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5-15-2021

A Bibliometric Perspective Survey of IoT controlled AI based Swarm robots

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Abstract

Robotics is the new-age domain of technology that deals with bringing a collaboration of all disciplines of sciences and engineering to create a mechanical machine that may or may not work entirely independently but definitely focuses on making human lives much easier. It has repeatedly shown its ability to change lives at home and in the industry. As the field of robotics research grows and reaches new worlds, the military is one area where advances can have a significant impact, and the government is aware of this. Military technology has come a long way from the days where soldiers had to walk into traps, putting their own lives in danger for their fellow soldiers, to today, when soldiers have robots walk into the same traps with possibility and result of zero human casualties. High-risk military operations such as mine detection, bomb defusing, fighter pilot aviation, and entering enemy territory without complete knowledge of what is to come are all tasks that can be programmed in a way that makes them accustomed to scenarios like these, either by intensive machine learning algorithms or artificially intelligent robot systems. Military soldiers are human capital; they are not self-driving robots; they are living beings with emotions, fears, and weaknesses, and they will almost always be unreliable as compared to computers and robots. They are easily affected by environmental effects and are vulnerable to external influences. The government's costs for deployed troops, such as training and salaries, are extremely high. As a result, the solution is to build AI robots for defence operations that can sense, collect data by observing surroundings as any human soldier would, and report it back to a workstation where it can be used for strategy building and planning on what the next step should be during a mission, thus making the army better prepared for any kind of trouble that might be on their way. In this paper, the survey and bibliometric analysis of AI-based IoT managed Swarm Robots from the Scopus repository is discussed, which analyses research by area, notable authors, organizations, funding agencies and countries. Statistical analysis of literature published as journals, articles and papers that aids in understanding the global influence of publication is called Bibliometric analysis. This paper is a thorough analysis of 84 research papers as obtained from the Scopus repository on the 3rd of April 2021. GPS Visualizer, Gephi, wordcloud, and ScienceScape are open source softwares used in the visualization review. As previously mentioned, the visualization assists in a quick and easy interpretation of the different viewpoints in a particular study domain pursuit.

Keywords :Swarm robotics, Swarm, Robotics, IoT, AI, ML, Military, Defence, Mines.

1. Introduction

Robotics & Automation is a field that is rapidly expanding. Industrial robots have become very popular in industries all over the world in recent years. Their success is growing every day as a result of their increased competitiveness, suitability, and profitability. Robots and automated machines have seen an exponential increase in applications in the industry. Increasing income rates and the need to improve productivity have led to increased employment of robots in various sectors across nearly all markets, and there is still a considerable amount of scope in many nations [1]. Scientists and researchers are focused on this white space in order to expand the field of and usage of robotics and automation. One type of robot that has shown immense potential are rescue robots, they have quickly become one of the most popular areas of robotics research. At the moment, robots are used to perform tasks in dangerous environments. Some robots are designed to run on uneven terrain and climb stairs. Robots when fitted with sensors and modules that allow wireless communication are being used for surveying remote areas [2]. The majority of articulated robots used in car and electronics manufacturing are automated, which means they are preprogrammed to perform complex sets of tasks repeatedly without the need for human interaction. However, in some cases, robots will be operated manually to perform tasks that have not been programmed previously. Manual robotic arms are needed for real-time operations in space and military missions [3]. For proper decision-making in a rescue mission, it is important for robots to be equipped enough to detect surrounding conditions in target territory. The photographs of the surroundings are first photographed with the cameras that are mounted on each mobile robot. Then, using feature extraction algorithms, features about mobile robots and landmarks are extracted from these images[4]. The design and development of an intelligent rescue robot with all of these main features was inspired by these multidimensional criteria for successful operations for rescue and surveying.

Every day, more and more things are being automated. Life has become more versatile as a result of automation. One of the most important elements of a country's protection is border control. It is a difficult job to keep an eye on the border with human labor because it necessitates continuous attention and surveillance. A drone is a device that has the capability of performing tasks that are risky or expensive for humans. It can be used to track a wide area for surveillance purposes. Drones are much less expensive than other aerial vehicles, so they may be a viable and cost-effective surveillance solution. In 2015, a group of researchers looked at how drones could be used for a variety of purposes, including surveillance, transportation, and couriering. Once the command is given correctly, the drones will complete all of the tasks [5].

The emergence of Mobile Robotics is another area that has changed the way we see things. One of the more notable recent advancements is the evolution of technologies in the field of autonomous navigation for robotics, where we must deal with massive quantities of unpredictability that is common in combat settings while defusing unexploded explosives or ensuring continuous surveillance [6]. In fields like bionomics and security guarding, visual servoing (VS) is a technique for controlling a robot and providing motion. The most important aspect of robotics is to position cameras in the workspace so that each and every location is visible during the mission. The aim of Visual Servoing is to achieve kinematics that make picking and placing objects simple [7]. The border protecting forces are vigilantly patrolling the border, but it is impossible to keep an eye on the border at all times. A robot that automatically identifies trespassers on the border and reports them to nearby board security control units is a must-have in this situation [8].

Since the fear of a terrorist attack has always been India's number one foe, since the incident at Taj, it is a necessity that robots be used to save lives now that there are enough resources and technological developments. All major terrorist attacks such as the 26/11 have forced the government and military to step up and focus on army intelligence for security of the lives of the people to the greatest extent possible, hence, since then, a lot of advancements have been made and when or if time comes, the country would be better prepared to deal with a situation like that, it would use robots instead of human soldiers to be put in jeopardy to save human lives. The Indian Army currently uses Daksh Military robots to fight on the battlefield. As technology advances in the automation sector, Military Robots as Soldiers in the War Field can be used to minimize grievance and death in war zones [9]. A robot may do work with much better efficiency and with possibility of zero casualties that humans are unable to do in military and security applications, such as remote operation, remote medical care, and remote surveillance in hazardous environments [10]. The military needs to be empowered with a tool that can minimize casualties and be of help in terms of accuracy of target acquisition, transport to search rescue and attack with a much greater efficiency. Over the years, robotics has evolved into a vast and complex field of concepts, methods, and technologies. It also includes behavior-based, cognitive, biologically motivated, and humanoid robots, in addition to its original origins in manipulator systems. Large data repositories from similar and rescue operations [11]. To begin with, it provided a distinct function of factory floor process automation in the late 1970s, and more recently, it has become a subject of research among many researchers as a driverless or autonomous transportation system. Unmanned fighter aircrafts are a dream for the military. Unmanned

Aerial Vehicles (UAVs) are becoming smaller and smarter, and they are becoming increasingly relevant in the Internet of Things (IoT). As a result, their applications are becoming more diverse. They were originally built and used for military purposes, but they are now used in a variety of settings including agriculture, distribution, logistics, and building [12]. While other companies strive for a hands-on approach, the military is pursuing the most hands-off approach possible, such as autonomous, robotic drones accompanying manned fighter jets to reduce casualties. For any military organization, border surveillance (BS) is the most important mission. It must be monitored 24 hours a day, seven days a week to keep the peace and ensure the protection of the borders. Illegal immigration, trading, smuggling drugs, implanting explosive devices, and terrorist acts are all common challenges at our country's border, especially in today's climate. To avoid such events from happening in border regions, an intelligent system connecting to the Internet will use very different realms, massive parallel processing from server farms, and sensor streams from other robots and automata to expand its local onboard data, computing, and sensors. In spite of this, the world is yet to see a robot that is intelligent enough to go on the offensive and take lethal action without human command. A great deal of research is still going on in this area but there are targets that can be met with the information that is available at present.

IoT is characterized as worldwide communication between large numbers of objects. The word "Internet of Things" has recently been used in a variety of areas such as mobile networks, cloud computing, cyber-physical systems, and big data analytics [13].The IoT is one of the newly rising technologies of Industry 4.0. Strain sensors that are wearable and allow multifunctional applications can help accelerate the advancement of human–machine intelligence in a variety of fields, including soft robotics, healthcare and IoT [14]. IoT is a mechanism that combines computational devices, mechanical and digital machines to form a network or new data transmission channel that does not involve human-to-computer interaction or human-to-human. IoT devices are typically used to perform specific tasks, while robots are expected to respond to unforeseen circumstances. The Internet of Robotic Things (IoRT) is said to have been created as a result of collaboration between the IoT and robotics communities [15]. One example of IoRT is a rescue robot [16]. IoT has been a significant part of society and has influenced robotics. The Surveillance Robot, for example, is based on a similar IoT and Robotics hybrid. From a distance, the user can monitor the robot's movement. The robot moves and broadcasts live video footage in response to user commands. All these things are done through Raspberry Pi microcontroller in such cases. Its purpose is to move around an area while transmitting live video information to users through a user screen. As a result, the monitoring operation has come to an end. Defence, healthcare, and infrastructure security are just some of the applications for the surveillance robot. Cost-effective, low-maintenance, and easy-to-deploy surveillance robots are required. These are mostly used to keep track of events. With the increase in crime, a smart surveillance system with minimal human interference is needed. A robot can carry out pre-programmed tasks, removing the need for manual labor and providing highly efficient results while also overcoming human limitations. Fixed surveillance cameras have dead spots that minimize their effectiveness, leaving the user helpless when the camera needs to be regulated, necessitating the use of mobile surveillance systems [17].

The IoT is rapidly emerging these days, with various types of wireless sensor networks (WSNs) at their heart. Hospitals, agriculture, industry, and military applications are all possible applications for these networks. It is a widely studied and accepted technology that allows both small and large network-enabled devices to be connected through the Internet. The operational efficiency of emergency response systems can be improved using data analytics based on advanced machine learning software, encryption frameworks such as blockchain, and information engineering concepts. IoT, in conjunction with various fields such as “Artificial Intelligence (AI)”, “Machine Learning (ML)”, “Deep Learning (DL)”, “Augmented Reality”, “Cloud Computing”, and “Swarm Intelligence”, will transform the field of robotics in the near future by proposing a new group of intelligent robotics dubbed "Internet of Robotic Things (IoRT)." The IoT is a ground-breaking networking model that is crucial in control operations and remote monitoring. This networking model benefits and finds intensive applications in the fields of healthcare, home automation, military, transportation, sewage management, agriculture, smart metering, protection, customer asset tracking, smart grid, and vehicular communication system to name most [18]. ThingSpeak is a very commonly used open IoT platform that allows for the collection of real-time data in the cloud and the visualization of that data through charts, as well as the development of plugins and applications for communicating with web services, social networks, and other Application Programming Interfaces (APIs) [19].

In WSN applications that collect a large amount of data, irregularities or deviation detection is an important research subject. The detection of inaccurate, wrong, and noisy nodes is aided by anomaly detection. Several techniques are used to detect irregularities. Machine learning algorithm (MLA)-based methods are the most useful and effective, as well as the most accurate. Learning is usually applied to the sensed data rather than the nodes because the sensors' batteries are tiny. The motive of anomalous statistics may be calculated using recognized outliers. In order to achieve unique measurements, its miles disabled if its miles generated through a defective or malicious node [20]. Ad hoc wireless networks are used by robots in military applications to connect with local networks. Using the above networks, you can get protection and a fast response. Due to labor shortages, the majority of fields depend on robots to carry out their tasks. To detect hindrance in various directions, various sensors and cameras are used to feel and watch the motion of robots [21]. There have been several schemes in the sense of ad hoc networks that offer solutions to boost network layer protection and detect packet dropping attacks [22]. A prudent, effective, and complete game model has been defined in the distributed intrusion detection system to detect any kind of interference in the IoT networks. WSN hence, is slowly picking up pace as it has a number of sensor nodes for sensing data from a particular area and sharing it with the base station [23]. The LORA-WAN Module also enables us to communicate over a distance of up to 10 kilometers. This project's efficiency is excellent. Using multiple robots to complete a task is more effective and simpler than using single robots. The project is not limited to only two robots; depending on the difficulty of the task, we can connect as many as possible [24]. Alongside the functioning of the system, its security is also very important. Attacks on cyber-bodily networks have ended up extra not unusual places and full-size in current years. Zero-day assaults are normally used. The exponential boom of the economic Internet of matters, the proliferation of carrier robotic software areas, the creation of the Internet of vehicles, and the Internet of army matters have all ended in a prime growth in publicity to deceptive attacks. Deceptive attacks that do not use secret malicious components are extremely difficult to detect. Robotic systems are well-suited to such attacks. A technique for detecting suspicious behavioral patterns has been suggested as a tool for creating an intrusion detection mechanism for closed-loop robotic systems. The computer is capable of detecting deceptive zero-day attacks [25]. A clever intrusion detection machine, referred to as a software program agent, examines assaults on large IoT subsystems using loads dependent on signatures, irregularities, characteristics, and even hybrid approaches, and the basic hypotheses suggested to obtain analytical outcomes can be easily enhanced to obtain extra sensible scenarios. As a result, in the provided matrices, the equilibrium solutions and costs of each subgame are used to quantify the performance of intrusion and attack detection systems. Furthermore, in comparison to similar work, the presentation of a game model to detect IoT attacks between sensor nodes and the platform server, which is used to detect further attacks, correct detection rates, and minimize wrong detection rates, is a distinct feature and advancement. Cryptography-based Models, Trust-based Models, and Detection-based Models are the most commonly used techniques [26].

According to Stratistics MRC, in 2016, the demand for Internet of Robotics Things (IoRT) was worth “$4.37 billion and is projected to reach $28.03 billion by 2023, with a 30.4% annual growth rate.

The primary factors responsible for this growth is the rise of E-Commerce platforms, Education Sector, Consumer Markets, Research and Development Wings and above all Industry 4.0". Swarm robotics is the latest method of commanding large groups of relatively simple robots. This concept is picked up from the system-level behavior as seen in the animal world of that of social insects, which exhibits robustness, stability, and scalability [27]. A swarm robot is a self-organizing system of multiple robots as the name suggests, it offers high redundancy that can be the best solution to problems that need to be solved on a large scale such as a few military operations, ones that are potentially fatal or catastrophic.

Nowadays, robotic vehicles exist with built-in intelligence which guides itself around obstacles. Any obstacle in front of it is detected by an ultrasonic sensor, which sends an order to the Arduino Nano. When compared to tasks performed by single robots, this project would have more advantages, such as completing the task in less time. In recent years, the use of UAVs in various domains has exploded, as well. A flying robot with software-driven flight plans in its embedded systems that work in tandem with onboard sensors and GPS and can be controlled remotely or autonomously. Drones are commonly used in a variety of industries, including agriculture, transportation, and the military. Depending on what kind of application is taken into consideration, different types of drones are suited with various other types of sensors [28]. In recent years, WSNs have grown in importance in the field of information, communication, and technology (ICT). It is expected to dominate the future with a wide range of applications in fields like the IoT, Cyber Physical Systems, medical, agriculture, structural engineering, and military [29]. Drones have recently been equipped with Light Detection and Ranging (LIDAR) sensors to collect depth data. These sensors have benefits, but they are very expensive and work poorly under direct sunlight. To provide depth perception of obstacles, drones can be equipped with stereo cameras, which are less costly and more efficient. With time, both hardware and software fields have witnessed immense growth and development in terms of components that can support AI/MLAs, hence, drones have found applications in various research activities [28].

The rising trend of replacing human troops with robots in military operations in order to reduce casualties is expected to spur industry growth. Extensive research is being done to make robots capable of performing a wider range of combat tasks that are usually carried out during army missions and military operations which include sniper elimination, bomb defusing and target acquisition, with greater efficiency than human soldiers. They can be used in unsafe or unsuitable environments for humans, and they can destroy or maim troops. If soldiers are exposed to extremely harsh environmental conditions, it can be alarming, although this is not as much of a problem with robots. Humans have feelings, worries, and non-battlefield accidents that cannot be quantified, so robots should be used to replace human military soldiers in this situation. Army robots will provide support in the event of heavy artillery fire, reducing the number of casualties. They can also accurately detect a variety of threats and map a potentially large hostile environment.

Clearing of mines in any given area, is a major problem that the military experiences during operations. Landmines are explosive mines that are laid on or just under the surface of the ground which detonate when some pressure is applied on them. These are one of the most common tactics that are used by the military when they are either marking their own territory somewhere or they experience laid landmines when they are entering enemy territory. Most army operations are time bound and hence, there is not sufficient time for the soldiers to clear out every patch of the geographical area that they will need to move the troops from one end to another. In cases like these, soldiers start walking towards the destination with sticks in their hands poking on various parts of the ground to check if there are any mines that might go off when walked on, this is a very hard way of clearing mines. Soldiers often have major injuries from a mine going off. The army arranges proper training for these soldiers just for clearing mines, specifically, as it requires a large number of personnel as there is no other way but to manually check for these planted mines. Studies say that it takes about six hours to clear just a few meters of area for mines which is a huge investment in terms of time. Often missions are called off because there is not enough time or time is not right to carry out certain tasks since every single mission is properly planned and hours of trial for just a few meters of clear area is a big factor that holds back troops from moving ahead as even if the area is small, casualties caused are too big a loss.

There are two main types of mines that the Military usually deals with. First, Anti-personnel mines, these are the mines that are designed to be used against humans. Anti-personnel mines are small but lethal enough to take on foot soldiers. Since these mines are small, they do not kill the commandos that they blew up near, but they are capable of severely injuring them. The motive behind doing this is to increase the logistical, medical support required. When this happens, the soldiers not only have to be cautious about the mission but must also take care of the fallen soldier and this adds to mental pressure. Some types of anti-personnel mines are capable of damaging tracks on armored vehicles or the tires of wheeled vehicles which again, is done to put the enemy in a difficult position. Second, anti-tank mines, these are the mines that are designed to destroy vehicles including tanks and armored fighting vehicles which are a huge investment for any military.

Swarm robotics is a subset of robotics that organizes a large number of robots in a decentralized and distributed fashion. It is inspired by social insects and focuses on the application of local laws and basic robots in relation to the complexity of the task to be performed. A group of simple robots can execute complex tasks even faster than a single robot, increasing the group's robustness and stability. A group of simple robots can execute complicated tasks even faster than a single robot, allowing the group to grow in size. Instead of commandos running straight into the fields with an intention to spot landmines that would eventually blow them up, a swarm of robots can be sent out in that same area. These robots would carry reasonable weight so that they can be carried to the battlefield and also be enough in mass to detonate the landmines. When the landmines detonate, the swarm robots in proximity will explode which is anytime better than experiencing the loss of a human commando. Ideally, the robots will essentially be of a physical design that will make locomotion easy and be quick to traverse a rough terrain with a significant speed. These robots will all have multiple legs so that in case one or two of them are lost to a mine, the bot will still continue to move ahead, it will move with a slower speed, but the mass would be enough to detonate a mine. Furthermore, the legs of these robots will be equipped with sensors, such as small cameras or ultrasonic sensors, that will continuously collect and transmit data to the operator station before being killed by a landmine [30]. Building a swarm of robots that addresses both the issue of human injury and the time-consuming process of mine clearance along with transmitting accurate data securely as sensed from the environment would greatly benefit the military.

2. Preliminary Data

The use of mathematical techniques to review books, papers, and other publications is referred to as “bibliometrics”. In this paper we to perform such a bibliometric analysis on the use of swarm robots for military applications.

This paper is formulated by the various research papers found in the Scopus repository. The data used in this paper is extracted from the “Scopus” repository on 3rd April 2021. The concoction of various keywords is queried in the search from the year 2014, when the research in this field started, till date. This is depicted in Table 1. Table 2 enumerates the top 10 keywords with the number of publications (NoP) from the obtained repository.

Table 1: The Search query for Scopus database.

Sr No.	Search
1	"swarm robotics" OR "swarm robots" OR "robots" AND "defence" OR "Military" AND "Internet of Things" AND "IoT" AND "artificial intelligence" AND "machine learning"

Table 2: Top ten keywords with the number of publications.

Keyword	NoP
Internet of Things	93
Machine Learning	52
Artificial Intelligence	46
Surveys	44
Internet of Things (IOT)	41
Network Security	38
Deep Learning	36
Learning Systems	30
Unmanned Aerial Vehicles (UAV)	26
Embedded Systems	25

2.1 Initial Search Results

By mentioning the keywords presented in Table 1; 284 publications were available in the "Scopus" repository. Table 3 presents the different NoP in various languages derived from the search. Maximum number of publications are in English comprising about 98.24% while only a handful of publications are in Chinese & Spanish.

Table 3: Language of Publications.

Language	NoP	Percentage
English	279	98.24%
Chinese	4	1.41%
Spanish	1	0.35%

Table 4 presents the types of publication. Almost half of the publications are Articles comprising of 50.70%, followed by 67 publications as Review. However, there are also 42 conference papers, 17 Books, 12 Book Chapters and 2 short surveys accounting for 14.79%. 5.99%, 4.23% and 0.70% respectively.

Table 4: Type of Publications.

Type of publication	NoP	Percentage
Article	144	50.70%
Review	67	23.59%
Conference Paper	42	14.79%
Book	17	5.99%
Book Chapter	12	4.23%
Short Survey	2	0.70%

2.2 Preliminary Data Analysis

The annual trend of publication is linear, and this can be seen in Figure 1 attached below. The maximum number of publications were 118 in the year 2020. Since, 2018 there has been an evident rise in the trend of research in this field. The most influential authors that are contributing to the area of swarm robotics, can be seen in Figure 2. Guizani M leads in number of publications with 5 of his works with only 1 publication more than Fortino G and Niyato D.

Figure 1: Yearly publication details in swarm robotics using IoT and AI.

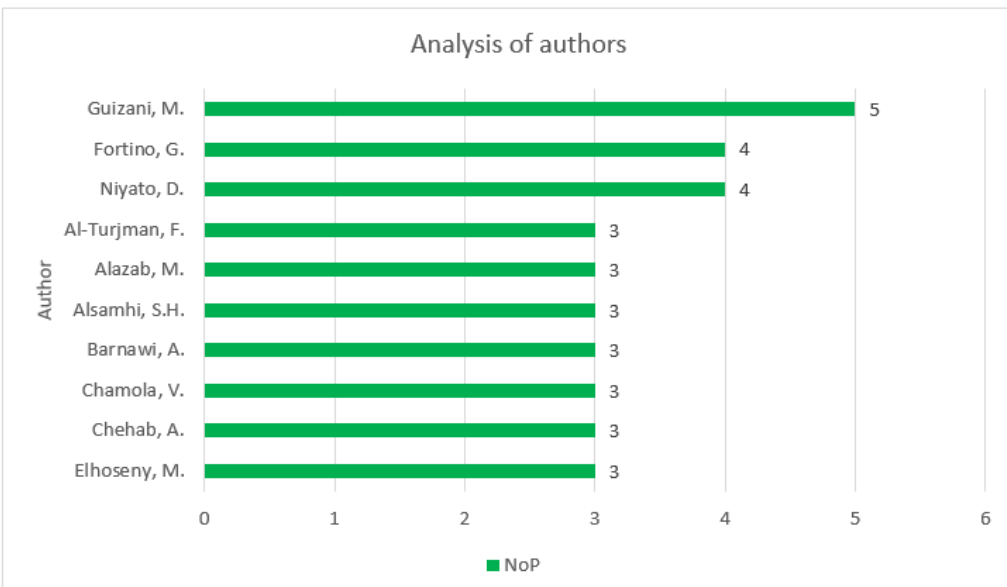

Figure 2: Top ten Influential authors in swarm robotics using IoT and AI.

Figure 3 represents the top 10 countries that actively participate in Scopus publications. 71 publications belong to the United States of America (USA). China and India come next in list, with 54 and 31 publications respectively.

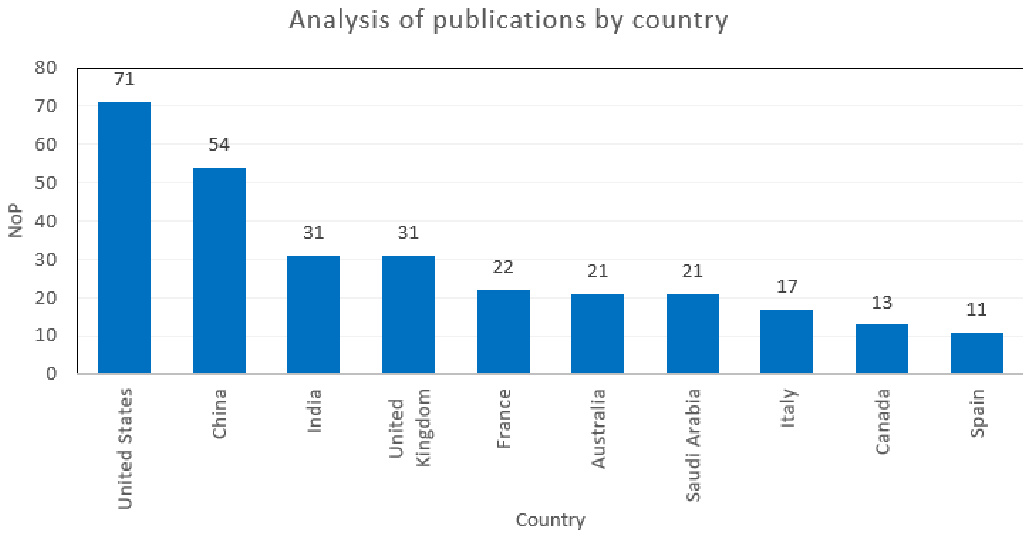

Figure 3: Top ten countries partaking in swarm robotics using IoT and AI from Scopus database.

In Figure 4, the various types of documents that are published in this field of research can be seen. Most published document types are articles and review documents. Figure 5 displays the document by source analysis. The graph in Figure 5(a) represents the “CiteScore” from the year 2014 to 2019.

With a “CiteScore” of 98.4, “IEEE Access” has the highest “Source normalized impact per paper (SNIP)” by year as indicated in Figure 5(b).

“IEEE Communications Surveys and Tutorials” has a “SNIP” value of 68.25. The “SCImago journal (SJR)” annual ranking is represented in Figure 5(c). IEEE Communications Surveys and Tutorials is having the maximum SJR of 26.23.

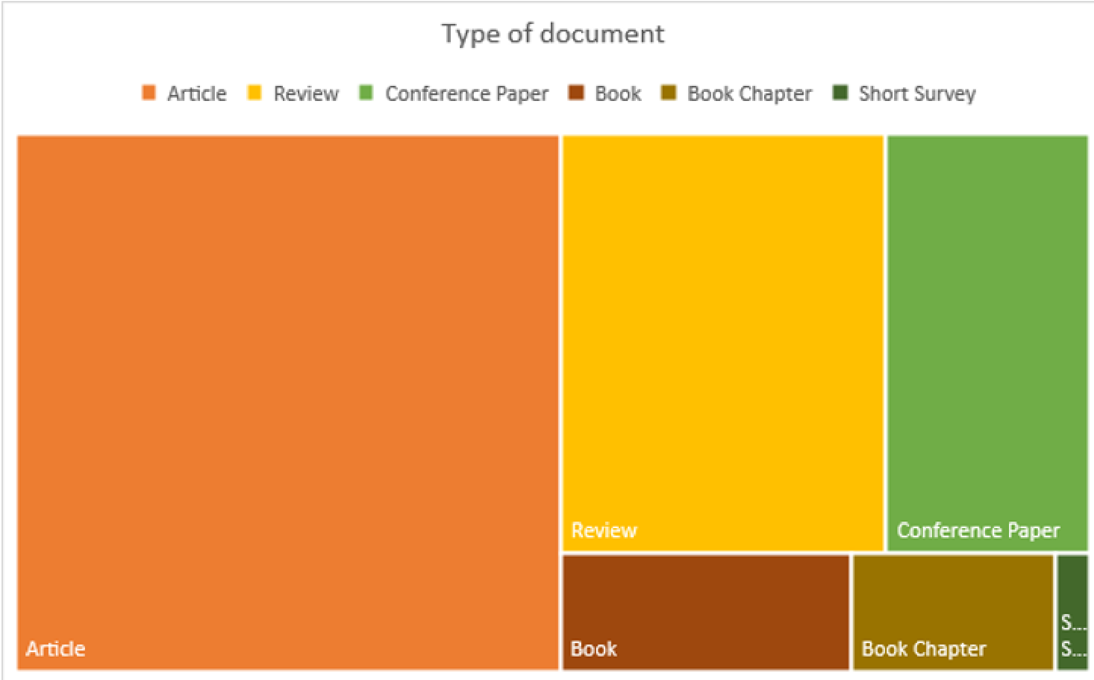

Figure 4: Types of document for publications in swarm robotics using IoT and AI.

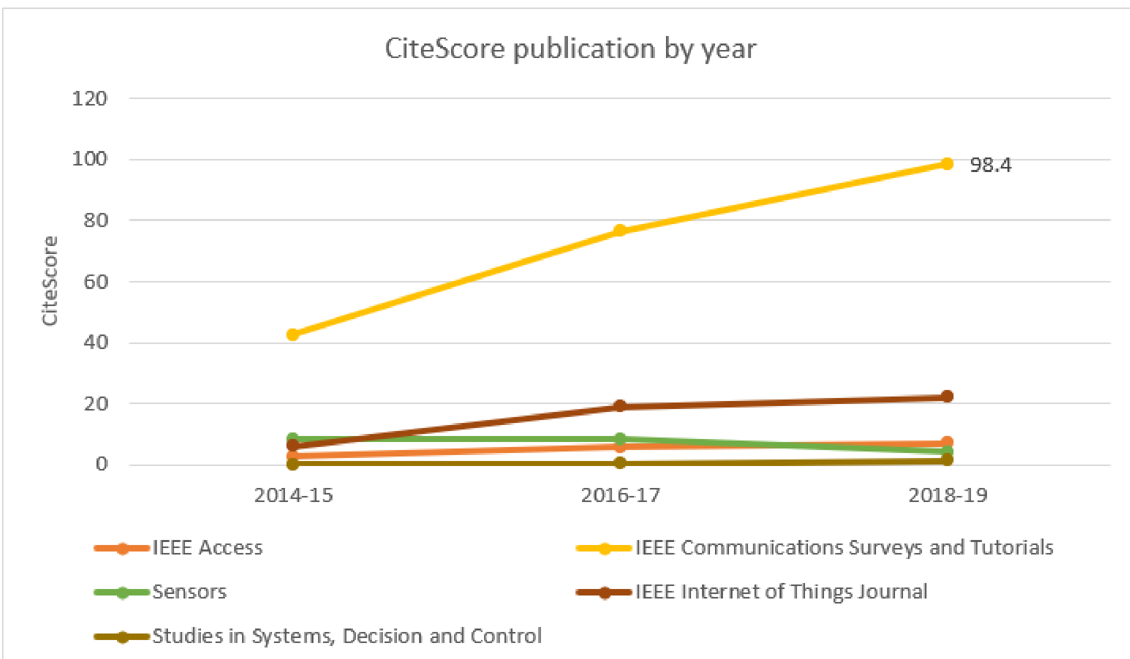

Figure 5 (a): CiteScore publication by year in swarm robotics using IoT and AI.

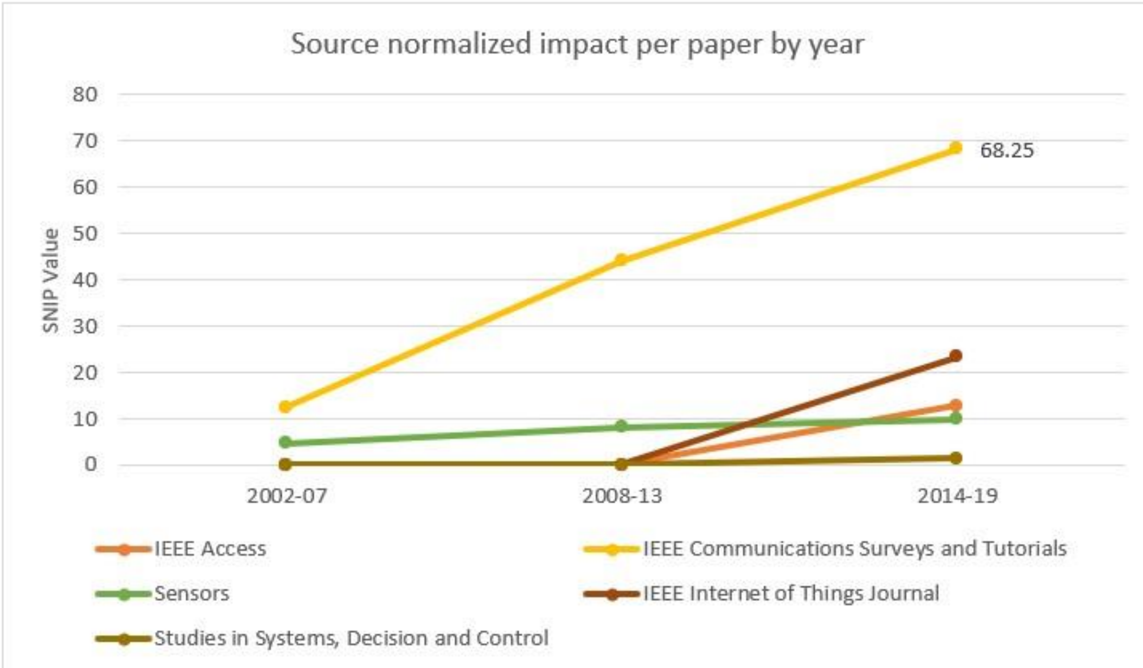

Figure 5 (b): Source normalized impact per paper by year in swarm robotics using IoT and AI.

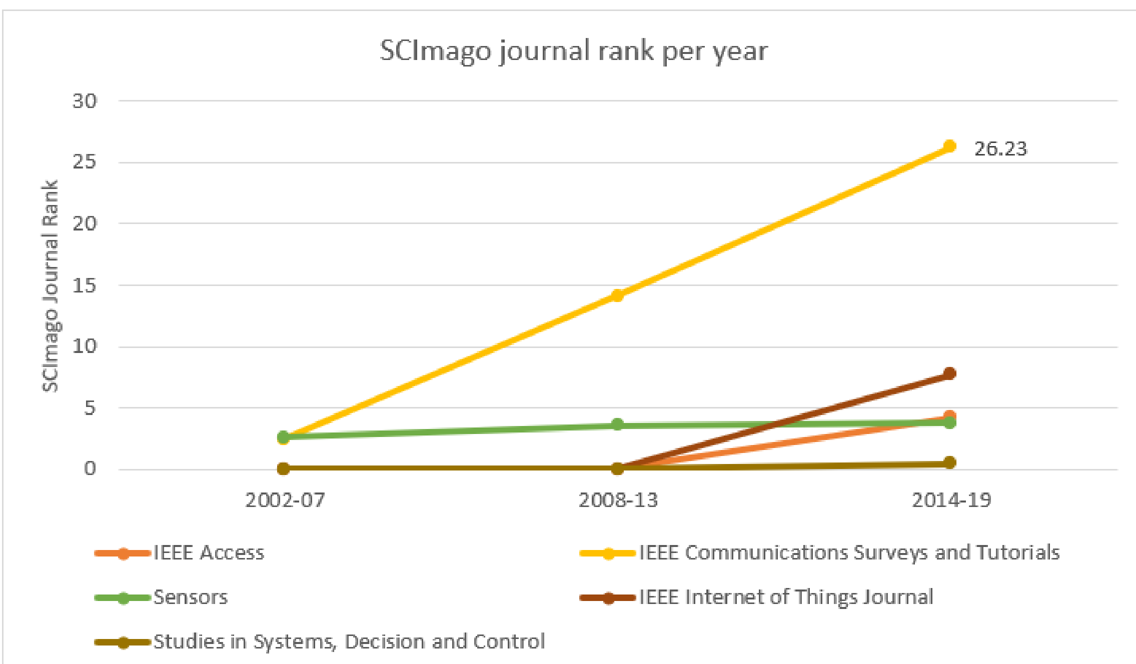

Figure 5 (c): SCImago journal rank per year in swarm robotics using IoT and AI.

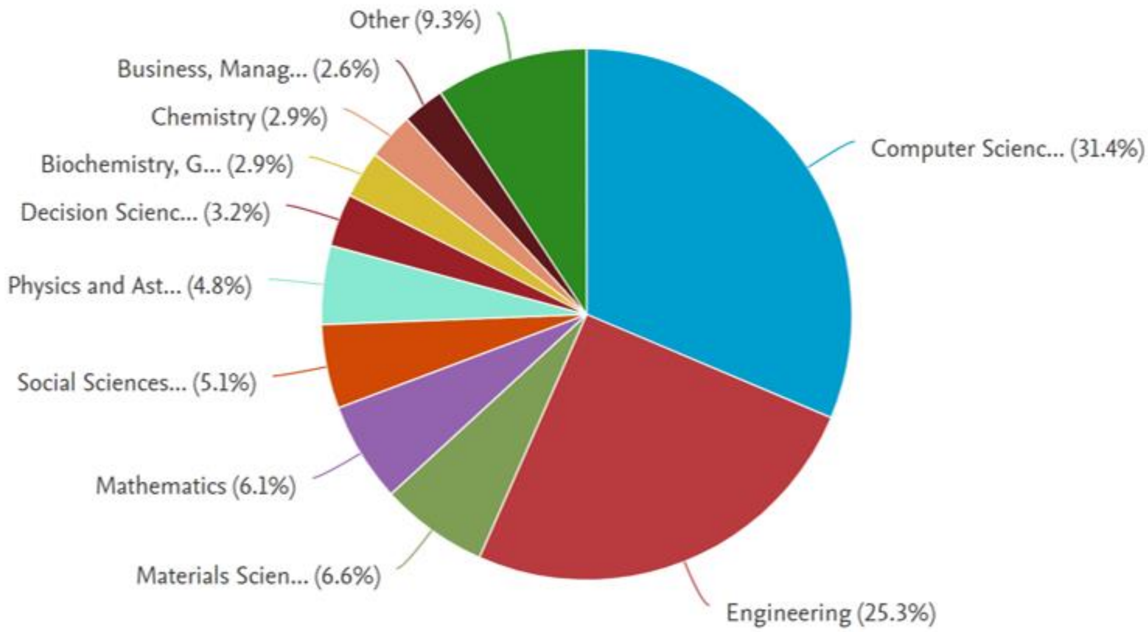

Figure 6: Analysis by subject area in swarm robotics using IoT and AI.

The study by subject area is depicted in Figure 6. Computer Science has the highest number of publications of 196 which is 31.4% of the total publications. Followed by Engineering with 158 publications and Material Sciences, Mathematics, Social Sciences, and others with over 100 publications.

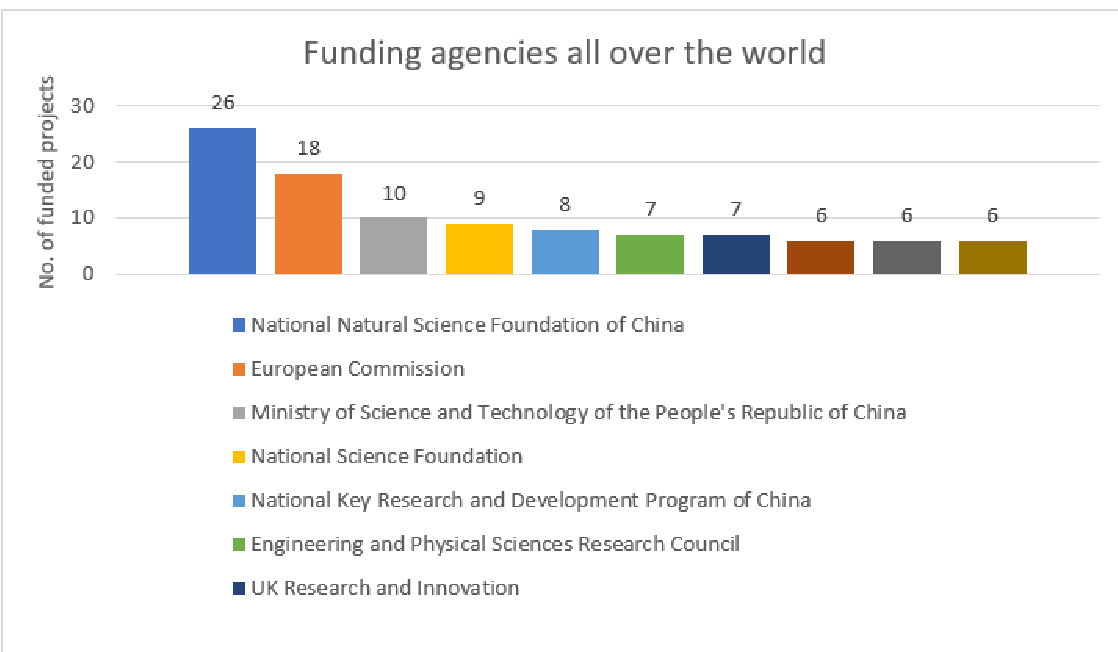

Figure 7: Top ten Funding agencies in swarm robotics using IoT and AI from Scopus database.

In Figure 7, the top 10 funding agency analysis of the world is shown. The maximum number of 26 projects have been funded by the “National Natural Science Foundation of China" ahead of the “European Commission” with 18 projects and the “Ministry of Science and Technology of the People's Republic of China” with 10 projects.

3. Bibliometric Analysis

Considering the uniqueness of the concept and depicting thorough research and study by involving the necessary metrics, the bibliometric analysis of Swarm robotics using IoT, and AI is as follows:

3.1 Geographical region analysis

The United States (US), China, and India have the most publications. Figure 8 depicts the geographical locations worldwide using a GPS visualizer tool, where research on Swarm robotics using IoT and AI is being conducted. This provides a global perspective on the analysis.

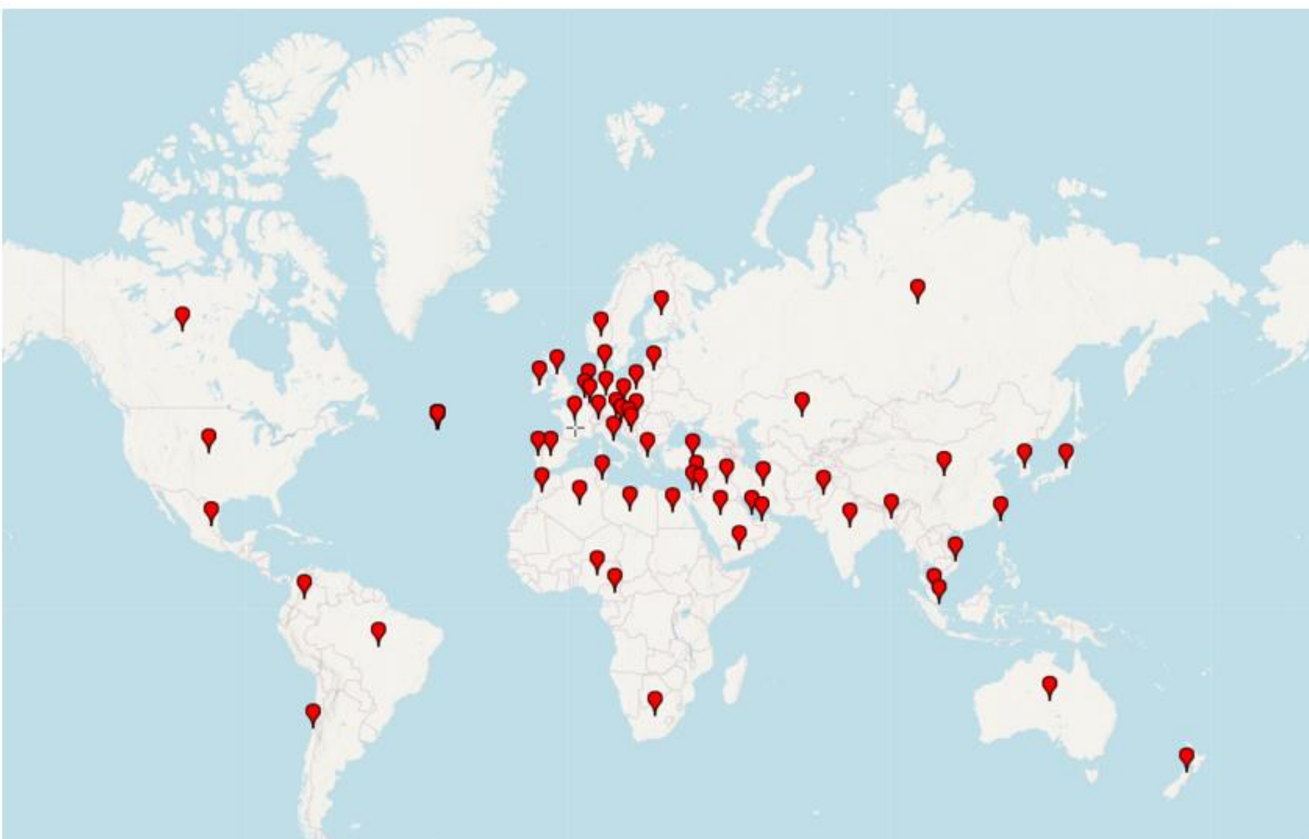

Figure 8. Geographic locations of the study of swarm robotics using IoT and AI.

3.2 Network Analysis

Visualizing tools such as Gephi, WordCloud, and ScienceScape have been used in this segment for visualization of network analysis.

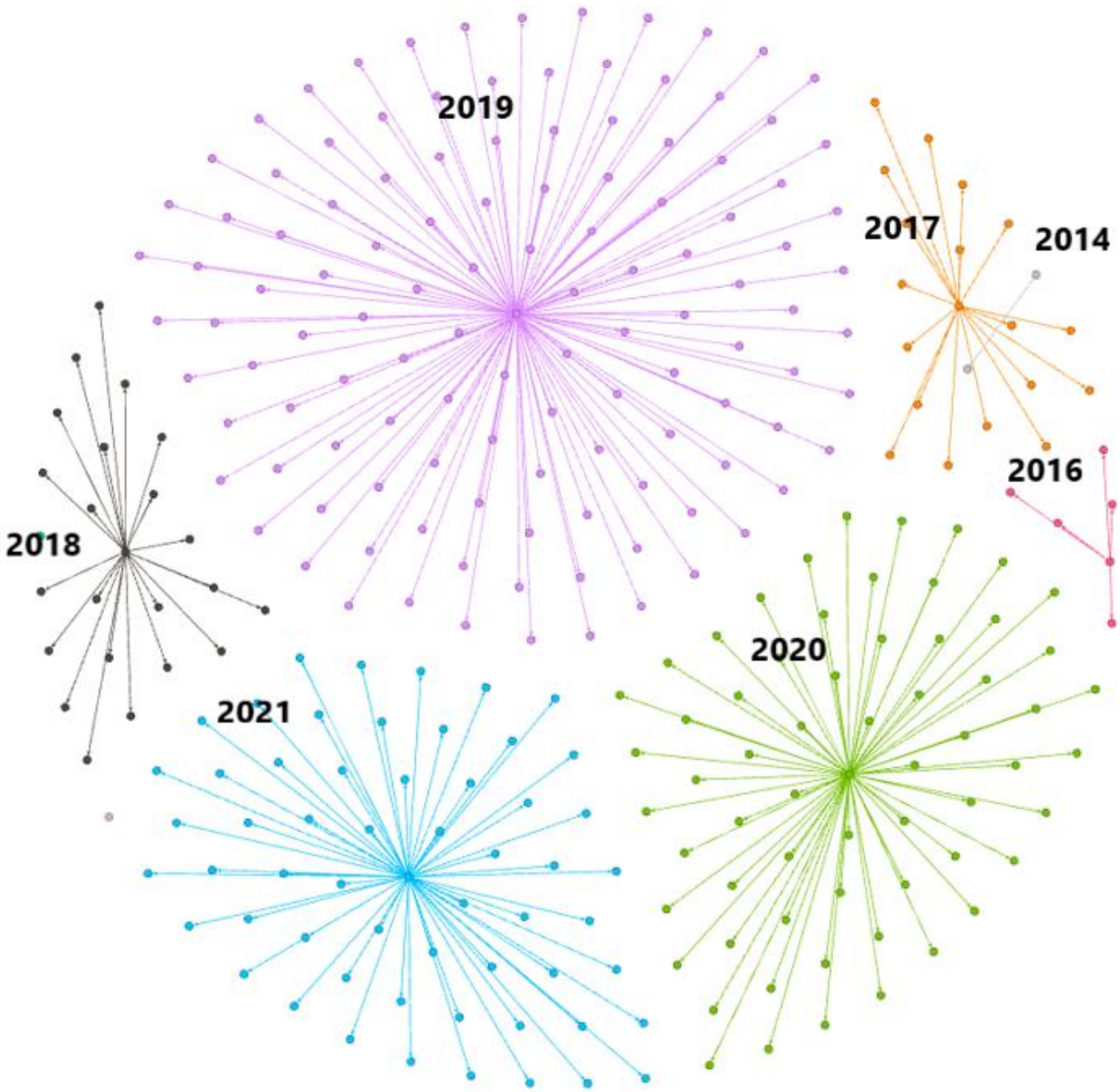

Figure 9: The Cluster of year and publication title in study of swarm robotics using IoT and AI from the Scopus database.

Figure 9 depicts a cluster that highlights the year and publication title as obtained from Scopus. The year 2019 has the most publications (139), followed by the year 2020. Figure 10 displays an established network between a group of authors and the keywords used that frequently appear in the same paper. Among the keywords, "Artificial Intelligence" appears to be the most significant.

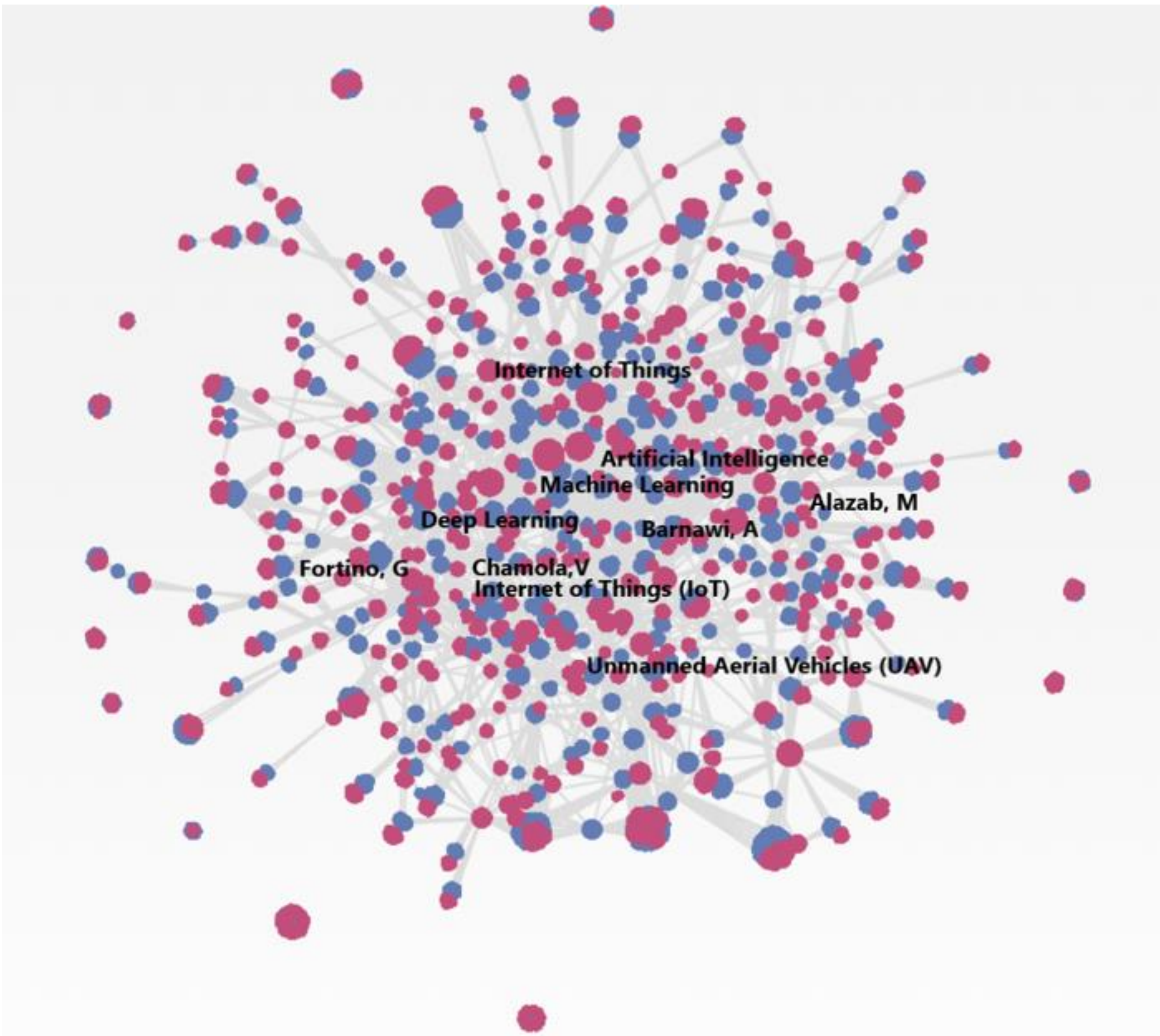

Figure 10: Author and author keyword appearing in the same paper.

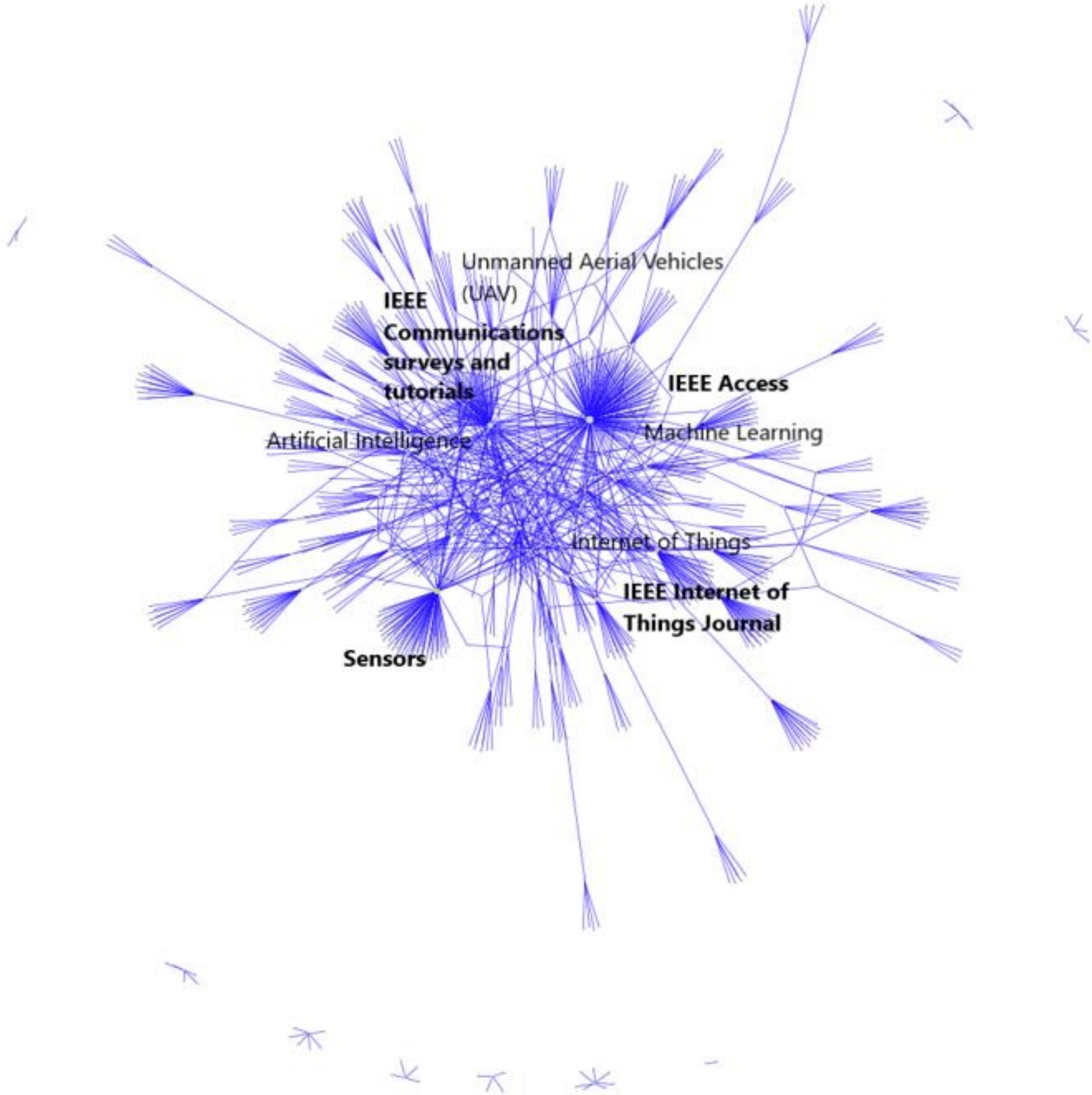

Figure 11: Source title and author keyword appearing in the same paper.

Figure 11 depicts a cluster of source title and keywords used by the authors that frequently appear in the same. Further details for these source names are given in Figure 5 that depicts the “CiteScore”, “SNIP”, as well as “SJR” information.

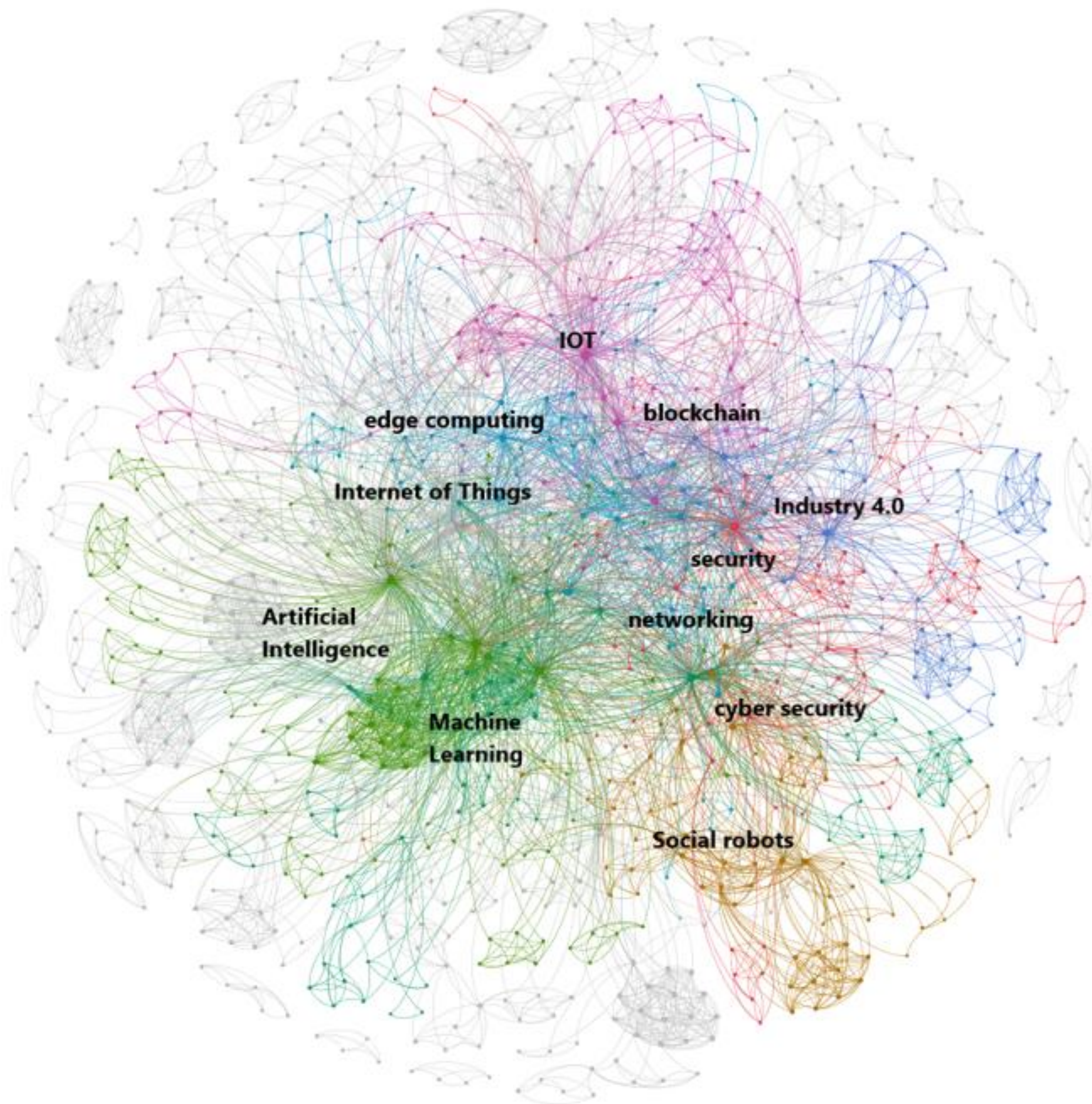

Figure 12: Author keywords appearing in the same paper.

Figure 12 depicts the author keywords that appear in the same paper. The most important author keywords appearing here are IoT, Internet of Things, Artificial Intelligence, Machine Learning, and Social Robots.

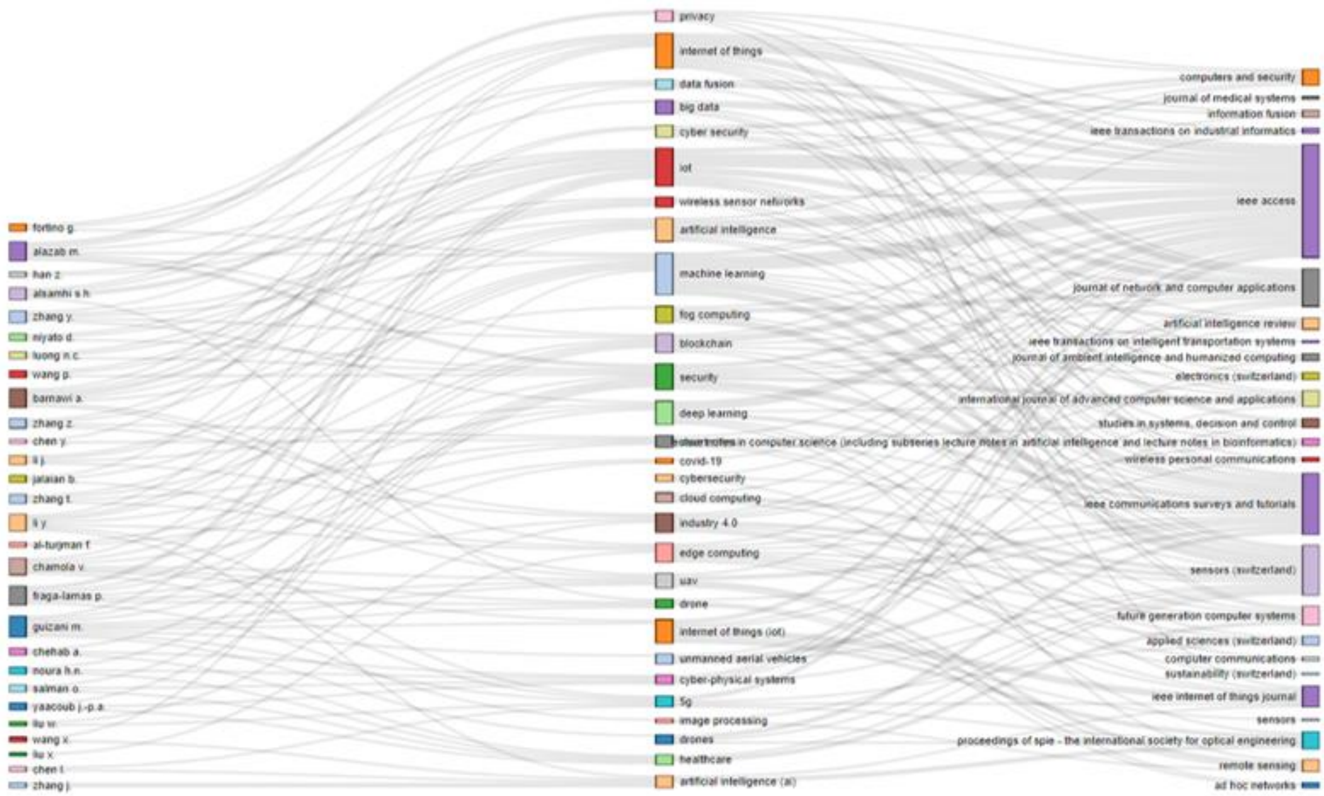

Fig 13: Sankey Graph -Main Authors, main keywords, and main journals

Figure 13 is the “Sankey Graph”– that shows interlinks between prominent authors, the keywords they use, and the published journals. The first column is of prominent authors, the next one displays the important keywords that have been used by them, and lastly a list of journals in which the report was published. The link signifies the interconnection of the terms. Figure 14 is a table with the information of the “Sankey Graph” of Figure 13.

Main authors

- guizani m. (5 papers)
- zhang y. (5 papers)
- fortino g. (4 papers)
- li y. (4 papers)
- liu x. (4 papers)
- niyato d. (4 papers)
- wang x. (4 papers)
- zhang j. (4 papers)
- zhang t. (4 papers)
- zhang z. (4 papers)
- al-turjman f. (3 papers)
- alazab m. (3 papers)
- alsamhi s.h. (3 papers)
- barnawi a. (3 papers)
- chamola v. (3 papers)
- chehab a. (3 papers)
- chen l. (3 papers)
- chen y. (3 papers)
- elhoseny m. (3 papers)
- fraga-lamas p. (3 papers)
- han z. (3 papers)
- jalaian b. (3 papers)
- li j. (3 papers)
- liu w. (3 papers)
- luong n.c. (3 papers)
- noura h.n. (3 papers)
- salman o. (3 papers)
- wang p. (3 papers)
- wang z. (3 papers)
- yaacoub j.-p.a. (3 papers)

Main keywords

- machine learning (38 papers)
- internet of things (32 papers)
- artificial intelligence (30 papers)
- security (22 papers)
- deep learning (21 papers)
- iot (21 papers)
- internet of things (iot) (16 papers)
- edge computing (13 papers)
- big data (12 papers)
- blockchain (11 papers)
- industry 4.0 (11 papers)
- cloud computing (9 papers)
- cyber-physical systems (9 papers)
- privacy (9 papers)
- smart cities (9 papers)
- uav (9 papers)
- fog computing (8 papers)
- artificial intelligence (ai) (7 papers)
- cyber security (7 papers)
- 5g (6 papers)
- data fusion (6 papers)
- drones (6 papers)
- unmanned aerial vehicles (6 papers)
- covid-19 (5 papers)
- cybersecurity (5 papers)
- drone (5 papers)
- healthcare (5 papers)
- wireless sensor networks (5 papers)
- autonomous systems (4 papers)
- image processing (4 papers)

Main journals

- ieee access (32 papers)
- ieee communications surveys and tutorials (19 papers)
- sensors (switzerland) (15 papers)
- studies in systems, decision and control (6 papers)
- ieee internet of things journal (5 papers)
- information fusion (5 papers)
- lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics) (5 papers)
- future generation computer systems (4 papers)
- journal of network and computer applications (4 papers)
- computer communications (3 papers)
- electronics (switzerland) (3 papers)
- international journal of advanced computer science and applications (3 papers)
- proceedings of spie - the international society for optical engineering (3 papers)
- sustainability (switzerland) (3 papers)
- transactions on emerging telecommunications technologies (3 papers)
- wireless personal communications (3 papers)
- aaai spring symposium - technical report (2 papers)
- acm international conference proceeding series (2 papers)
- ad hoc networks (2 papers)
- advances in information security (2 papers)
- applied sciences (switzerland) (2 papers)
- artificial intelligence review (2 papers)
- complexity (2 papers)
- computers and security (2 papers)
- ieee transactions on industrial informatics (2 papers)
- ieee transactions on intelligent transportation systems (2 papers)
- journal of ambient intelligence and humanized computing (2 papers)
- journal of medical systems (2 papers)
- remote sensing (2 papers)
- sensors (2 papers)

Figure 14: Tabular Information of Sankey Graph in Figure. 13.

2014

- artificial intelligence 1 paper
- neural network 1 paper
- computational intelligence 1 paper
- fuzzy logic 1 paper
- machine intelligence 1 paper
- evolutionary computing 1 paper
- machine learning 0 paper
- internet of things 0 paper
- security 0 paper
- deep learning 0 paper

2015

- machine learning 0 paper
- internet of things 0 paper
- artificial intelligence 0 paper
- security 0 paper
- deep learning 0 paper
- iot 0 paper
- internet of things (iot) 0 paper
- edge computing 0 paper
- big data 0 paper
- blockchain 0 paper

2016

- iot 1 paper
- wireless sensor networks 1 paper
- economic models 1 paper
- pricing models 1 paper
- situation awareness 1 paper
- advanced driving assisted systems 1 paper
- crowdsensing network 1 paper
- high-level information fusion 1 paper
- internet of cars 1 paper
- m2m communication 1 paper

2017

- machine learning 2 papers
- internet of things 2 papers
- internet of things (iot) 2 papers
- artificial intelligence 1 paper
- deep learning 1 paper
- big data 1 paper
- smart cities 1 paper
- uav 1 paper
- cyber security 1 paper
- data fusion 1 paper

2018

- internet of things 4 papers
- iot 4 papers
- machine learning 2 papers
- big data 2 papers
- cyber security 2 papers
- artificial intelligence 1 paper
- security 1 paper
- deep learning 1 paper
- cyber-physical systems 1 paper
- privacy 1 paper

2019

- security 9 papers
- machine learning 6 papers
- iot 6 papers
- deep learning 5 papers
- internet of things 4 papers
- artificial intelligence 4 papers
- big data 4 papers
- privacy 4 papers
- artificial intelligence (ai) 4 papers
- drones 4 papers

2020

- machine learning 18 papers
- internet of things 17 papers
- artificial intelligence 16 papers
- edge computing 11 papers
- deep learning 10 papers
- security 8 papers
- internet of things (iot) 8 papers
- iot 7 papers
- fog computing 7 papers
- blockchain 6 papers

2021

- machine learning 10 papers
- artificial intelligence 7 papers
- internet of things 5 papers
- security 4 papers
- deep learning 4 papers
- iot 3 papers
- internet of things (iot) 3 papers
- smart cities 3 papers
- unmanned aerial vehicles 3 papers
- covid-19 3 papers

Figure 15: Top keywords by year.

The top keywords by year can be seen in Figure 15. The majorly used keywords in the research documents per year have the NoP written right beside it.

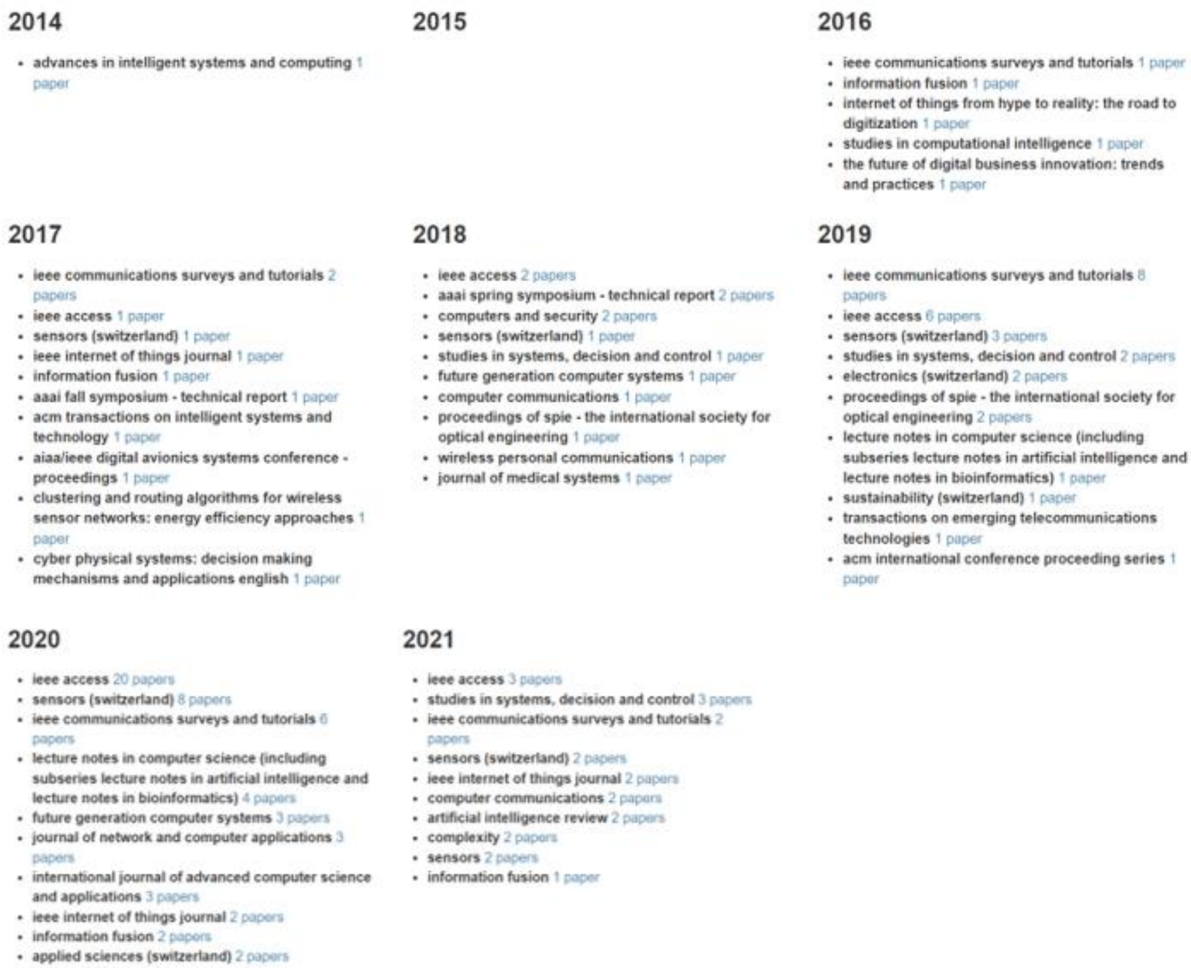

Figure 16: Top journals per year.

Yearly publications of top journals from “Scopus” are shown in Figure 16. The first paper was published in 2014. No papers were published in 2015 but thereafter every year a considerable number of papers were published, in the year 2020, a maximum number of 53 papers were published.

Figure 17: The words in the publication are visualized with word clouds in swarm robotics using IoT and AI.

Figure 17 depicts a word cloud with the most commonly used words in publications for swarm robotics using IoT and AI. The important keywords that were used the most in the study are shown with a larger font scale. The terms "information" and "sensors" are widely mentioned in publications done in this field of research.

3.3 Statistical analysis of publication citation

Table 5 shows annual citations of publications in the field of swarm robotics. According to Scopus, the cumulative number of citations for the 284 publications is 5308. Table 6 displays a list of the top five publications in terms of citations in the Scopus index.

Table 5: Analysis of citations for publications in swarm robotics using IoT and AI.

Year	<2017	2017	2018	2019	2020	2021	Total
No of citations (Scopus)	12	96	317	1020	2742	1121	5308

Table 6: A citation analysis of the top ten publications in swarm robotics using IoT and AI

Sr No.	Publication title	Yearly citations received by the publication						
		<2017	2017	2018	2019	20	2020	Total
1	"Multi-sensor fusion in body sensor networks: State-of-the-art and research challenges"	1	53	76	133	101	30	394
2	"A Tutorial on UAVs for Wireless Networks: Applications, Challenges, and Open Problems"	-	-	-	71	246	65	382
3	"State-of-the-Art Deep Learning: Evolving Machine Intelligence Toward Tomorrow's Intelligent Network Traffic Control Systems"	-	3	58	120	152	38	371
4.	"Unmanned Aerial Vehicles (UAVs): A Survey on Civil Applications and Key Research Challenges"	-	-	-	43	161	50	254

5	"Smart radio environments empowered by reconfigurable AI meta-surfaces: an idea whose time has come"	-	-	-	8	158	43	209
6	"State-of-the-art in artificial neural network applications: A survey"	-	-	-	34	110	54	198
7	"Applications of Deep Reinforcement Learning in Communications and Networking: A Survey"	-	-	-	10	128	52	190
8	"A Survey of Deep Learning: Platforms, Applications and Emerging Research Trends"	-	-	11	45	82	21	159
9	"Survey on UAV Cellular Communications: Practical Aspects, Standardization Advancements, Regulation, and Security Challenges"	-	-	-	19	96	31	146
10	"Data Collection and Wireless Communication in Internet of Things (IoT) Using Economic Analysis	1	15	31	54	29	4	133

Conclusion

This bibliometric analysis of IoT-controlled AI-based Swarm robots is based on Scopus repository research publication results. "Computer Sciences", followed by "Engineering" are some of the leading subject areas in swarm robotics using IoT and AI. In this field of research, the “Internet of Things” journal has by far the most NoP. Major research authors in the articles and conference papers come from a variety of nations, including the United States and China. India and the United Kingdom stand on the same level in terms of their contribution for the key research contributors. The 19 different visualization tools have helped in highlighting the prominent characteristics used in the domain that our topic belongs to with noteworthy authors publishing in the same research area. With each day, the world of robotics undergoes a variety of changes. When these changes are integrated with “Big Data” along with “Data Science Algorithms”, it empowers individuals, the military, and the industry to bring some of the most cutting-edge technologies to life and in use and when robotics is combined with IoT and AI, it demonstrates tremendous potential. These technologies after evolution and success, benefits society by reducing the amount of physical work needed for various activities, as well as adding to and supporting the economy and development of a country. This bibliometric survey will help new researchers identify the research gaps in the field of IoT-controlled AI-based Swarm robots.

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