents over the past six years included remediation equipment for organic pollution in soils and soil additive. Microbial inoculant and composites (biomass and minerals, etc.) are main soil additives, others include biochar and nanomaterials. Remediation equipment for organic pollution in soils focuses on thermal desorption, microbial remediation, and enhanced solubilization-washing.

Table 2.2.1 Countries or regions with the greatest output of core patents on “remediation technology for organic pollution in soils”

No.	Country /Region	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	China	766	98.21%	1 015	90.95%	1.33
2	USA	4	0.51%	28	2.51%	7.00
3	Canada	3	0.38%	22	1.97%	7.33
4	South Korea	2	0.26%	1	0.09%	0.50
5	Australia	1	0.13%	47	4.21%	47.00
6	Ireland	1	0.13%	1	0.09%	1.00
7	Israel	1	0.13%	0	0.00%	0.00
8	Japan	1	0.13%	2	0.18%	2.00
9	Netherlands	1	0.13%	0	0.00%	0.00

Table 2.2.2 Institutions with the greatest output of core patents on “remediation technology for organic pollution in soils”

No.	Institution	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	UNQT	19	2.44%	1	0.09%	0.05
2	BER	14	1.79%	16	1.43%	1.14
3	JSER	13	1.67%	22	1.97%	1.69
4	BDEE	11	1.41%	62	5.56%	5.64
5	CSAE	11	1.41%	22	1.97%	2.00
6	UNZH	11	1.41%	53	4.75%	4.82
7	BGET	10	1.28%	0	0.00%	0.00
8	CISS	10	1.28%	47	4.21%	4.70
9	CMEG	10	1.28%	12	1.08%	1.20
10	UNCZ	8	1.03%	3	0.27%	0.38

UNQT: Univ. Qingdao Technological; BER: BCEG Environmental Remediation Co., Ltd.; JSER: Jiangsu Suntime Environmental Remediation Co., Ltd.; BDEE: Beijing Dingshi Environmental Engineering Co., Ltd.; CSAE: Shenyang Applied Ecology Inst.; UNZH: Univ. Zhejiang; BGET: Beijing Geoenviron. Eng. & Technology Inc.; CISS: Inst. Soil Sci. Chinese Acad. Sci.; CMEG: China City Environment Protection Engineering Co., Ltd.; UNCZ: Univ. Changzhou.

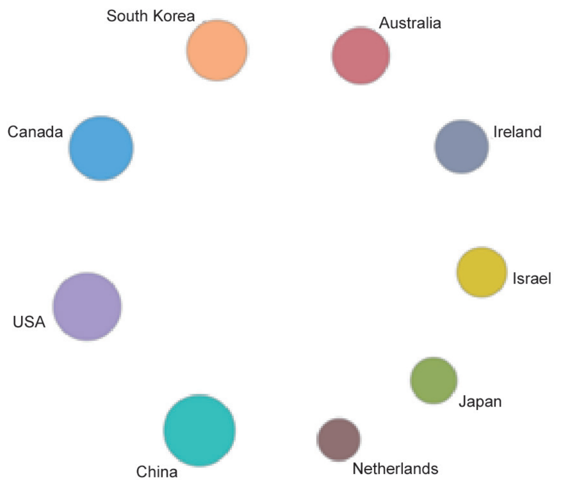

Figure 2.2.1 Collaboration network among main countries/regions on “remediation technology for organic pollution in soils”

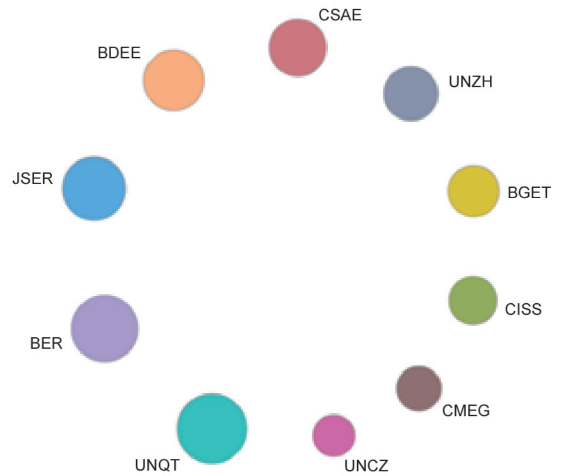

Figure 2.2.2 Collaboration network among main institutions on “remediation technology for organic pollution in soils”

Components were improved and optimized—using electricity, microwaves, solar energy, plasma or other technologies—in thermal desorption and vapor extractions to enhance the decomposition of organic pollutants; however, no mechanism innovation has been discovered. Biochar, nanomaterials, and degradable carbon sources have been used to enhance the mineralization of pollutants in microbial remediation, solubilization-washing, and phytoremediation. Furthermore, reaction conditions are optimized on the patents of chemical oxidation.

Combined remediation techniques have developed rapidly, especially since 2017. Patents for combined remediation techniques and equipment, such as the chemical oxidation-microbial degradation of organic pollutants, surfactant enhanced phyto-microbial remediation of organic pollutants, and electrochemical oxidation, have increased remarkably. These promising combined techniques would be more effective at remediating soils contaminated with a mixture of organic pollutants, and heavy metals, as well as soil-groundwater organic pollution. Developing these will be a future development trend in the field.

2.2.2 Automatic monitoring technology of remote sensing radar

In recent years, with the increasing frequency of extreme weather events, remote sensing radar data has had important applications for short-term disaster weather monitoring; however, some problems still persist. Further development is needed in the areas of the automatic monitoring technology of remote sensing radars and the level of radar and sounding intelligence. In addition, it is necessary to further improve the observation layout of weather radars by considering the diverse needs of water, civil aviation, and the military, and uniformly distributing weather radars throughout the country. Existing weather radar stations must be supplemented and improved, with particular emphasis placed on disaster-prone areas and the monitoring of new-generation weather radars in blank areas. At the same time, according to meteorological disaster prevention needs, all localities should coordinate the layout of local weather radar stations and other ground-based remote sensing observation facilities according to the unified observation methods, technical standards, and data format principles. They should also gradually unify the technical states and the use of remote control or pre-programming to achieve operation control, software upgrades, parameter modification, and online calibration to further enhance the adaptability of the devices’ observation modes. Using its automatic identification function, the equipment automatically adjusts the observation mode according to the external situation. Through these adjustments, it can alter the existing working mode, collect different observation factors from various weather phenomena, and carry out the experimental application of the intelligent observation mode. Through the development of aircraft meteorological observation capabilities and long-time patrol, high-performance, meteorological drones, airborne remote sensing can be carried out over high-altitude, unmanned areas and low-altitude substations. The construction of a special meteorological exploration aircraft with hurricane detection and meteorological satellite-borne flight functions will enable even more comprehensive observation in key areas.

The top 3 countries or regions with the highest number of patents on the engineering development front of "automatic monitoring technology of remote sensing radar" include the USA (126), China (5), and Finland (5), and the top 3 countries or regions with the highest citation frequency are the USA (4345), Finland (115), and Japan (86) (Table 2.2.3).

The top 3 institutions or enterprises with the highest number of patents include GOOG (11), MICT(7), and ITLC (6), and the top 3 institutions with the highest citations per paper are FITBIT INC (54.33), MICT (51.86), and ALARM.COM INC (44.33), which are all from the USA (Table 2.2.4).

Core patents on "automatic monitoring technology of remote sensing radar" are mostly from the USA. Although China is in second place, it is far behind the USA, which indicates that the country should increase investment in this research field and promote relevant research fields to accelerate development efforts in this area.

Figure 2.2.3 shows the collaborative network of the major

Table 2.2.3 Countries or regions with the greatest output of core patents on "automatic monitoring technology of remote sensing radar"

No.	Country/Region	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	USA	126	84.56%	4 345	85.48%	34.48
2	China	5	3.36%	62	1.22%	12.40
3	Finland	5	3.36%	115	2.26%	23.00
4	Canada	4	2.68%	59	1.16%	14.75
5	UK	4	2.68%	59	1.16%	14.75
6	Germany	3	2.01%	44	0.87%	14.67
7	Japan	3	2.01%	86	1.69%	28.67
8	South Korea	2	1.34%	36	0.71%	18.00
9	Switzerland	1	0.67%	38	0.75%	38.00
10	France	1	0.67%	43	0.85%	43.00

Table 2.2.4 Institutions with the greatest output of core patents on "automatic monitoring technology of remote sensing radar"

No.	Institution	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	GOOG	USA	11	7.38%	232	4.56%	21.09
2	MICT	USA	7	4.70%	363	7.14%	51.86
3	ITLC	USA	6	4.03%	149	2.93%	24.83
4	DEXM	USA	5	3.36%	171	3.36%	34.20
5	APPY	USA	4	2.68%	73	1.44%	18.25
6	OYNO	USA	4	2.68%	99	1.95%	24.75
7	ALARM.COM INC	USA	3	2.01%	133	2.62%	44.33
8	FITBIT INC	USA	3	2.01%	163	3.21%	54.33
9	FULL RECOVERY INC	USA	3	2.01%	72	1.42%	24.00
10	MEBX	USA	3	2.01%	52	1.02%	17.33

GOOG: Google Inc. or Google LLC; MICT: Microsoft Corporation; ITLC: Intel Corporation; DEXM: Dexcom Inc.; APPY: Apple Inc.; OYNO: Nokia Corporation or Nokia Technologies OY; ALARM.COM INC: Alarm.com Incorporated; FITBIT INC: Fitbit Incorporated; FULL RECOVERY INC: Full Recovery Incorporated; MEBX: State Farm Mutual Automobile Insurance or State Farm Mutual Automobile.

producing countries or regions of core patents with the engineering development focus “automatic monitoring technology of remote sensing radar”. Close relationships between the USA and other countries can be found; however, there is no research and development cooperation between individual institutes or enterprises in the field (Figure 2.2.4).

2.2.3 E-innovation of monitoring techniques for pesticide residues

The informationization of pesticide multi-residue monitoring technology includes three aspects: electronic detection technology, intelligent detection data analysis, and risk traceability visualization.

The residue of pesticide chemical pollutants has become one of the most pressing food safety issues around the world. The detection of pesticides in agricultural products sold in China is still widespread, and illegal and highly toxic pesticide residues are still threatening human health. At present, there are more than 1600 kinds of chemical pollutants, including pesticides and PCBs, that are currently detectable. The EU, Japan, and the USA have set strict maximum pesticide limits for 50 000 to 160 000 items and nearly 1000 types of pesticides. Traditional detection techniques and targeted detection methods based on physical standards can no longer meet the needs of current food safety risk monitoring. However, informationization monitoring technology based on accurate quality numbers and full spectrum scanning can accurately inform qualitative analyses of “Target”, “Non-Target”, and “Unknown” pesticides. Therefore, it is necessary to develop reliable informatization monitoring technology to screen the high throughput of chemical pollutants in food.

In view of the high degree of digitalization, informationization, and automation of high-resolution mass spectrometry detection technology, the resulting data exhibits the 4V’s of big data: large volume, variety, high generation velocity, and low-value density characteristics. This presents a significant challenge for the collection, processing, storage, and analysis of pesticide residue data. Therefore, to carry out fast and intelligent analyses of massive amounts of data, a detection technology platform that can be used for the collection, transmission, and statistical and intelligent analysis of pesticide residue data must be developed urgently.

In the context of the current big data era, it is important for the field of pesticide residue analysis to conduct research on the most effective methods for obtaining mass pesticide residue detection data and displaying them directly on a map in real time. Web-GIS technology combined with the application of data statistical analysis methods can innovatively use visual expression methods such as maps, statistical charts, and thematic maps to present the current situation of pesticide residues in China across multiple forms, perspectives, and levels. Using this program, a pesticide residue map can be created to provide an effective tool for tracking pesticide residue risk.

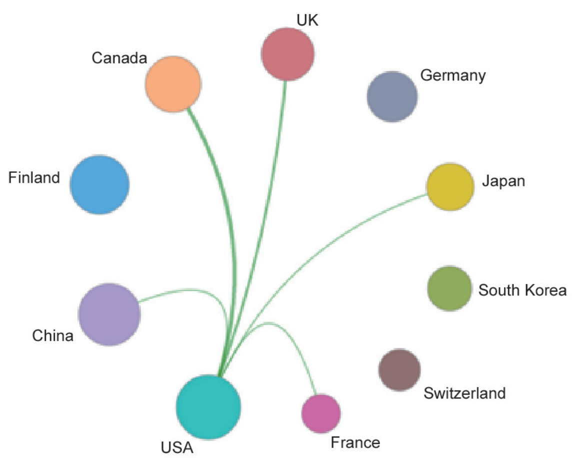

Figure 2.2.3 Collaboration network among major countries or regions in the engineering development front of “automatic monitoring technology of remote sensing radar”

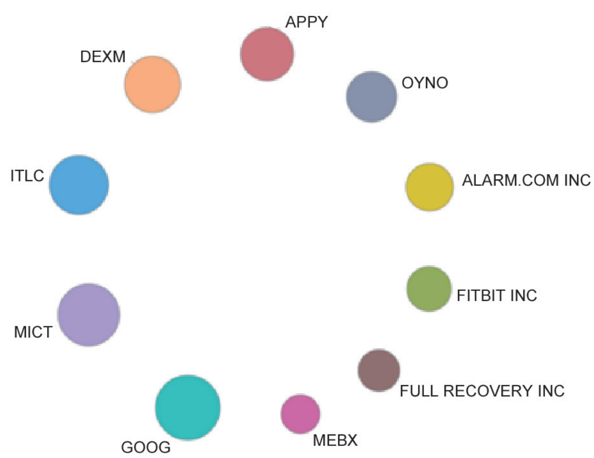

Figure 2.2.4 Collaboration network among major institutions in the engineering development front of “automatic monitoring technology of remote sensing radar”

(1) Electronic detection technology refers to the replacement of physical standards with electronic standards (retention time, first-order additive ion accurate mass, isotope distribution and abundance, and secondary fragment accurate mass and spectrum) to qualitatively determine “Target”, “Non-Target”, and “Unknown” pesticides. This will enable a shift from targeted detection to a non-targeted screening of pesticide residues.

A number of key technologies must be developed in this field. ① To establish a theoretical foundation for the high-throughput screening method, researchers must evaluate the mass spectrometric characteristics of 1200 pesticide chemical contaminants worldwide, establish the TOFMS, QE, and NMR accurate mass database, the fragment ion spectrum library, and the NMR library. ② Rapid pretreatment techniques for hundreds of pesticide chemical contaminants in plants, fruits, and vegetables must be established. ③ High-throughput screening methods capable of meeting the requirements of maximum residue limits (MRLs) in the EU, Japan, and the USA must be established to achieve a comprehensive screening of more than 1000 pesticide residues in the sample through one sample preparation and one sample injection—the method performance is unparalleled compared with traditional chromatography and mass spectrometry.

(2) Intelligent detection of test data: a pesticide residue data acquisition system and intelligent analysis system must be created to realize online data collection, result determination, statistical analysis and the automation of a “one-click download” report production.

A number of key technologies to be developed include: ① a basic database to provide the standard and scientific basis for analysis of the pesticide residue detection data and to determine pollution levels; ② the establishment of a data acquisition system to perform automatic uploading of test results, data preprocessing, and pollution level determination, and to build a database of pesticide residue detection results; ③ and the establishment of a data analysis system to correlate pesticide residue detection results database and the basic database, to achieve the automation of single-item and comprehensive statistical analysis of multi-dimensional pesticide residue data, and automation of the report generation of graphical results.

(3) Visualization of risk traceability: Pesticide residue electronic detection technology should be combined with Web-GIS technology to construct a visualization system for pesticide residue risk monitoring.

A number of key technologies to be developed include: ① the research and development of online mapping systems: Web-GIS technology combined with the application of data statistical analysis methods that can innovatively use visual expression methods such as maps, statistical charts, and thematic maps to present the current situation of pesticide residues in China across multiple forms, perspectives, and levels; and ② research and compile paper maps: systematic ideas should be used to integrate spatial information such as the spatial distribution of pesticide residues, types of pesticides, types of agricultural products, residues, toxicity, and conditions over the standards.

Presently, the detection technology of pesticide residues typically combines gas chromatography or liquid chromatography with a selective detector, and low-resolution primary mass spectrometry and secondary mass spectrometry. The common characteristic shared by these methods is that the qualitative identification cannot be separated from the reference of the standard sample. Besides, because of the limitations of the slow scanning speed and dwell time, about 100 compounds can be scanned each time; thus, it takes more than 6 iterations to finish the scanning of 500 compounds. Moreover, it is tedious to compile the data theory method for each collection method.

Statistical analyses of pesticide residues over the past 20 years show that the detection technology has developed from traditional chromatography and mass spectrometry to high-resolution mass spectrometry (HRMS). HRMS uses accurate mass measurements, combined with information on compound retention times and isotope abundance and distribution, to improve the qualitative identification of compounds and reduce the rate of false positives. In full scan mode, the qualitative points are higher than 10 and the sensitivity is high (≤10 μg/kg); it can be used for the rapid qualitative identification of compounds in a complex matrix and the detection of unknown compounds. A high scanning speed of four times per second allows for the simultaneous high-throughput screening of pesticides without being limited by the number of compounds. The identification of isomeric compounds is achieved through the determination of the differences in the species and the abundance of compound fragments. Thus, a clear trend in the field of pesticide multi-residue is to conduct detection based on the accurate mass number of HRMS without the qualitative control of standard samples.

Since 2009, Guofang Pang's research team at the Chinese Academy of Inspection and Quarantine has conducted HRMS in pesticide multi-residue analysis. ① GC/LC-Q-TOFMS has been developed to replace the traditional pesticide multi-residue method based on physical standards with a precise mass number, realizing a significant advancement in the development of pesticide residue detection technology from targeted detection to non-targeted screening. ② A platform for pesticide residue detection technology based on high-resolution mass spectrometry, internet, and data science ternary fusion technology was established. The real-time detection, data collection, management, and intelligent analysis of pesticide residues in edible agricultural products were realized, and the automatic generation of pesticide residue detection reports was achieved. ③ HRMS and GIS fusion technology were established, and a map for visualizing pesticide residue results was created. ④ Big data fusion technology was established to evaluate the risk and warning signs of dietary exposure to pesticide residues, and a special software for the automatic calculation of risk value and multi-dimensional information collection and analysis was developed. Furthermore, the comprehensive and rapid diagnosis of pesticide residue risk was realized. These achievements have initially solved the four major problems facing the field of pesticide residue research in China and provided technical support for the construction of a sound pesticide residue monitoring system.

As shown in Table 2.2.5, China (964), South Korea (20), and the USA (6) are the top three countries with the greatest output of core patents in the front of e-innovation of monitoring techniques for pesticide residues. As shown in Table 2.2.6, the three institutions with the greatest output of core patents are CAIQ (28), CNTA (19), and CAGS (15).

As shown in the collaboration network among major countries/regions in the development front of e-innovation of monitoring techniques for pesticide residues (Figure 2.2.5), cooperation exists between China and the Netherlands as well as Spain and the UK. As shown in the collaboration network among main institutions in this front (Figure 2.2.6), cooperation among the institutions or enterprises is weak or even barely exits.

Table 2.2.5 Countries or regions with the greatest output of core patents on "e-innovation of monitoring techniques for pesticide residues"

No.	Country/Region	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	China	964	96.40%	1 010	91.82%	1.05
2	South Korea	20	2.00%	36	3.27%	1.80
3	USA	6	0.60%	31	2.82%	5.17
4	Taiwan of China	3	0.30%	0	0.00%	0.00
5	Spain	2	0.20%	13	1.18%	6.50
6	Japan	2	0.20%	8	0.73%	4.00
7	Germany	1	0.10%	2	0.18%	2.00
8	UK	1	0.10%	0	0.00%	0.00
9	India	1	0.10%	0	0.00%	0.00
10	Netherlands	1	0.10%	4	0.36%	4.00

Table 2.2.6 Institutions with the greatest output of core patents on “e-innovation of monitoring techniques for pesticide residues”

No.	Institution	Country	Published patents	Percentage of published patents	Citations	Percentage of citations	Citations per patent
1	CAIQ	China	28	2.80%	5	0.45%	0.18
2	CNTA	China	19	1.90%	44	4.00%	2.32
3	CAGS	China	15	1.50%	50	4.55%	3.33
4	Beosen Jiangsu Food Safety Technology Co	China	14	1.40%	0	0.00%	0.00
5	Guangzhou Jindian Jingfang Pharm Co Ltd	China	12	1.20%	0	0.00%	0.00
6	XRES	China	11	1.10%	1	0.09%	0.09
7	Runtivo Biological Technology Beijing Co	China	9	0.90%	14	1.27%	1.56
8	UYJS	China	9	0.90%	5	0.45%	0.56
9	Qingdao Baolikang New Materials Co Ltd	China	8	0.80%	8	0.73%	1.00
10	UCAG	China	8	0.80%	17	1.55%	2.13

CAIQ: Chinese Academy of Inspection and Quarantine; CNTA: China National Tobacco of Chinese Academy of Agricultural Sciences; CAGS: Chinese Academy of Geological Sciences; XRES: Wuxi X Research Product Design & Research Co., Ltd.; UYJS: Jiangsu University; UCAG: China Agricultural University.

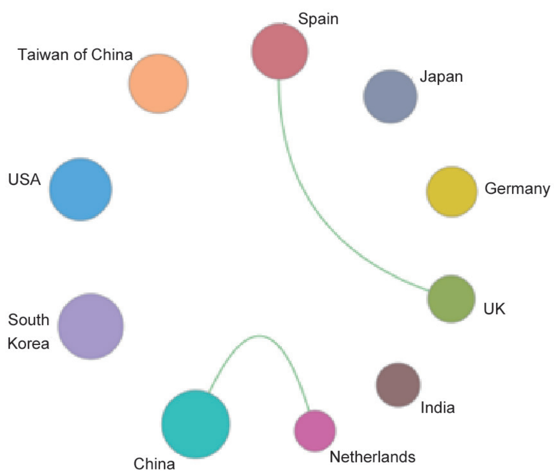

Figure 2.2.5 Collaboration network among major countries or regions in the engineering development front of “e-innovation of monitoring techniques for pesticide residues”

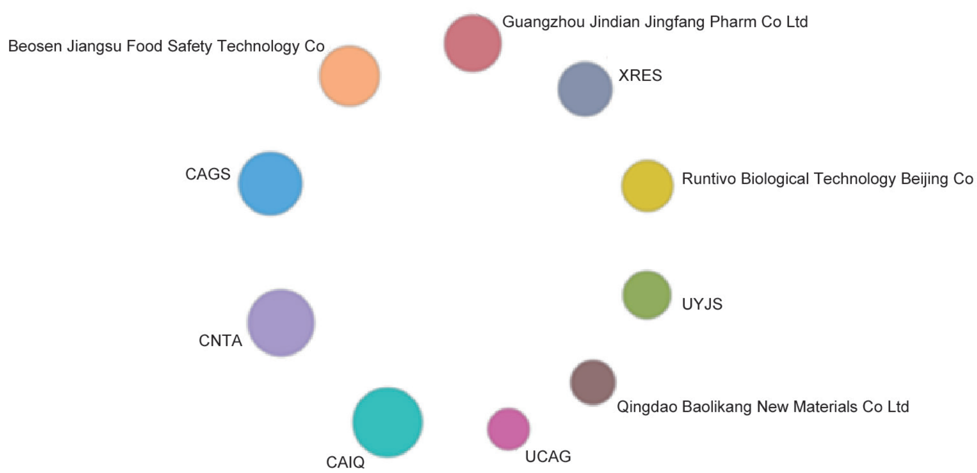

Figure 2.2.6 Collaboration network among major institutions in the engineering development front of “e-innovation of monitoring techniques for pesticide residues”

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