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Global Patent Analysis on Computer Vision Powered Crop Phenotyping

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Abstract. The objective of this work is to obtain the research trend and technical composition of computer vision powered crop phenotyping by analyzing related patents in a global scale. Based on the retrieved patent data, we analyze the global innovation distribution, research hotspots, major countries, and major patent applicants. It is revealed that the patents of computer vision powered crop phenotyping has been booming in the past two decades. With number of patent and patent applicant both rising steadily in recent years, this technology is still on a sharply growing stage. Results show that the total number of patents related to computer vision powered crop phenotyping is 3 765, of which 3 446 are invention patents. The top 3 countries by patent number are China, the United States and Japan. The vast majority of patents are owned by private corporations and universities, including several major applicants such as Pioneer Seed and Monsanto. Pattern recognition, image analysis, sensor application and computational models are among the research hotspots. This study presents a panoramic view of the global patent on crop phenotyping, and provides references for the research layouts and innovation decision-making organizations.

Keywords: data mining and processing, computer vision, patent analysis, crop phenotyping

1. Introduction

Due to global climate change, fast rising population and natural resource shortage, there is an increasingly urgent need in improving crop yield and quality for the upcoming decades [1]. Of all the practical ways to increase crop yield and quality, genetic improvement offers a promising, efficient and sustainable solution [2]. The rapid development of high-throughput sequencing provides economical and efficient genomic information, which greatly accelerates the mining of genes regulating important traits of crops. However, due to the complexity of plant phenotype, the variability affected by the environment and the dynamic change of the whole process, crop phenotyping research seriously lags behind the genotype research [3].

Crop phenotyping technology based on computer vision is a major solution to high throughput plant phenotypic determination. The state-of-the-art computer vision technology, which incorporates imaging technique and analyzing methods, has powered many infrastructure platforms specifically designed for crop phenotyping [4]. Crop phenotypic performance involves a complex interaction between genotypes and environmental factors, which include climate, soil factors, abiotic/biotic factors, and crop management methods [5]. Highly automated crop phenotyping combined with genomic information can cultivate crops with higher yield, better quality and more stress tolerance, so as to greatly improve the efficiency of crop breeding and improvement [6].

Previous reviews and analysis have been focused on the published academic papers [7-8]. However, the advancement of crop phenotyping technology is not confined to academic research. Instead, research innovations from global industrial corporations also contribute a lot, which is clearly revealed by patent data. Patent analysis is to collect and examine a large amount of targeted patent documents, and use statistical methods or technical means to have the function of overview and prediction. In this paper, we provide an overview of global crop phenotyping research based on a comprehensive study of related patent data.

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2. Global Patent Retrieval

The patent data used in the research comes from PatSnap global patent database, which has more than 170 million global patent data, covering more than 158 countries/regions. In order not to omit any patent documents related to computer vision powered crop phenotyping, the search scope includes not only title, but also abstract and claims of patent document. Since the crop phenotyping involves a large variety of crops, the keyword of crop is extended to major crop species. To avoid unrelated patent retrieval, international patent classification (IPC) is introduced to narrow the search scope. Both keywords and IPC are used.

The database search formula is: ((TAC:(crop OR plant OR rice OR wheat OR barley OR corn OR maize OR soybean OR cotton OR tobacco OR potato) AND TAC:((phenomics OR phenotype OR phenotyping) OR ((grow OR growth) AND (image OR picture) AND (analyse OR process OR estimate))) AND MIPC:(A01G OR A01D OR A01C1 OR A01B OR B07C OR B25J OR B65G OR B61J OR B62D OR G01B OR G01C OR G01D OR G01S OR G01N OR G01J OR G01G OR G03B OR G05B OR G05D OR G06F OR G06T OR G06K OR G06Q OR G06M OR G16B))). The data retrieval date is April 30, 2022.

For the initial data retrieval obtained by search formula, the result is then cleaned manually to remove irrelevant patent documents. Finally, 3 765 patent documents from 50 countries or regions are retrieved for further analysis in this paper.

3. Patent Data Analysis

Based on the retrieved data, a comprehensive patent analysis is carried out from multiple perspectives including patent quantity and type, temporal variation, technology life cycle, global distribution of innovation, application composition and ranking, innovation hotspots.

3.1. Patent Quantity and Type

The total number of patent application related to computer vision powered crop phenotyping is 3 765, of which 3 446 are invention patent and 319 are design patent. Results show that invention patents account for 91.5% of the total number of patents.

3.2. Temporal Variation

From temporal perspective, crop phenotyping patent has been booming for the recent two decades. The overall development could be clearly divided into three periods. Period one includes the years before 2009. During Period one, crop phenotyping technology develops slowly but steadily. Period two is from 2009 to 2013. During Period two, the patent application has been increasing very rapidly compared with Period one. The average number of patent application in Period one is 13.7, while the number in Period two is 82.0. Period three includes the years after 2013, especially from 2015 to 2020. In 2015, the global patent application number related to crop phenotyping is 198, while the application number jumps up to 650 in 2020. Due to patent disclosure procedures in many countries, the patent documents after 2020 is not completely retrieved, causing an abrupt drop of number in 2021 and 2022. It is clear that crop phenotyping is still on a sharp rising period. The temporal variation of crop phenotyping patent application number from 2003 to 2022 is shown in Fig 1.

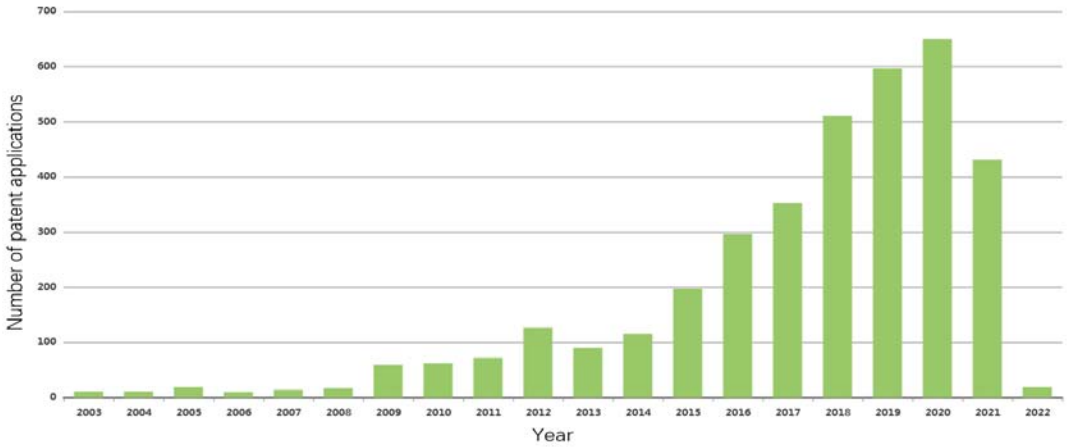

Fig. 1: Temporal variation of crop phenotyping patent application number.

3.3. Technology Life Cycle

From technology life cycle perspective, crop phenotyping is also in a rapid development stage. Results show that since 2013, the number of both patent application and applicants has been rising year by year. In 2013, the number of patent application is 90, while the number of applicants is 76. In 2020, the number of patent application is 650, while the number of applicants is 483. Within 7 years, the number of patent application has risen by more than 6 times, while the number of applicants more than 5 times. These numbers show that crop phenotyping is attracting more and more technical R&D personnel. The technology life cycle diagram of crop phenotyping from 2013 to 2020 is shown in Fig 2. It is also clearly shown in the diagram that there is a noticeable increase in number of applicants in 2020 compared with former years, which indicates technology innovation activity is still very active in latest years.

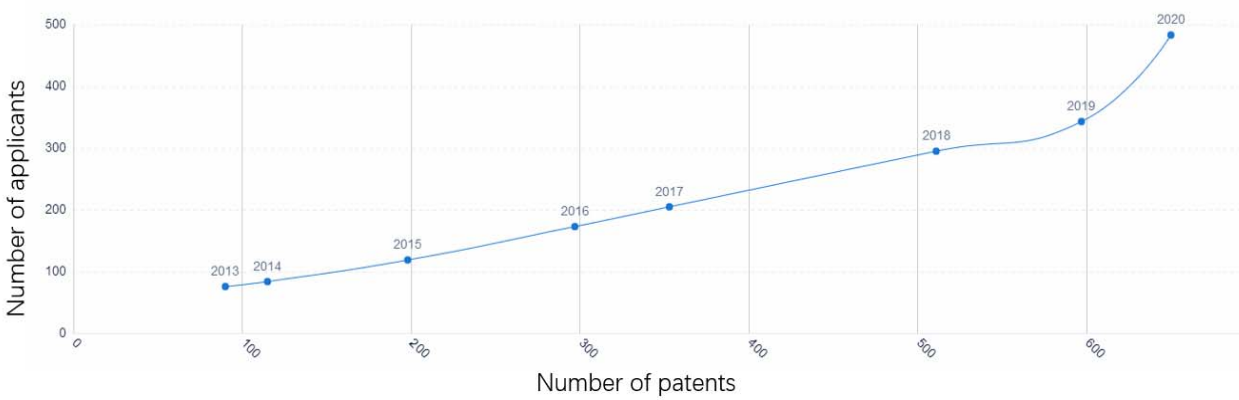

Fig. 2: The technology life cycle diagram of crop phenotyping from 2013 to 2020.

3.4. Global Innovation Distribution

Through the analysis of crop phenotyping patent applications in different countries/regions around the world, we can have an overview of the global development distribution of this technology. Based on the retrieved patent data, crop phenotyping patents are mainly distributed in China, the United States, Japan, Europe and South Korea. Among them, the cumulative number of related patent applications from China is 1 895, ranking the first in the world. The number in the United States is 1 072, ranking the second. The number in Japan is 255, ranking the third. The number in Europe is 124, ranking the fourth. The number in South Korea is 96, ranking the fifth. This shows that technology innovation of crop phenotyping is mainly from East Asia, Europe and the United States.

Concerning the patent layout distribution, results show that innovators are mostly interested in applying patents in the bellowing targeted countries/regions: China, the United States, Europe, Japan, Australia, Canada, South Korea, India and Brazil. This shows that technology markets from these countries/regions are more active and highly valued by innovators.

3.5. Application Composition and Ranking

In order to better understanding the technology innovation organization and personnel in crop phenotyping, we analyse the applicant composition of all retrieved patents by classifying all applicant into five major types: private corporation, university & institute, individual, government branch and others. Results show that private corporation and university & research institute have applied for or owned the majority of patents in this field, with the former taking 60.8%, and the latter taking 34.8% of all patent applications. Innovation in crop phenotyping requires substantial amount of material resource and consistent investment, which could explain why the major applicants are large corporates.

A deeper analysis of the retrieved patents reveals that the top 10 applicants are all from the United States and China. According to the ranking order of the number of applications from high to low, top 10 applicants are listed as below: Pioneer Hi-Bred International, Monsanto Technology, Nanjing Agricultural University, Beijing Research Center for Information Technology in Agriculture, The Climte Corporation, X Development, Zhejiang University, Grow Solutions Tech, Nanjing Huitong Phenomics and Huazhong Agriculture University. For the top 10 applicants, more detailed information is shown in table 1.

Compared with the other applicants, Pioneer Hi-Bred and Monstanto Technology both have a long history of technology innovation in crop phenotyping, with the application time span covering nearly 20 years. The newly-joined applicants include Nanjing Agricultural University, X Development, Grow Solutions Tech and Nanjing Huitong Phenomics, of which the recent 5 years application percentage exceeds 85%, showing that these corporates have significantly increased their innovation activity on crop phenotyping in recent years.

Table 1: Top 10 patent applicant in crop phenotyping

	Country	Patent number	Application time span	Applications in recent 5 years	Valid Patent number
Pioneer Hi-Bred	U.S.	100	2001-2020	13 (13.0%)	38
Monsanto Technology	U.S.	87	1993-2020	20 (23.0%)	16
Nanjing Agricultural Univ.	China	83	2012-2021	79 (95.2%)	46
Beijing Res. Center ITA	China	69	2008-2021	41 (59.4%)	42
The Climte Corporation	U.S.	54	2015-2021	30 (55.6%)	15
X Development	U.S.	45	2015-2021	39 (86.7%)	12
Zhejiang Univ.	China	45	2010-2021	28 (62.2%)	18
Grow Solutions Tech	U.S.	44	2017-2021	43 (97.7%)	3
Nanjing Huitong Phenomics	China	43	2019-2020	43 (100.0%)	24
Huazhong Agri. Univ.	China	38	2013-2021	28 (73.7%)	14

3.6. Innovation Hotspots

The International Patent Classification (IPC) of all retrieved patent documents are analysed to understand the research hotspots of crop phenotyping innovation. Results show that G06K9, G06T7, G06Q50, G01N21, A01G7, A01G9, G01N33, G06Q10, G01D21and G06N3 are the top 10 IPCs, which means that these technical branches are among the research interests of crop phenotyping innovation. All detailed technical meanings of the IPCs are listed below.

- G06K9: Methods or arrangements for recognizing patterns
- G06T7: Image analysis
- G06Q50: Systems or methods specially adapted for specific business sectors
- G01N21: Investigating or analyzing materials by the use of optical means, i.e. using sub-millimeter waves, infrared, visible or ultraviolet light
- A01G7: Botany in general
- A01G9: Cultivation in receptacles, forcing-frames or greenhouses
- G01N33: Investigating or analyzing materials by specific methods not covered by groups
- G06Q10: Administration; Management
- G01D21: Measuring or testing not otherwise provided for
- G06N3: Computing arrangements based on biological models

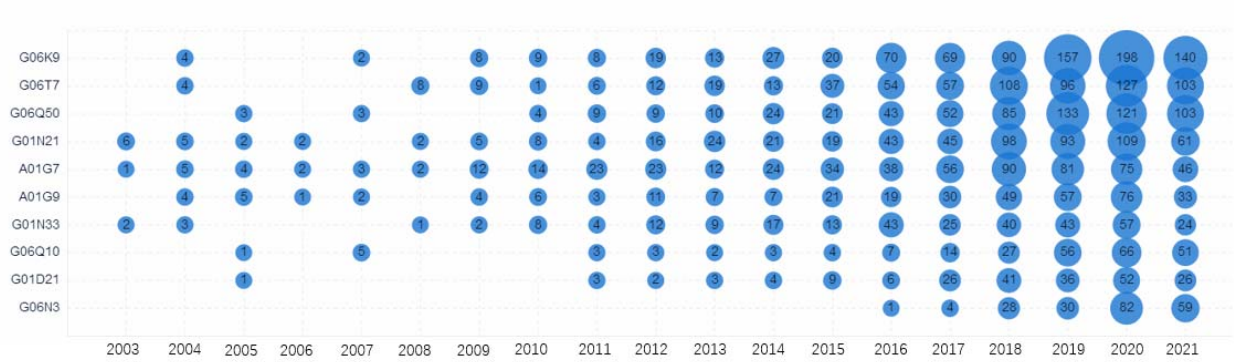

Fig. 3: Temporal variation of crop phenotyping innovation hotspots

The temporal variation of crop phenotyping innovation hotspots is shown in Fig 3. In recent 5 years, the patent application related to G06K, G06T7, G06Q50 and G01N21 have significantly multiplied. This shows that innovation hotspots of crop phenotyping are highly focused on pattern recognition, image analysis and sensor application. G06N3 indicates a newly emerging innovation hotspot, as computational models are increasingly applied in crop phenotyping. This has much to do with the fast-developing technology in artificial intelligence and neural network. Though the number of other IPC patents have also increased to a certain degree, yet the increase rate is not as noticeable as the above four IPCs patents.

4. Conclusion

The total number of patent application related to computer vision powered crop phenotyping is 3 765, of which 3 446 are invention patent. Invention patents account for 91.5% of the total number of patents. From temporal perspective, crop phenotyping patent has been booming for the recent years, especially after 2014. Since 2013, the number of both patent application and applicants has been rising year by year, indicating that crop phenotyping is attracting more and more technical R&D personnel. Crop phenotyping technology innovation are mainly distributed in China, the United States, Japan, Europe and South Korea. Private corporation and university & institute have applied for or owned the majority of patents in this field. The top 10 applicants are all from the United States and China. Pioneer Hi-Bred and Monstanto Technology both have a long history of technology innovation in crop phenotyping, with the application time span covering nearly 20 years. The newly-joined applicants include Nanjing Agricultural University, X Development, Grow Solutions Tech and Nanjing Huitong Phenomics, of which the recent 5 years application percentage exceeds 85%, showing that these corporates have significantly increased their innovation activity on crop phenotyping in recent years. From the innovation hotspots perspective, pattern recognition, image analysis, sensor application and computational models are highly focused for computer vision powered crop phenotyping. Computational models are increasingly applied in crop phenotyping in recent few years.

5. Acknowledgements

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