

Air-quality Sensors: Patent Portfolio and Technology Development

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Abstract—Air-quality sensors have become one of the most discussed topics in the field of energy management, but research on their patent portfolio is still lacking. This study explored the technological development and patent portfolio of air-quality sensors, investigated the air-quality sensors in major countries to identify the trends in their development, and provided suggestions in terms of policy making and industrial development. Data-mining methods, including correspondence analysis and K-means clustering, were employed in investigating the competitive and strategic-group relationships among major countries in air-quality sensor technologies. The results indicated that the countries vary in their technology positioning and patent portfolio, and suggestions for the air-quality sensor industry in terms of policy making and technology development are provided accordingly.

Keywords—air-quality sensor, patent portfolio, correspondence analysis, k-means clustering

I. Introduction

Air pollution harms human health and has become a major public concern [1]-[3]. Therefore, governments worldwide have sought improved air quality as a governance priority. Sensors have become increasingly sophisticated and have been integrated in everyday smart devices as part of the push toward the Internet of Things (IoT). Thus, scholars and practitioners have focused on developing air quality sensors [1], [4]-[5]. For governments, the optimal allocation of resources in support of key technologies depends on an understanding of the state of the art, which can be revealed through patent analysis.

Thus, the present study analyzed patents to characterize the state of air quality sensor technology in various countries; specifically, multidimensional scaling analysis and K-means clustering were used to determine competitive and strategic group relationships among major countries. The goals of this study are as follows: (1) to characterize the state of the art of mainstream air quality sensor technology, (2) to analyze trends in major patentee countries and identify different strategic groups, and (3) to compare these patentee countries with respect to their technological focus. Patent landscape analysis and multidimensional scaling analysis were conducted to clarify the correspondence between the patentee countries and air quality sensor technology. The results were visualized to illustrate the technological gap between competing countries. The findings aid governments in formulating policies on technical collaboration and scientific investment.

II. Literature Review

A. Importance of Air Quality Sensor Technology

IoT technology has matured, and sensors have become less expensive to deploy. Furthermore, the public's demand for information on daily air quality is increasing. The size of the market for air quality monitoring worldwide was valued at US\$4,178.5 million in 2020 and was projected to reach US\$8,032.6 million by 2030, for a compound annual growth rate of 6.7% from 2021 to 2030 [6]. By sensor type, the overall market is segmented into the markets for signal-gas monitoring sensors and multi-gas monitoring sensors. By application, the overall market is segmented into the markets for gas detection, particulate matter monitoring, outdoor air quality monitoring, indoor air quality monitoring, and other applications [6]. The main goal of air quality monitoring is to track the evolution of regional pollution sources, ambient air quality, and air pollutant concentrations; such information is key to evaluating efforts at improving air quality.

In particular, IoT-capable air sensors have undergone intense development worldwide as part of environmental monitoring networks in smart cities. Air quality monitoring has also become mandatory in increasingly stringent air quality regulations, such as the European Directive 2008/50/EC [7]. In general, air quality sensor technology is becoming increasingly prominent in the private and public sectors.

B. Patent Landscape Analysis

Patent analysis, primarily through public databases provided by the government, is conducted to understand the technical and legal state of an industry, to identify technological and investment hotspots, and to determine relationships between technologies. According to Stefano and Fabio [8], firms have incentives to intensify patenting and to use their intellectual property rights strategically, primarily as bargaining chips in negotiations.

Studies on air quality sensors have mostly focused on the technology itself [1]-[3] and have rarely explored the patent landscape in various countries. In general, the development of air quality sensors implicates many domains, such as IoT, artificial intelligence, and machining [1], [4]-[5], [9]. Thus, this study categorized patented technologies and compared countries with respect to their trends in the development of the technology. The patent

analysis findings were used to identify the main domains where air quality sensor technology has been applied.

III. Research Methods

A. Data Sources and Search Strategies

The United States is the world's largest commercial market and has a history of world-leading system development that can be traced back to 1975 [10]. Therefore, this study analyzed 212 approved patents published at any time from September 28, 2012, to September 28, 2021, in the United States Patent and Trademark Office database; these patents were searched for using the term "(TTL/air-quality sensor) or (ABST/air-quality sensor) or (ACLM/air-quality sensor)."

B. Correspondence Analysis and Cluster Analysis

Correspondence analysis involves the use of a low-dimensional space to illustrate the relationship between two or more categorical variables. It is a powerful multivariate statistical method that provides a graphical representation of multivariate categorical data from a large and complex dataset [11]. Correspondence analysis has been applied in a variety of fields ranging from epidemiology to the social sciences [12]. However, when there are too much categorical data to be separated and classified, these data cannot be easily graphed using correspondence analysis alone. Therefore, recent studies have used cluster analysis together with correspondence analysis [13]. This study employed two-step cluster analysis to classify patentee countries and International Patent Classification (IPC) codes. The coordinates obtained through correspondence analysis were classified through cluster analysis to determine the patent landscape and clusters among the countries.

In the correspondence analysis of air quality sensor technology, the categorical variables were patentee countries and IPC. A perceptual map was illustrated to identify (1) the relationship between countries (countries that are closer to each other exhibit higher technical correlations) and (2) the relationship countries and IPC (the closer a country is to an IPC code, the better the country's performance in the IPC category).

IV. Result Analysis

A. Patent Search Result

Before the correspondence analysis was performed, the patent search results were analyzed to clarify the overall trend of technological development. Table 1 describes the distribution of the top 10 IPC domains.

TABLE I. Top 10 IPC domains

Rank	IPC code	N	%
1	G08B	47	7.79%
2	H04L	45	7.46%
3	G01N	36	5.97%
4	H04W	32	5.31%
5	F24F	29	4.81%
6	G06F	27	4.48%
7	G05B	25	4.15%
8	H05B	20	3.32%
9	H04N	16	2.65%
10	A61B	16	2.65%

Note: One patent may have more than one IPC code.

Most of the air quality sensor patents were concentrated in G08D, H04L, G01N, and H04W. Under the definitions of the IPC patent categories, G08B refers to signaling or calling systems, order telegraphs, and alarm systems; H04L refers to technologies for the transmission of digital information; G01N refers to technologies for investigating or analyzing materials on the basis of their chemical or physical properties; and H04W refers to wireless communication networks. The most prominent patentee countries were the United States (158 patents), China (7 patents), France (6 patents), South Korea (4 patents), and Germany (4 patents).

B. Patent Portfolio Analysis

The air quality sensor patents spanned 116 IPC codes. To simplify the model, this study conducted correspondence analysis on the top 30 four-digit IPC classification codes and the top 10 countries. The results demonstrated that air quality sensor patents spanned a wide range of domains and that correspondence analysis can be used to analyze assignee countries and IPC categories. The optimal number of clusters was 4, and the IPC codes were classified into four categories through K-means clustering. After the correspondence analysis, the significant differences were identified in the overall model analysis ($\chi^2 = 313.879$, $p < .05$), indicating that patentees from different countries held different IPC patents. Figure 1 illustrates the layouts of patentee countries and IPC codes, and Table 2 lists the primary members of each cluster.

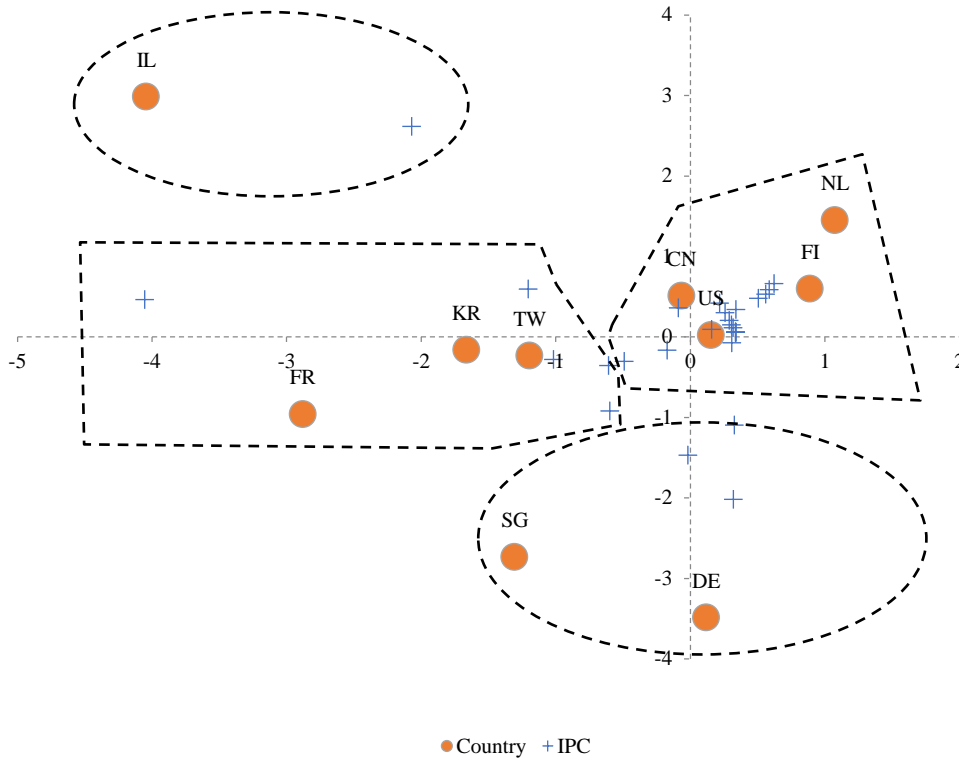


Figure 1 Air quality sensor patent landscape

TABLE III Primary members of each cluster

Group	Main members of groups
1	G05B, G06F, H04L, H04N, H04W, China, Finland, Netherlands, United States
2	A61B, A61M, B01D, G01N, H02J, France, South Korea, Taiwan
3	B60H, G01J, G01K, Germany, Singapore
4	A62B, Israel

Most of the patentees belonged to Cluster 1, whose primary technologies fell under categories G05B, G06F, H04L, H04N, and H04W. The countries included in this clusters were China, Finland, the Netherlands, and the United States. Accordingly, most of the countries were similar in their fields of development regarding air quality sensor technology, primarily control or regulating systems (G05B), technologies for electric digital data processing (G06F), technologies for electric digital data processing (H04L), technologies for pictorial communication (H04N), and wireless communication networks (H04W). France, South Korea, and Taiwan were similar in their technological focus, which centered on medical diagnosis (e.g., A61B and A61M) and the measurement and distribution of electric power (G01N, H02J). Germany and Singapore prioritized air-treatment devices specially designed for vehicles (B60H) and measurement technologies (G01J, G01K). Israel prioritized life-saving and fire-fighting technologies (A62B).

v. Conclusion and Recommendations

Correspondence analysis and cluster analysis were conducted to clarify trends in air quality sensor technology with respect to technology types and the patent landscape of

countries. Air quality sensor patents were concentrated in signaling or calling system (G08B), digital transmission (H04L), and measurement and wireless communication (G01N, H04W) technologies, indicating a focus on communication technologies. This is consistent with the trend of IoT technology being incorporated into air quality sensors [1], [4]-[5].

The patent landscapes of China, Finland, the Netherlands, and the United States centered on digital data processing, transmission, and wireless communication. Sensors are composed of core and peripheral signal components and are incorporated with wireless transmission technology and environmental monitoring platforms as part of an IoT system. The Smart America Project involves creating a “sustainability lens” by installing an air quality monitoring network, a host of sound sensors, and several microweather stations to measure the levels of environmental parameters in urban areas, such as the levels of particulate matter, noise, and traffic flow [14]; these data are then used to enhance sustainability and improve the living environment. France, South Korea, and Taiwan have focused their efforts on air quality sensor deployment and information transmission. These efforts address problems such as faulty power supply circuits, which cause batteries to become not chargeable after being depleted and thus result in data loss. Germany and Singapore have focused their efforts on vehicle-mounted sensors, and Israel has focused its efforts on disaster prevention technology, where data on pollutant levels (e.g., flammable aerosols) recorded by air microsensors and data on wind direction and wind speed are used for disaster prevention.

Urban governance is crucial to environmental sustainability given the increasing urbanization worldwide.

Advances in microsensor and IoT technologies have given governments a wealth of data to make cities smarter and more sustainable.

This study has several limitations that can be addressed in future studies. First, this study only focused on the United States Patent and Trademark Office database. Thus, future studies should analyze data from other patent offices such as the European Patent Office. Second, this study only focused on patentee countries. Thus, future studies can analyze other patent-related variables, such as patentees and inventors. Finally, future studies can also incorporate qualitative methods such as interviews or expert meetings to obtain more nuanced findings.

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