Journal of Intellectual Property Rights
Vol 29 July 2024, pp 276-284
DOI: 10.56042/jipr.v29i4.1158

Patent Analytics of Internet of Things (IoT) based Technologies for Smart Greenhouses

Manju Gerard[1†], Monika Gupta[2], R Kalpana Sastry[3] and K Srinivas[1]

[1]Intellectual Property & Technology Management (IP&TM) Unit, ICAR, New Delhi —110 012, India

[2] ICAR-National Academy of Agricultural Research Management, Hyderabad—500 030, India

[3]AgHub, Professor Jayashankar Telangana State Agricultural University Rajendranagar, Hyderabad— 500 030, India

Received: 3rd May 2023; revised: 22nd May 2024

Digitalization has led to manifestation of many novel technologies for predictive and prescriptive analysis in agriculture sector. One of the potential technologies is IoT (Internet of Things) with dynamic innovations for multiple applications in farming. IoT enabled smart greenhouses have increased market potential as these controlled systems help in monitoring a microclimate environment for crops, nutrient management and yield remotely. The current study depicts a systematic approach to assess the trends in IoT based smart greenhouses using patent analytics. Trends indicate a surge in patent filing in IoT based devices in agriculture from 2014 onwards with China in lead and the spread more in private firms than in public universities.The study shows the temporal trends, patent timeline, identity of applicants etc. and provide insights about the development of most relevant IoT technologies for smart greenhouses.

Keywords: Internet of Things, Patent analysis, Innovation, Smart Greenhouses

Digitalization of technologies has revolutionized the system of agriculture paving the way for manifestation of dynamic innovations in this sector. The 'Internet of Things' is one of the promising technologies of the last decade, capable of offering innovative solutions towards modernisation of agriculture.[1-4] Applications of IoT are redefining modern agriculture in a way that now it has started becoming an indispensable part of every commercial farmland.[5] Increased data availability due to IoT provides improved decision-making and strategy development opportunity in agriculture. Some of the technology led devices associated with this include Bluetooth, Wireless Sensor Networks (WSN), Radio-frequency Identification (RFID), Near–field communication technologies (NFC), Long Term Evolution (LTE) and numerous other smart communication technologies.[6-8]

Technology revolution in Agriculture @ 1.0, started with animal power when farming was labour intensive and locally adopted with the productivity less than 1.2t/ha.[9] Between 1960-90 Agriculture @ 2.0, was influenced by the use of machines in irrigation, chemical fertilizers and quality seeds and the productivity increased to 1.6t/ha. Gradually, the productivity has risen to 2.5t/ha with the use of hybrid seeds, Genetically Modified (GM) seeds, improved chemical fertilizers, micro-irrigation system, improved pesticides etc.[10-11] From 2020 onwards, use of sensors for irrigation requirement, pest forecasting, use of biotech seeds, Marker Assisted Selection (MAS) etc. has led to increased productivity of 3.1t/ha. The use of IoT platforms and the ICT ecosystems have helped farmers to make better use of resources.[12-13] However, challenges of food scarcity has driven to Agriculture @ 4.0, wherein cross industry knowledge and applications in Artificial Intelligence (AI) and precision farming are providing technological solutions.[14-15] The accuracy in precision agriculture for increased efficiency has helped in managing the costs also.[16-18] The chronology of the technological evolution in agriculture is shown in Table 1.

Some of the major applications of IoT include resource management, real-time crop health monitoring and forecasting stress and yield estimations, etc. achieved by specific sensors (Fig. 1). Coupled with big data, IoT provides crop specific customized solutions to farmers for precise crop management practices. Apart from these applications on standing crops, IoT solutions adopted significantly for cultivation in controlled environment or

†Corresponding author: Email: manju.gerard@icar.gov.in

Table 1 — Technological evolution in agriculture

Time line	Technology version	Productivity	Technology usage	Reference
Before 1960	Agriculture 1.0	Less than 1.2 t/ha	Seeds from farmers exchange, FYM as nutrient supplement, harvesting and threshing in local tools etc.	Adam Cagliarini and Anthony Rush (2011)
1960-1990	Agriculture 2.0	1.6 t/ha	High yielding varieties, Use of chemical fertilizer, Irrigation system development	Pathak H, Mishra JP and Mohapatra T (2022)
1990-2020	Agriculture 3.0	2.5 t/ha	Hybrid seeds, GM seeds, Improved chemical fertilizer, Micro-irrigation system, improved pesticide	Pathak H, Mishra JP and Mohapatra T (2022)
2020 Onwards	Agriculture 4.0	3.1 t/ha	User of Sensors for irrigation requirement, pest forecasting, use of biotech seeds, MAS etc.	Gustavo A. Mesías-Ruiz, María Pérez-Ortiz, José Dorado, Ana I. de Castro, and José M. Peña (2023)

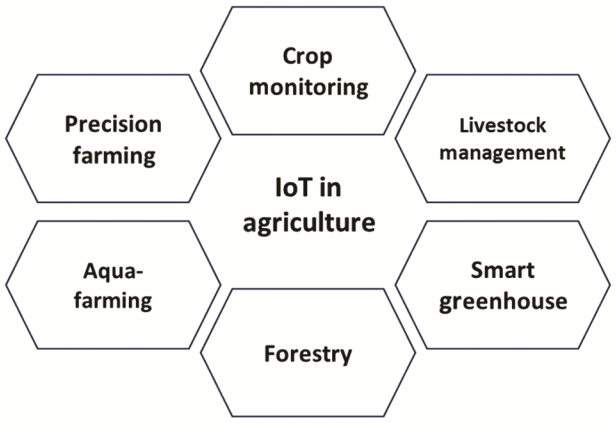

Fig. 1 — Potential applications of Internet of Things (IoT) in agriculture and allied sectors

greenhouses, over the years have evolved into commercial farming structures, more than just being experimental chambers.[19]

IoT enabled smart greenhouses are adopted in modern farming to improve agricultural yields with limited resources and increased requirements to protect crops from unexpected climatic changes. These controlled systems help in maintaining a microclimate environment for crops, yield monitoring, water and nutrient management with minimum human intervention. Simultaneously, increased demand for quality products has influenced development of hydroponics and new technological developments in this field. Countries in Europe, such as the Netherlands, Spain, and Italy and Israel where agriculture sector is highly professional and technologically advanced have large areas under greenhouse cultivation. The value of the global smart greenhouse in 2019 was at $1.37 billion and estimated to reach $3.23 billion by 2027, rising at a CAGR of 11.4% from 2020 to 2027.[20] This market is further bifurcated into hydroponic and non-hydroponic type based on type, component, end user and region. On the basis of components, it is divided into LED growth lights, irrigation system, valves and pumps, heating, ventilation and air conditioning (HVAC) systems, sensorand control system and others.[20] Many of these technologies are patent protected indicting its commercial importance in the intelligent greenhouse monitoring market.

Significant advances made in the area of patent analytics helps in analysing enormous amount of Intellectual Property (IP) data, in relation to other information sources to analyse the trends and the relationships. In order to make informed decisions by the decision makers, patent analytics provide highly detailed, accurate and actionable insights. The overall objective of this study is to decipher technology development in the field of precision agriculture using tools of patent analytics. Increasing numbers of patents of IoT led technologies applied in specific domain of cropping under controlled environmental conditions[21] form the base of this study.

Patents related to IoT applications with special reference to crop plants in closed environment is searched from Orbit Intelligence.[22] A set of subject specific keywords and standardized search strings are identified; truncation, appropriate Boolean operators are used for preparing standardized search strings and selected keywords to perform search of patents. The keywords used in patent search is shown in Table 2. Retrieved relevant records are then subjected to full text search of patents (patent title, abstract andclaims) analysis through IPC (International Patent Classification). The patent review process shown in Fig. 2 has been carried out in accordance with the PRISMA[23] statement following a 3-step process including searching, refining and filtering. An initial patent search on Questal database

Table 2 — Keywords used in patent search

Category	Keywords
Technology	Search (Internet ofthings or Cloud Server or Networking technology or IoT or Internet technology or Sensor network or Intelligent" sensing or IoT network or IoT circuit or IoT environment or Internet of things basis or Technical element" or Sliding window superposition coding or Hybrid fsk or Ultrahigh Density Network or Advanced coding or Digital Education or Safety related service or Node card or Non orthogonal multiple or 5G Communication technology or IoT gateway or Wireless data commercialization or Smart card car or life human intelligent service or Smart" card" car node or Image processing or Monitoring system) AND (Close or Control or Greenhouse or Glasshouse or Polyhouse or Vinylhouseor Arch shelter or Shade or Shed or Sun room or Solar house or Glass roof) (Title, Abstract, Claims)
IPC Groups	Search (A01G OR A01C OR A01D OR A01B OR A01H OR A01N OR A01P)

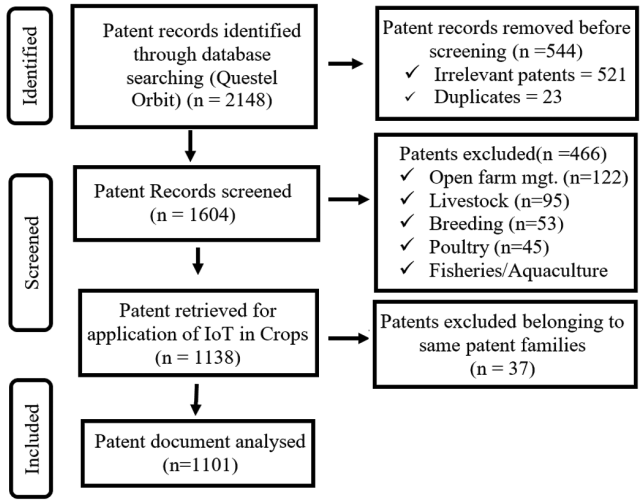

Fig. 2 — Patent review process in accordance with PRISMA[23] flow diagram

gave a total of 2148 patents. The search result was further refined based on criteria relevant to IoT applications. A total of 544 patents were removed as they were deemed irrelevant. All the search results were combined and replicas removed and temporary work sheet was exported in CSV format. A set of 1138 patent documents retrieved belonging to 1101 patent families and only one priority member per FAMPAT family was analysed.

Results & Discussion

Bibliographic Analysis

Patent Timeline

Timeline analysis performed using priority year, indicates inventive undertakings starting from 2004. It was observed that IoT applications in agriculture are relatively new as major surge in filing is seen from 2014 onwards.[24] There was a six-fold increase in patent filings from 2014-2018 (Fig. 3). This rise in the number of patents corroborated with the increased use of ICT, sensors, guidance systems in the evolution of agriculture 3.0. The increase in patenting rate is interpreted as significant though the divisional applications and patent families are not been taken in account. The data suggest intensified technological and economic attention in the technology. Increase in patenting rate could have significant implications for competitive strategies. It was observed that early patent applications have wider claims but recent ones navigate in a more crowded space with narrower claims. This may lead to establishing increasing inter-dependency among key patent portfolio owners and prompt the need for new collaborations.

Distribution of Patents in Leading Countries

All retrieved patent documents classified are based on priority country of filings. It was interesting to observe that in the IoT based applications in controlled/protected environment in agriculture sector, China is dominating with 93% of applications filed in China as priority country (Fig. 4). These patent applications from China are mainly restricted to its own jurisdiction, with only few applications filed in other countries.In a study, Freidman[25] has reported that China may emerge as a worldwide leader in innovation and adoption of IoT. In comparison to patent filings of US (1065) and German inventors (441), Chinese inventors filed about 2541 IoT based patents.[26] Ardito *et al*.[27] have also reported this intensive patent filing trend by China in the area of IoT. In order to create an appropriate environment for support of the IoT innovations, the proactive policies of Chinese government and other interventions have played a key role.China's five-year plan (2011–2015) comprised IoT as a national strategic priority played crucial role. Technologies and expertise provided by foreign multinationals have also influenced the IoT based innovations especially in the area of agriculture and environment.[28-29] Specially designed policies targeted at fostering R&D efforts in the IoT domain, and investing about $800 million by People's Republic of

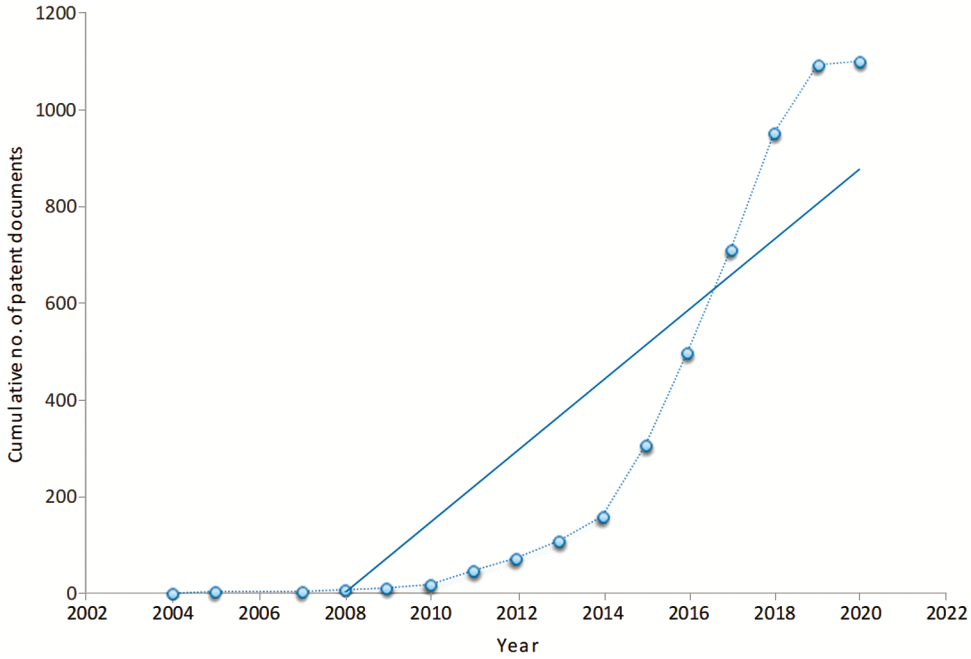

Fig. 3 — Year-wise filing of patents (n=1101, one priority document per family) from2004-2018

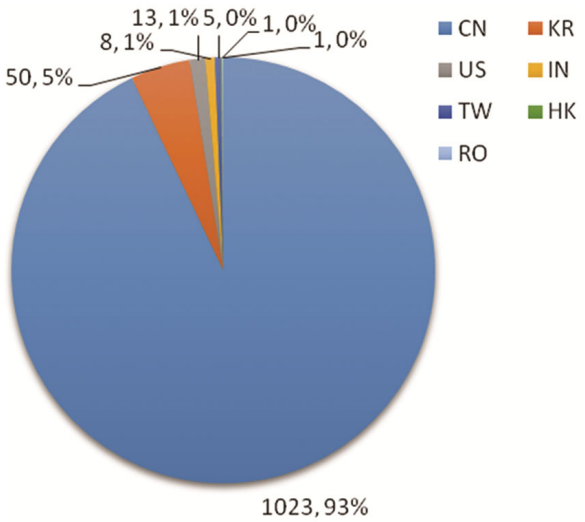

Fig. 4 — Distribution of patents based on earliest priority country (n=1101)

China may have led to the surge of Chinese patents.[30] After China, Korea follows with 5% patent documents, out of 1103, filed in South Korea as priority country followed by US and India.

Patents based on Jurisdiction

A summary of patent documents classified based on jurisdiction is shown in Table 3. It was interesting to observe that the maximum filings are in China (1029) followed by South Korea (50) and US (21). India ranks fourth in the list with (12) documents. Only seven (7) patents out of 1029 patents of China have been filed in other jurisdictions (Table 4). This may be attributed to the defensive strategy by China in this sector.

Innovative Organizations

Patent data was analysed based on the profile of the assignees. The assignees include both public and private organizations, including individual inventors. It was evident from the data that the patent race dynamics is distributed more in private than academic sector. Further, it was observed that the entry of individual applications is increasing IP claim by potential startups. This development is likely to have a noteworthy impact on the nature of the business deals as well as shaping the nature of patenting and technological trajectories. Ardito *et al.,*[27] reported a similar trend of central role of profit-oriented organizations as catalysts of innovative effort in this domain. Figure 5 shows the top ten assignees in the IoT sector in smart greenhouses.

Legal Status of Patents

Legal status of patents shows nearly 33% pending applications, while 30% are granted (Fig. 6). As this technology is relatively new in agriculture sector, no expired patents were seen. Since the results earlier indicated the initiation of these technologies in agriculture from 2014 only, there was no data set of

Table 3 — Patents based on jurisdiction (n=1138)

Country	No. of patent documents	Country	No. of patent documents	Country	No. of patent documents
China	1029	Taiwan	5	Russia	1
South Korea	50	Europe	2	Japan	1
United States	21	Canada	2	Mexico	1
India	12	Romania	1	Hong Kong	1
WIPO	12				

Table 4 — List of Chinese patents filed in other jurisdictions

S. No.	Publication Number	Priority Country	IPC	Assignee	Other Jurisdictions
1	CN201510317290	CN	A01G9/26	Xiaomi Tech	IN, RU, JP, MX, KR, EP, US, WO, CN
2	CN201510699411	CN	A01G9/02	Liu Zixue	CN, WO
3	CN201110355839	CN	A01G31/047	Luo Yi	WO, CN
4	CN201510151450	CN	A01G25/16	Chengdu Huinong Information Technology	WO, CN
5	CN201810106695	CN	A01G25/16	Boe Technology	WO, CN
6	CN107272620	CN	G05B19/4183	Shenzhen Shenglu IoT Communication Technology	WO, CN
7	CN102445933	CN	A01G9/24	Lan Yuqing, Lan, Zehua	US, CN

IN (India), RU (Russia), JP (Japan), MX (Mexico), KR (Korea), EP (European Patent Office), US (United States), WO (WIPO), CN (China)

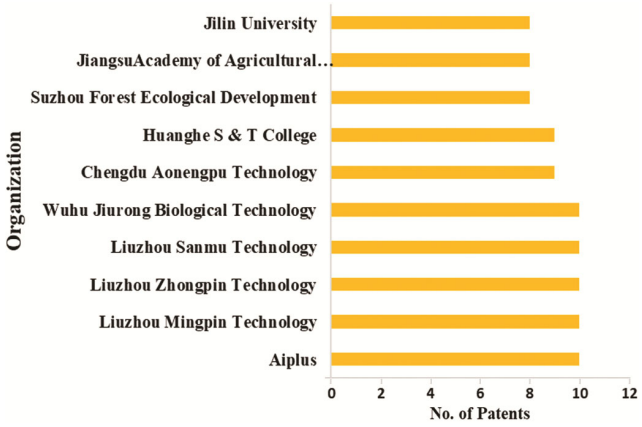

Fig. 5 —Top ten players in the market of IoT based patents in smart greenhouses

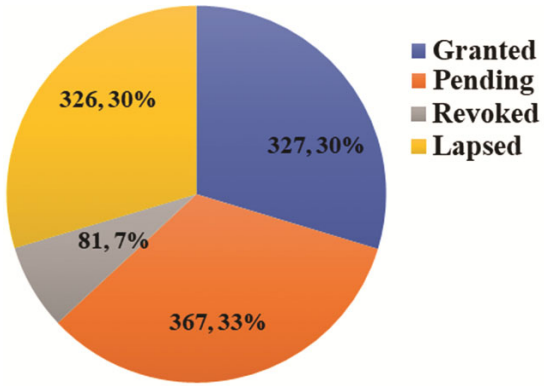

Fig. 6 — Distribution of patents based on their legal status (n=1101)

anyexpired patent. The comparatively high number of lapsed patents (n=326) may also indicate the defensive approach of China in filing patents as post filing exercises are not followed up very enthusiastically. It appears that the strategy of China is to set international standards for new IoT based technologies to be in leading position[31] and strengthen the IPR landscape to reduce the dependency on foreign IP for core technologies.[32] The $800 million investment in IoT solutions by People's Republic of China and identifying IoT as an 'emerging strategic industry' corroborate their intention of becoming front-runners at the global level.[33]

Technology Analysis

Citation Analysis

Technological evaluation of patents has been often done by citation analysis; count of forward citations gives a measurement of strength of the present innovation that provides base to building of new future technologies. Few of the highly cited patents in our dataset is indicated in Table 5. The most cited patent, "Internet of things-based farm greenhouse monitor and alarm management system" (Publication No. US8643495) describes the system that can automatically collect greenhouse environmental parameters such as humidity, temperature, light, soil temperature and soil moisture etc. and can evaluate the critical value of every parameter and alarm the

Table 5 — Top five highly cited patents

S. No.	Title	Priority Date	Publication Number(s)	IPC	Assignee	Earliest Priority Country	Citation Count
1	Internet of things based farm greenhouse monitor and alarm management system	2011-10-14	US8643495 CN102445933	G08B 21/00	Lan Zehua Ma Lixia	China	88
2	A smart agriculture monitoring system based on Web of Things	2015-05-29	CN104852989	H04L67/12	Beijing Dongfang Haian Internet of Things Technology	China	47
3	Intelligent greenhouse demonstration measurement and control system based on Internet of things technology	2011-05-07	CN102307222	Y02P90/02	Hefei University of Technology	China	34
4	IoT (Internet of Things) based intelligent agricultural management system	2014-07-28	CN104181877	G05B19/418	Chengdu Intelligent Networking Technology	China	29
5	Intelligent measurement and control system of greenhouse based on internet of things	2012-08-30	CN102789222	Y02P90/18	Chien Shiung Institute of Technology	China	28

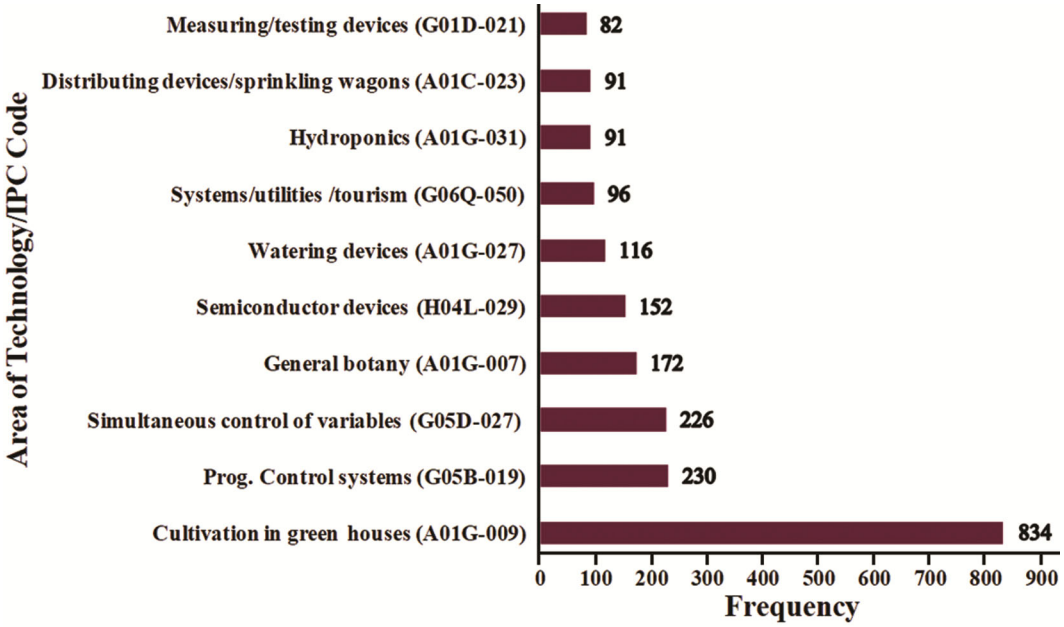

Fig. 7 — Frequency of IPC group occurrences

users. This patent has 88 forward citations indicating the importance of the technology in the green house monitoring. Significantly, all these highly cited patents have priority country as China.

Technological Nature of IoT Patents in Smart Greenhouses

Patents were analyzed for their IPC categorization for assessment of technological domain in IoT based smart greenhouses. A summary of analysis of main IPC codes pertaining to our dataset is shown in Fig. 7. Most frequently used IPC code is A01G-009 with 834 occurrences belong to cultivation in greenhouse followed by G05B-019 which pertains to programme-control systems and G05D-027 relates to simultaneous control of variables.

IoT Based Smart Greenhouse Market Demand

In the overall industry sectors based on IoT, Qualcomm has positioned itself as a potential market leader.[30] Qualcomm has enhanced its patent portfolio with increase in the number of granted patents in the recent years, solidifying its position in the IoT space followed by LG, Erricson etc. The

IoT Market size in Global Agriculture was valued at US$ 16,330 Million in 2017 and is projected to reach USD 48,714 Million by 2025, growing at a CAGR of 14.7% from 2018 to 2025.[34] In the agriculture sector market the IoT based companies are dominated by Deere & Company, Trimble Inc., Farmers's Inc. andCisco etc. which are US based working in the area of Farm Machinery and Precision Agriculture. It was observed that these companies do not own the patents in protected cultivation especially in IoT based greenhouses and the strategy for business will be licencing from the Chinese companies. As per themarket report[35], the major companies formulating the competitive landscape of IoT based Smart Greenhouse market are Modine, Schaefer Ventilation, Coolair, Trueleaf and Delta T Solution etc. which are majorly US based. It was also exciting to see many IoT based startups such as Stellapps technologies Pvt. Ltd., Cultyvate, Lentera, Xfarm, Auroras, Mycroclime andSwinesmart, etc. emerging especially in the area of Precision Agriculture and Resource Management.

Although, the market potential of IoT based smart greenhouses is growing steadily, there are several challenges which constraints the adoption of IoT by many farmers in developing countries because of high cost of equipment and installation involved. In addition, integration of different components and technologies is difficult and cost intensive. Most of the developers try to go for some sort of intellectual protection for these products thus a huge cost is involved in developing the technology as well as in the patent protection and its maintenance. Another constraint for adoption is the requirement for wider internet coverage, especially in remote and rural areas for which huge investment and working capital is required. Further, untrained human resource and fear of adoption of new technology also prove to be a serious challenge in the proper implementation of this technology. In the absence of industrial standards for maintenance of farm data, its implementation at wider scale becomes very difficult.

Conclusion

The application of data science in agriculture for higher productivity and quality has increased with the growing knowledge of big data analytics and sophisticated computing infrastructure such as super/cloud computing, Artificial intelligence, IoT, sensor innovations, robotic platforms etc.[36] The present study brings forth a comprehensive patent landscape on the application of IoT in smart green houses. Innovation and technology management studies use patents for analysing the key trends. Further, sector specific dynamics (especially the IoT based smart greenhouses) and insights about technological domains through IPC have been highlighted. Useful information was provided through patent analysis about the competitive and technological position of companies and countries over a period from 2006-18. It was observed that modernization and automation of smart green houses have significantly improved by IoT technological solutions. China has leapfrogged in the domain of R&D frontiers in IoT based greenhouses followed by South Korea and US. As a defensive patent strategy, China is filing aggressively and mostly in their own jurisdiction of national phase.For the market demand of IoT based technologies, at global level US is still the preferred market but the big players in farm management are not holding many patents in IoT based smart greenhouses. It will be interesting to see the commercialization approach requiring niche transitions before entering mainstream markets. The trends also indicate the entry of several innovative startups with their patented technologies in this sector. IoT technologies are key enabler in the creation of new digital ecosystem in agriculture sectors and have revolutionized the agri-tech sector through predictive and prescriptive solutions. This has made farming more attractive, smart and sustainable with improved access of remote services. New technological systems for food production like hydroponics, aquaponics and vertical farming in green houses are also increasing. Despite such advantages, major challenges for deployment of IoT based sensors in green houses on a larger scale include high cost and maintenance of sophisticated hardware and software. The technologies based on cloud-based network platform can help to a greater extent in overcoming the problems of data storage space, scalability and reliability. The analysis of patent trends in these technologies would help governments to frame policies benefiting the stakeholders.

References

1 Bandyopadhyay D & Sen J, Internet of Things: Applications and challenges in technology and standardization, *Wireless Personal Communications,* 58 (2011) 49.

2 Rehman A, Abbasi A Z, Islam N & Shaikh Z A, A review of wireless sensors and networks' applications in agriculture, *Computer Standard Interfaces*, 36 (2) (2014) 263.

3 Farooq M S, Javid R, Riaz S & Atal Z, IoT based smart greehouses framework and control strategies for sustainable agriculture, *IEEE Access*, 10 (2022) 99394.

4 Rajak P, Ganguly A, Adhikary S & Bhattacharya S, Internet of Things and smart sensors in agriculture: Scope and challenges, *Journal of Agriculture & Food Research*, 14 (2023) 100776.

5 Ayaz M, Ammad-uddin M, Sharif Z, Mansour A & Aggoune E-H M, Internet-of-Things (IoT) based Smart Agriculture: Towards Making the Fields Talk, *IEEE Access,* 7 (2019) 129551.

6 Ojha T, Misra S & Raghuwanshi N S, Wireless sensor networks for agriculture: The state-of-the-art in practice and future challenges, *Computers and Electronics in Agriculture,* 118 (2015) 66.

7 Greenwood D J, Zhang K, Hilton H W & Thompson A J, Opportunities for improving irrigation efficiency with quantitative models, soil water sensors and wireless technology, *Journal of Agriculture Sciences*, 148 (2010) 1.

8 Pathak H, Mishra J P & Mohapatra T, Indian agriculture after independence, *Indian Council of Agricultural Research*, New Delhi 110 001, (2022) 426.

9 Cagliarini A & Rush A, Economic development and agriculture in India, *Reserve Bank of Australia Bulletin*, June Quarter (2011) 15.

10 Marucci A, Colantoni A, Zambon I & Egidi G, Precision farming in hilly areas: The use of network RTK in GNSS technology, *Agriculture*, 7 (60) (2017) 1, doi:10.3390/agriculture7070060.

11 Karanisa T, Achour Y, Ouanmi A & Sayadi S, Smart greenhouses as the path towards precision agriculture in the food-energy and water nexus: Case study of Qatar, *Environment Systems and Decisions*, 42 (2022) 521.

12 DiPrinzio D, Kumar R, Dhandapani A, Srinivas K, Nadiminti V, Kalpana Sastry R & Srinivasa Rao Ch, How can open data platforms support the Indian Agri-Ecosystem? (2018) *Occasional Paper 19*, ICAR-NAARM.

13 Coble K H, Mishra A K, Ferrell S & Griffin, T, Big data in agriculture: A challenge for the future, *Applied Economic Perspectives and Policy*,40 (1) (2018) 79.

14 Zambon I, Cecchini M, Egidi G, Saporito M G & Colantoni A, Revolution 4.0: *Industry* v *Agriculture* in a future development for SMEs, *Processes*, 7 (2019) 36.

15 Gustavo A Mesías-Ruiz, María Pérez-Ortiz, José Dorado, Ana I de Castro & José M Peña, Boosting precision crop protection towards agriculture 5.0 *via* machine learning and emerging technologies: A contextual review: *Frontier Plant Science*, (2023) 22 March 2023, 14, https://doi.org/10.3389/fpls.2023.1143326.

16 Paustian M & Theuvsen L, Adoption of precision agriculture technologies by German crop farmers, *Precision Agriculture*, 18 (5) (2017) 701.

17 Khanna A & Kaur S, Evolution of Internet of Things (IoT) and its significant impact in the field of Precision Agriculture, *Computers and Electronics in Agriculture*, 157 (2019) 218.

18 Verma S, Bhatia A, Chug A, Singh A P, Recent advancements in multimedia big data computing for IoT applications in precision agriculture: Opportunities, issues, and challenges, In Tanwar S, Tyagi S, Kumar N (ed), *Multimedia Big Data Computing for IoT Applications*, Springer, (2019) 391.

19 Shamshiri R R, Kalantari F, Ting K C, Thorp K R, Hameed I A, Weltzien C, Ahmad D & Shad Z M, Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture, *International Journal of Agricultural and Biological Engineering*, 11 (1) (2018) 1.

20 Anonymous (2020);Smart greenhouse market size, share, competitive landscape and trend analysis report by type, component and end user**:** Global opportunity analysis and industry forecast, 2020-2027 allied market research, 238 (2020), https://www.researchandmarkets.com/r/oml879. (accessed on 16October 2020).

21 Controlled environment in this manuscript is referred to cultivation in any type of closed chamber such as greenhouse or glasshouse or polyhouse and any kind of indoor planting, excluding cultivation in open roof gardens.

22 https://www.orbit.com.

23 Moher D, Liberati A, Tetzlaff J & Altman D G, PRISMA Group, Preferred reporting items for systematic reviews and meta-analysis: The PRISMA statement, *PLoS Medicine*, 151 (2009) 264.

24 Gerard M & Srinivas K, Innovation trends in IoT based smart greenhouses through patent data, Third IP & Innovation Researchers of Asia Conference, 24-27 March 2021 on line, (2021) (part of the research data presented in conference).

25 Friedman D, Why China will leapfrog the world in internet of things, *Venturebeat,* 2014, http://venturebeat.com/2014/10/04/why-china-will-leapfrog-theworld- in-internet-of-things, (accessed on 16October 2020).

26 Koeling M, Internet of Things, industry 4.0 and the role of Japan, *Japan Industry News*, (2015), https://www.japanindustrynews.com/2015/10/internet-of-thingsindustry- 4-0-and-the-role-of-japan/ (accessed on 16 October 2020)

27 Ardito L, D'Adda D & Petruzzall A M, Mapping innovation dynamics in the Internet of Things domain: Evidence from patent analysis, *Technological Forecasting & Social Change*, 136 (2018) 317.

28 Chinadaily, China unicom pushing 'Internet Plus' in inner Mongolia, *Chinadaily,* (2015) http://innermongolia.chinadaily.com.cn/2015-06/26/content_21113596.htm, (accessed on 16 October 2020)

29 Kshetri N, The evolution of the internet of things industry and market in china: An interplay of institutions, demands and supply, *Telecommunications Policy*, 41 (1) (2017) 49.

30 LexInnova, Internet of Things: Patent Landscape Analysis. LexInnova Technologies LLP, San Francisco, 2014.

31 Voigt K, China looks to lead the Internet of Things, *CNN Business*, 2012 http://www.cnn.com/2012/11/28/business/china-internet-of-things/ (accessed 4 November 2020).

32 Cao C, Patent picture overblown, *Chinadaily*, 2013, http://usa.chinadaily.com.cn/weekly/2013-03/01/content_16265895.htm (accessed on 16 October 2020).

33 Li S, Xu L D & Zhao S, The internet of things: A survey, *Information System Frontier,* 17 (2015) 243.

34 Internet of Things (IOT) in agriculture market by system (automation and control systems, sensing and monitoring

devices, livestock monitoring hardware, fish farming hardware, smart greenhouse hardware, and software), Application (precision farming, livestock monitoring, smart greenhouse, and fish farm monitoring): *Global Opportunity Analysis and Industry Forecast, 2018–2025,* 2019, https://reports.valuates.com/market-reports/ALLI-Auto-0H300/internet-of-things-iot-in-agriculture, (accessed on 4 November 2020).

35 Global IoT based smart greenhouse market report 2020 by key players, types, applications, countries, market size, forecast to 2026 (Based on 2020 COVID-19 worldwide spread) 2020, https://www.marketstudyreport.com/reports/global-iot-based-smart-greenhouse-market-report-2020-by-key-players-types-applications-countries-market-size-forecast-to-2026-based-on-2020-covid-19-worldwide-spread (accessed on 4 November 2020).

36 Tzounis A, Katsoulas N, Bartzanas T & Kittas C, Internet of Things in agriculture, recent advances and future challenges, *Biosystems Engineering*, 164 (2017) 31–48.