Bibliometric Review on Inertial Sensors based Position Estimation using Sensor Fusion

Animesh Mishra
Symbiosis Institute of Technology, animesh.mishra.btech2018@sitpune.edu.in

Hamshita Kancharlapalli
Symbiosis Institute of Technology, kancharlapalli.hamshita.btech2018@sitpune.edu.in

Ankit Kumar
Symbiosis Institute of Technology, Ankit.subham.btech2018@sitpune.edu.in

Aditya Chauhan
Symbiosis Institute of Technology, aditya.chauhan.btech2018@sitpune.edu.in

Parag Narkhede
Symbiosis Institute of Technology, ns.parag@yahoo.com

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Animesh Mishra, Hamshita Kancharlapalli, Ankit Kumar, Aditya Chauhan, Parag Narkhede*

Symbiosis Institute of Technology, Symbiosis International (Deemed University), Pune, India 412115
*parag.narkhede@sitpune.edu.in

Abstract

Background: This paper analyzes the position estimation of UAV in a 3D environment, on the basis of inertial sensors and sensor fusion algorithm, done from the year 1994 to 2020. This paper contains various bibliometric analyses previously done on this topic.

Methods: The content for this topic was taken from the popular Scopus database. The Scopus provides many filters for searching databases with different document categories like document by year, country, etc. The research carried in this paper also includes co-authorship, citation analysis, etc.

Results: A total of 345 articles were obtained from the last 20 years, on the topic of position estimation using inertial sensors based on sensor fusion. After analyzing this, it was concluded that the maximum amount of research was done in the year 2020 and it was seen that the contribution from china is maximum on this topic. The research is also increasing year by year.

Conclusions: Out of 345 articles the English language has the largest number of articles on the position estimation of UAV in a 3D environment. From the analysis of it, it was seen that the number of articles was increased drastically in recent years; it was mostly due to the advancement in algorithms. This was clearly indicating that soon more advanced algorithms will come, which will provide a lot of scope for further research.

Keywords: Inertial Sensors; Inertial Measurement Unit; Position Estimation; Sensor Fusion; Unmanned Aerial Vehicle

1. INTRODUCTION

In today’s autonomous world the demand for autonomous vehicles is increasing rapidly. The Unmanned Aerial Vehicles (UAV) have compact size and great ability to move in places where humans cannot go directly and hence, they can be deployed anywhere. In the past UAV was mostly used in military applications like finding enemy bases, search operations, etc [1]. But as time passes by it gained popularity and it is now used by civilians for surveying, monitoring farms, monitoring forest, etc. [2].

To control the operations of unmanned vehicles, the important parameter required to be considered is the position of the vehicle with respect to the known reference. Estimating position of UAV is required to avoid the collision as there may be chances that more than one UAV is flying in a nearby environment. Also, if UAV is deployed in a dense forest, then there is a great chance of collision with trees [3]. Estimating the position is also essential to know the exact location of the UAV as well as it helps to back track the vehicle to its base location [4]. The real time applications require the knowledge of the position of the system in 3-dimensional environment. The prediction in a 3D environment is a little more complex than in a 2D [5]. In the literature, there are many research who have done the work towards position estimation of UAV. Earlier UAV was manually controlled however, due to the increase in technology, now UAV flies autonomously with a pre-planned flight path, which uses automatic navigation with onboard Inertial Measurement Unit (IMU) [6].

IMU consists of a tri-axial gyroscope, tri-axial accelerometer, and tri axial magnetometer. These sensors measure angular velocity, linear movement, and magnetic field, respectively, around the body from the starting point. Accurate and precise sensor measurements are essential for accurate estimation of the position of vehicle. However, the problem with IMU is that it is prone to time varying error and as time increases the measurements are highly affected and becomes less efficient. Drift error which is very small at the start would also become very large over time. To overcome and compensate the error, generally Global Positioning System (GPS) is used along with IMU [7].

Although use of GPS increases the accuracy of position estimation system; it has some drawbacks. UAV flies near mountains, water bodies, forests may be tunnels etc. and at such locations GPS signals are weak or even absent [8]. Hence, at such times the navigation of the vehicle is completely dependent on the IMU sensors which become quite troublesome as the inaccurate sensors may led to some unavoidable conditions. To overcome these drawbacks, various vision-based techniques were discussed researchers in the literature [9]. These techniques include methods like mounting cameras, using LiDAR-based methods, and many more.

It has also been reported that the single sensor-based systems are less accurate due to limitations of individual sensors. Generally, sensors have limited temporal and spatial coverage, sensors are limited to their individual sensing capabilities and responses. Hence to overcome these disadvantages sensor fusion techniques are developed. Sensor fusion is the process of combining measurements of two or more sensors to obtain improved response compared to that of individual. Sensor fusion provides the advantage of improvement in coverages as well as improvement in accuracy of the system [10]. In the application of robotic position estimation, various sensors including gyroscope, accelerometer, magnetometer, GPS, and vision sensors etc. Sensor fusion has shown remarkable performance UAV attitude estimation application [11-15]. in the These sensors have individual limitations and hence combinations of these have proven to be giving better estimations of the position of moving vehicle. Kalman filter and its variants are the most widely used sensor fusion algorithm observed in the literature.

A fusion of optical sensor and inertial sensors is discussed in [16] for the estimation of position and orientation of AR Drone 2.0. A design of an optimal proportional integral derivative controller that follows multi objective particle swarm optimization is also presented in this work. Zhao et al. solved the problem of accumulation of error in IMU sensors by developing system using sensors for determining the orientation and position by using complementary sensors such as the accelerometer, gyroscopes, magnetometer along with the ultrasonic sensor [17]. In this work, accelerometers are used for measuring the displacement that takes place and the ultrasonic sensors are used to estimate the accelerometer drift in the measurements of the position. The approach is presented to estimate the accurate position and orientation of the moving body. Use of a single sensor does not guarantee for the accuracy of the results. Hence in [18] vision sensor is also used along with the IMU to get the accurate position estimation of a device. 6 degrees of freedom IMU having three axes accelerometer along with three axis gyroscope is considered in the work. A low-cost vision sensor is also used for determining the accurate position in case of mobile robot. Objection detection algorithm Speed Up Robust Feature (SURF) and the random sample consensus are used for a monocular vision. The fusion of IMU and vision sensors is carried out using the Extended Kalman Filter algorithm. The results shows that the fusion of various measurements provide better results than a single sensor-based system.

Position estimation plays an important role in the obstacle avoidance system. An optimized vision-based robot control system is presented in [19] for avoiding obstacles. The fusion of active beacon and tri axial IMU is proposed for the application of position estimation by Lee et al [20]. Due to presence of obstacles, indoor environment is generally unstable and hence active beacon system is used to update the position estimations by IMU. In case of uncertain data regarding the position, absolute data about the position is provided by the active beacon system. Robot rotation angle is calculated with the help of beacon system as it consists of two ultrasonic sensors. Kalman filter and a low pass filter are used to reduce noise in the inputs.

Zhang in 2019 proposed an IMU aided radio frequency positioning system for improved position estimation in indoor environment. In this the IMU is connected to a wireless transmission module that allows the users to monitor process related motion parameters. Radio frequency alone is often inadequate in case of providing the accurate position and stability due the complication and unpredictability of the indoor signals. it shown that an IMU-aided RF positioning system provides improvement in the accuracy of the system in indoor environment [21]. As the measurements of inertial sensors suffer from errors which lead to a quick divergence of the position estimation. Angelino et al in [22] proposed a methodology of integration of measurements from inertial sensors, GPS, and video system. This system has many advantages with respect to the traditional GNSS such as high accuracy and greater rate of data.

Projective transformation of a planar object is utilized for robust and real-time three-dimensional pose estimation of UAV in [23].

The UAVs are made to communicate with Long Range Wide Area Network (LoRaWAN) along with an enlarged version of Constant Turn Rate and Acceleration (CTRA) motion model, that has been used for predicting the motion of the Drone in three-dimensional environment in [24]. A monocular camera is implemented on the drone and images from that are used to estimate the position of the Drone using Unscented Kalman Filter in [25]. Arreola et al. presented a sensor fusion methodology for improvement in the position estimation of UAV using IMU, GPS and vision sensors. The results are validated using a quadcopter platform and found that fusion has improved the estimation accuracy [26].

2. MATERIALS AND METHODS

2.1 Primary Dataset Collection

Research community used various databases to carry out their research work in cutting edge things. The different databases include Scopus, Google Scholar, Web of Science, EBSCO etc. amongst these Scopus is the one of the most popular and authentic database. Hence, the analysis done in this paper is based on the Scopus databases. The database search on Scopus is carried out on May 14, 2021 with publication year restricted till year 2020.

Initially a search is carried out using popular keywords observed in the literature. Primary keywords used in Scopus to search the articles are

- Position Estimation
- Kalman filter
- Inertial Measurement Unit
- Inertial Navigation Systems

On carrying out the search using these keywords, other relevant keywords are found. Table 1 shows the publication count per keyword for the top few keywords.

Table 1: List of keywords

Keywords	**Number of publications**	**Keywords**	**Number of publications**
Inertial measurement unit	151	Accelerometers	47
Position estimation	107	Sensor fusion	32
Unit of errors	107	Cameras	29
Global positioning system	100	Robotics	29
Kalman filters	99	Robot	29
Inertial navigation system	90	Vehicles	30
Navigation	81	UAV	28
Tracking(position)	80	State estimation	27
Estimation	73	Position estimation	25
Extended Kalman filters	60	Pose estimation	25
Sensors	57	Sensor data fusion	24
Gyroscope	33	Data fusion	24
		Motion estimation	22

English being the most popular language used by researchers worldwide, it is observed that from the of total 345 publications, 327 publications are written and published in English language. Table 2 shows the trend of Publishing language.

Table 2: Latest Publishing Language trends

Publication Types	Publication Count
English	327
Chinese	12
Korean	5
Turkish	1
Total	**345**

Researchers have contributed up to 50 % papers in journal articles whereas almost 48 % articles in conference proceedings. Table 3 indicates the details of the document type publications.

Table 3: Document Types

Document Type	Number of Publications	Percentage out of 345
Article	173	50.14%
Conference Proceedings	166	48.12%
Review	3	0.87%
Book Chapter	2	0.58%
Letter	1	0.29%

2.2 Preliminary Data Highlights

Keyword based Scopus search resulted into 345 publications. The search result shows that, in the initial years, the publication count was less and in almost last decade the count is c=increasing significantly. Publication count per year is shown in Table 4 and year wise publication analysis is indicated in Figure 1.

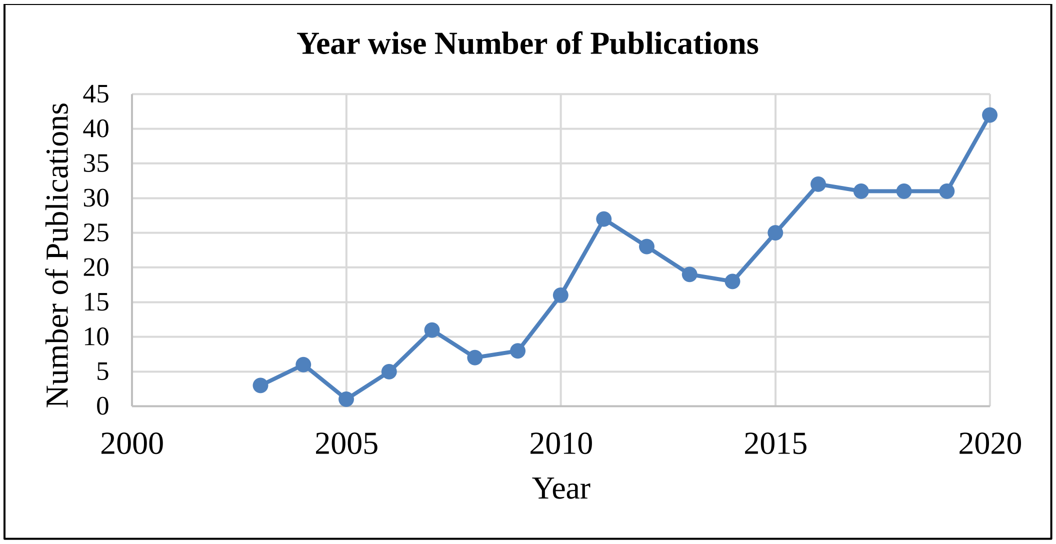

Figure 1: Yearly data Vs number of publications

Table 4: Publication count per year

Year	**Publication Count**	**Year**	**Publication Count**
2020	42	2008	7
2019	31	2007	11
2018	31	2006	5
2017	31	2005	1
2016	32	2004	6
2015	25	2003	3
2014	18	2002	3
2013	19	2001	1
2012	23	2000	1
2011	27	1999	2
2010	16	1998	1
2009	8	1992	1
Total 345			

3. BIBLIOMETRIC ANALYSIS

In this segment bibliometric analysis were looked out in terms of contributions from each countries, subject area, contributions from author and their affiliations and more relevant data for this project.

3.1 Geographical analysis

Researcher across the globe have contributed to position estimation of UAV in 3D environment projects. But out of those countries China, USA, Japan, Germany, South Korea are some of major countries contributing into this. Figure 2 indicates about the geographical mapping of the countries contributing to the research of position estimation of UAV in 3D environment.

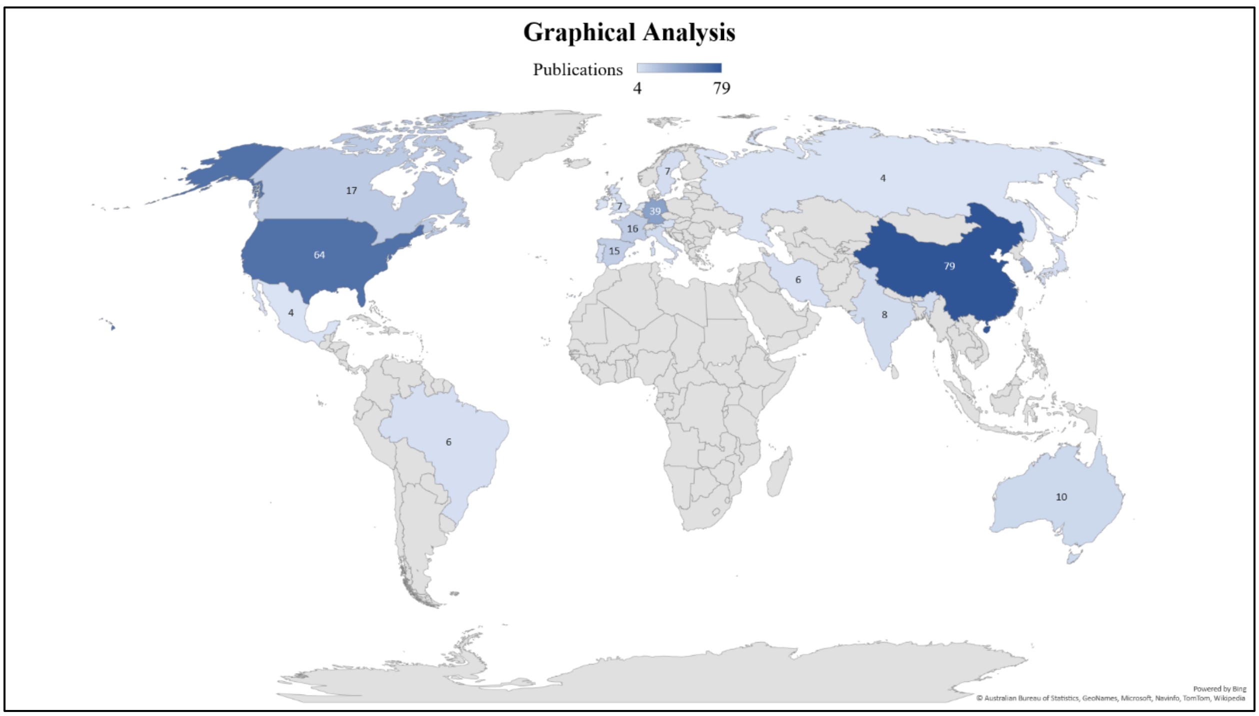

Figure 2: Geographical mapping of the countries

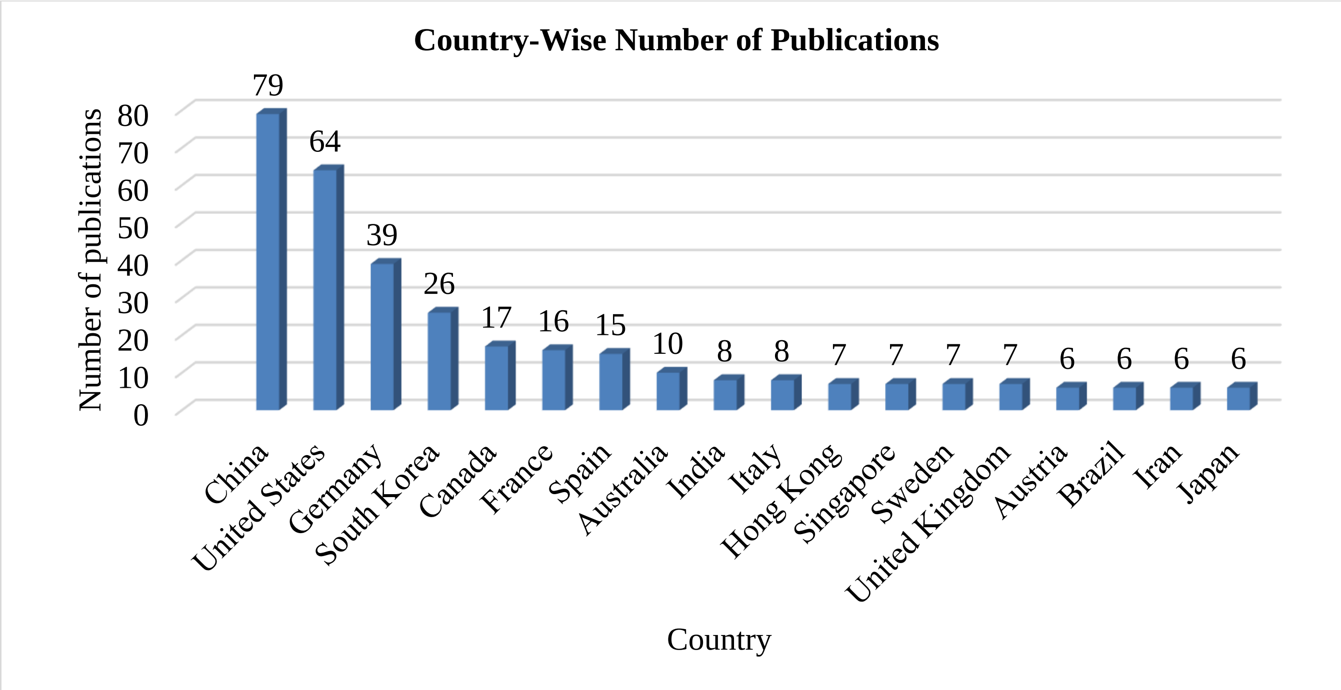

Figure 3: Analysis of publications: Country specific

3.2 Analysis based on the subject area

Figure 4 indicates the subject wise contribution for research papers. Engineering and Computer Science constitute the maximum number of papers in position estimation of UAV in 3D environment. Mathematics, physics, and astronomy are the major subjects in the research of position estimation of UAV. Chemical engineering, material sciences, social sciences contribute less to the research of position estimation.

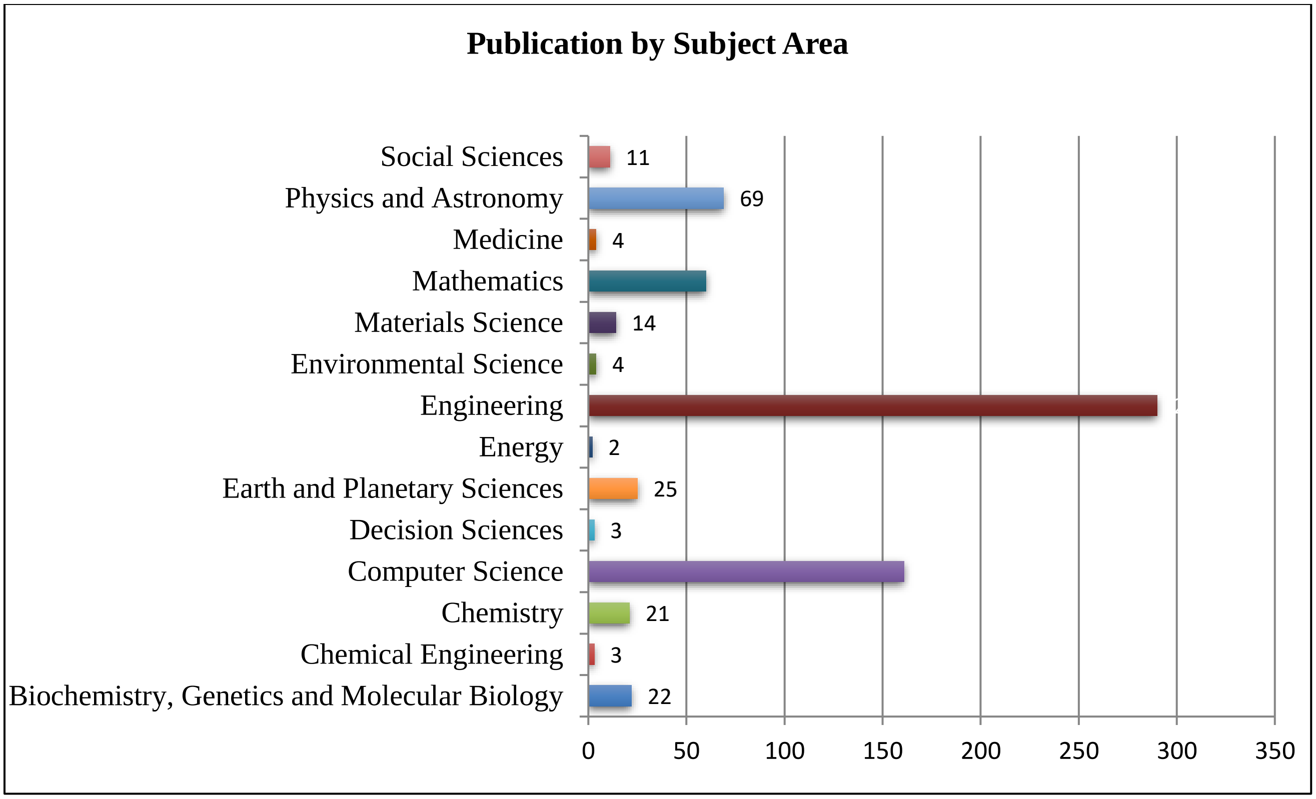

Figure 4: Subject area wise analysis of position estimation of UAV

3.3 Affiliations based Analysis

The contribution of top 17 organizations and universities from all over the world in project related to Inertial Sensors based Position Estimation is presented in figure 5. The research in this field of Position Estimation is dominated by The Beihang University.

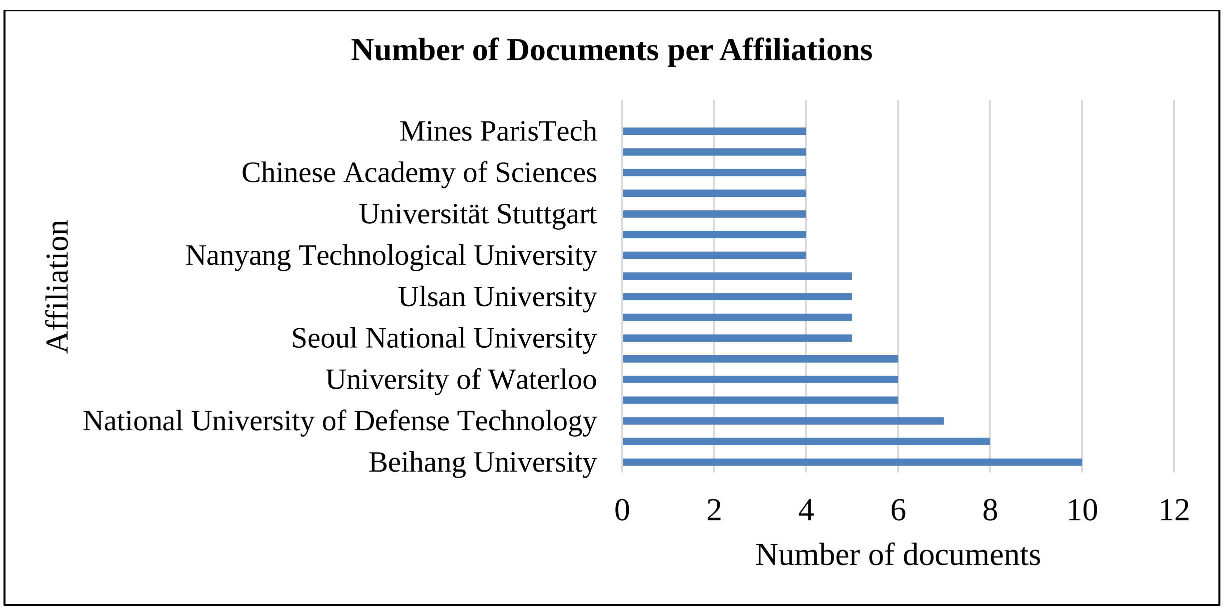

Figure 5: Analysis of affiliations for publications for position estimation

3.4 Author-wise publication details

Figure 6 indicates the list of authors contributing to the research of position estimation of UAV. Bachmann, E.R. and Yun, X. are two main contributing authors with about 5 publications followed by Fang, J. and Fourati, H. with 4 publications each.

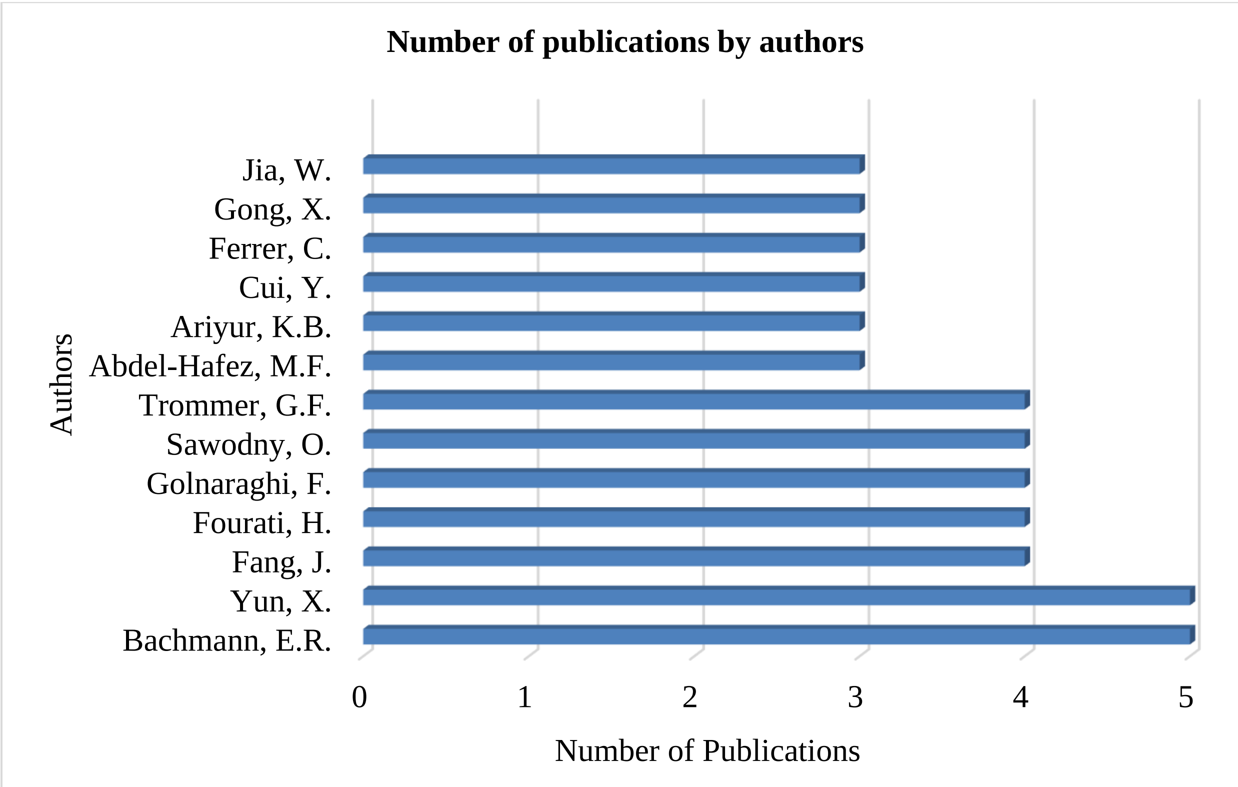

Figure 6: Majorly contributing authors in position estimation research

3.5 Funding sources and publications

Figure 7 indicates number of publications and funding sources analysis in the field of Position Estimation of UAV. National Natural Science Foundation of China dominated the world by around 35 publications followed by the Fundamental Research Funds for the Central Universities and Ministry of Education of the People's Republic of China

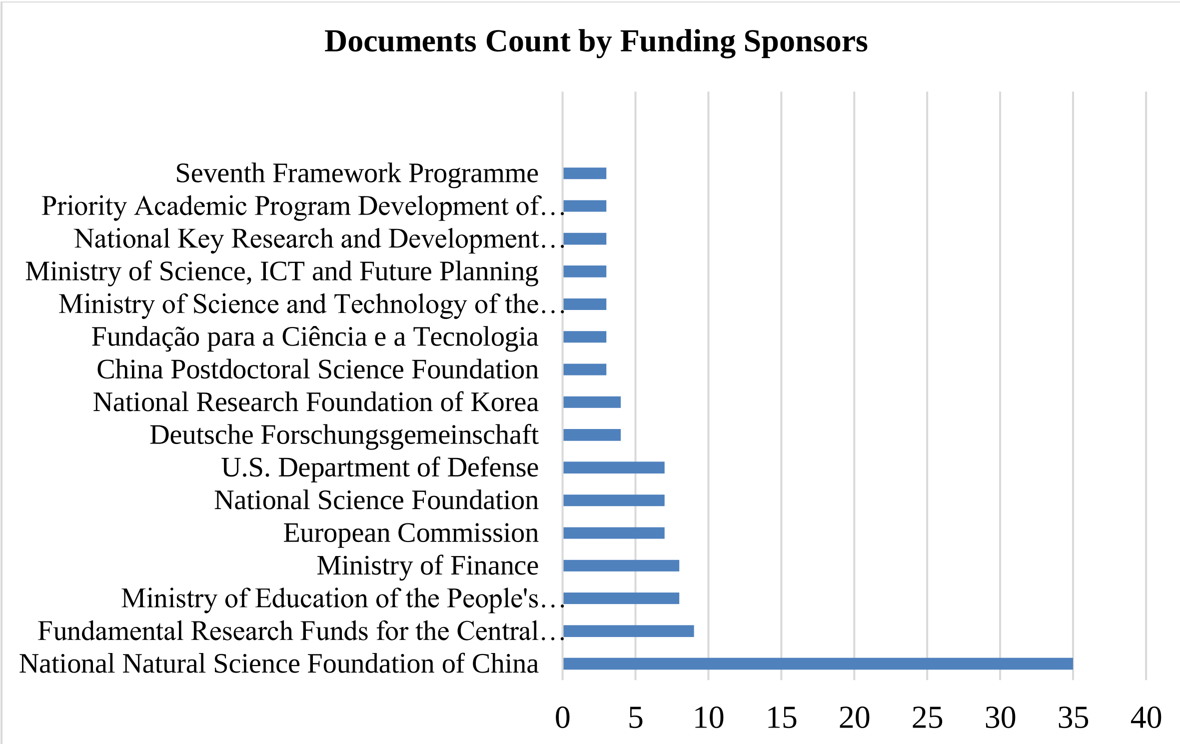

Figure 7: Number of publications and Funding sources Analysis

3.6 Analysis by Publication Source

Figure 8 mainly indicates publications in position estimation of UAV based on type of the document. It has been observed that out of total publication 50.14% papers are mainly published in journals. Also, the researchers are keen in publishing their research work in conferences as 48.12% contributes to conference papers. Nearly 1.16% documents are providing book series about various aspects about position estimation of UAV.

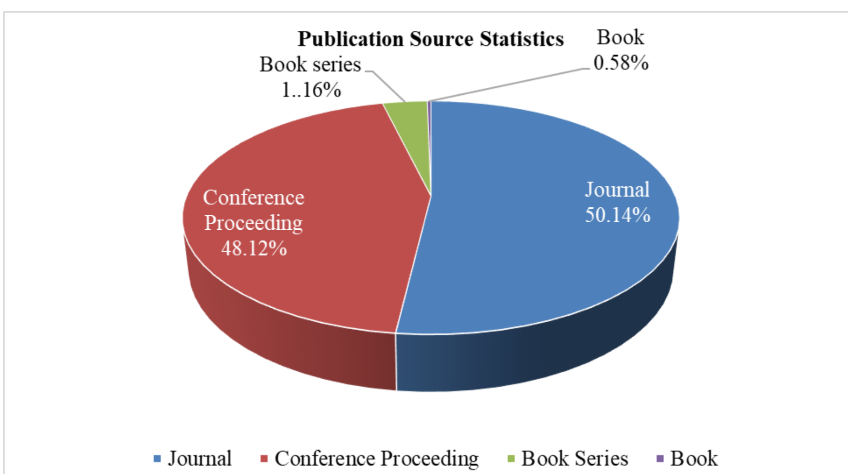

Figure 8: Analysis on Types of Document

3.7 Analysis by Document Source

Figure 9 shows the documents published in top journals. 19 articles are published in Sensors journal is at the top.

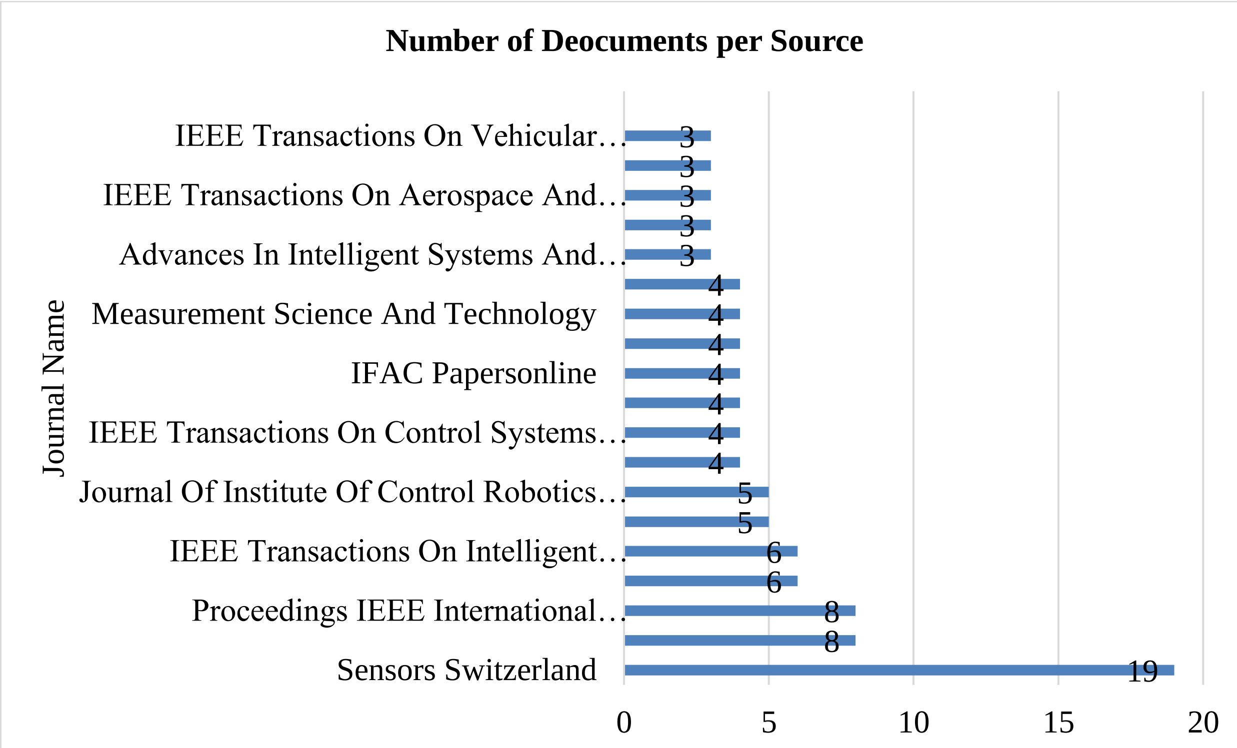

Figure 9: Document analysis by document source

4. NETWORK ANALYSIS

Network analysis plays a major role in knowing the co-authored publications and research relations between multiple entities. To carry out the network analysis, VOSviewer software is used. It is an open source and easy to use tool to carry out network analysis. While doing this network analysis maximum 25 authors per document are considered.

4.1 Co-authorship analysis

Co-authorship analysis is carried out in three categories, authors, organizations, and countries. Co-authorship network analysis based on authors is shown in figure 10. In this work, 2 documents per author are considered to be minimum network criteria. Out of total 964 authors, 128 meet the threshold of 2 documents. Only the top authors are shown in figure.

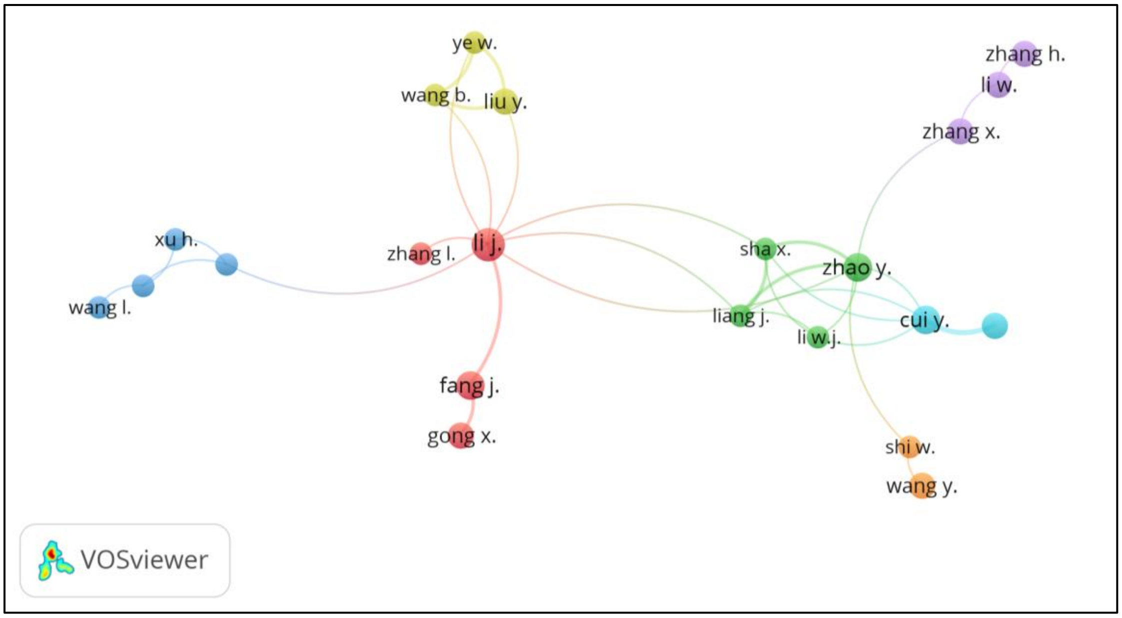

Figure 10: Co-authorship network analysis in terms of authors

In the co-authorship network analysis by organizations, organizations having minimum 2 documents are considered. Out of total total 571 organization 22 meet the criteria. Figure 11 indicates the Co-authorship network analysis in terms of organizations.

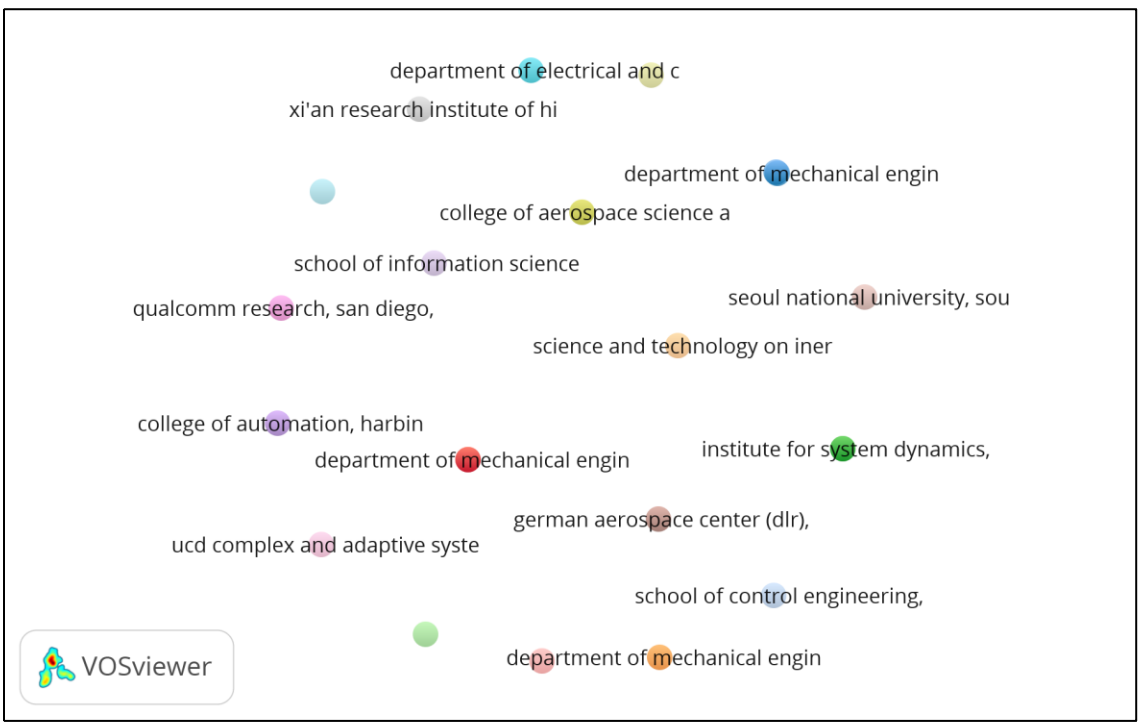

Figure 11: Co-authorship network analysis based on organizations

Figure 12 shows the coauthor ship network analysis in terms of countries. Only the top ranked networks are shown in figure 12.

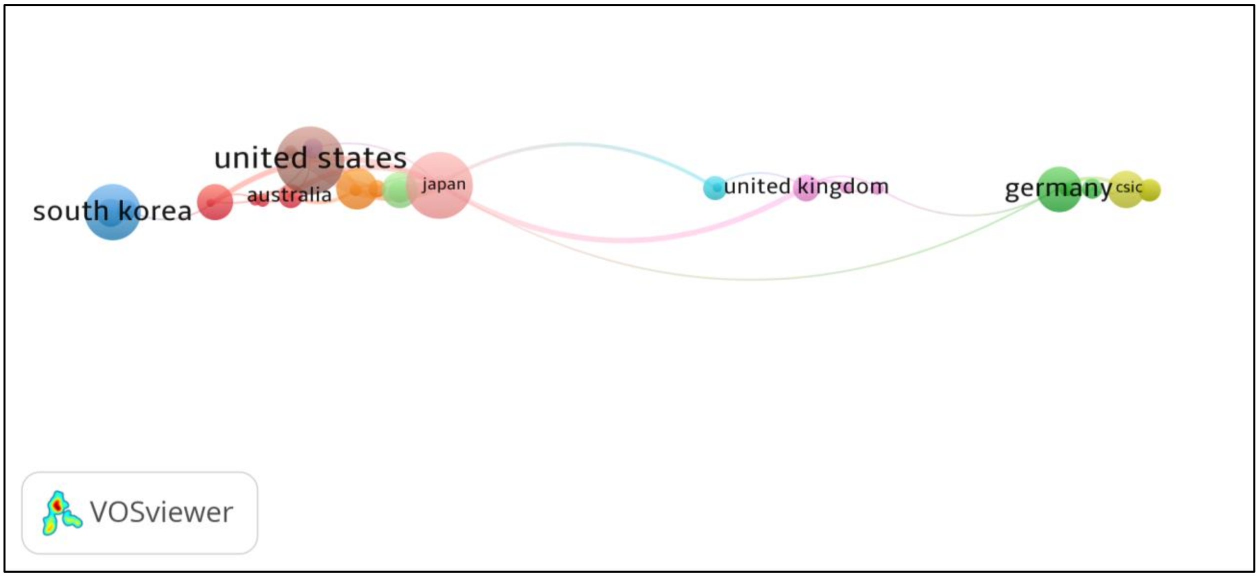

Figure 12: Co-authorship network analysis based of countries

4.2 Citation Analysis

Network analysis based in Country wise citation is shown in figure 13. Countries with minimum 2 documents are considered, and hence out of total 56 countries 19 meet the criteria. Only the top countries are shown in figure.

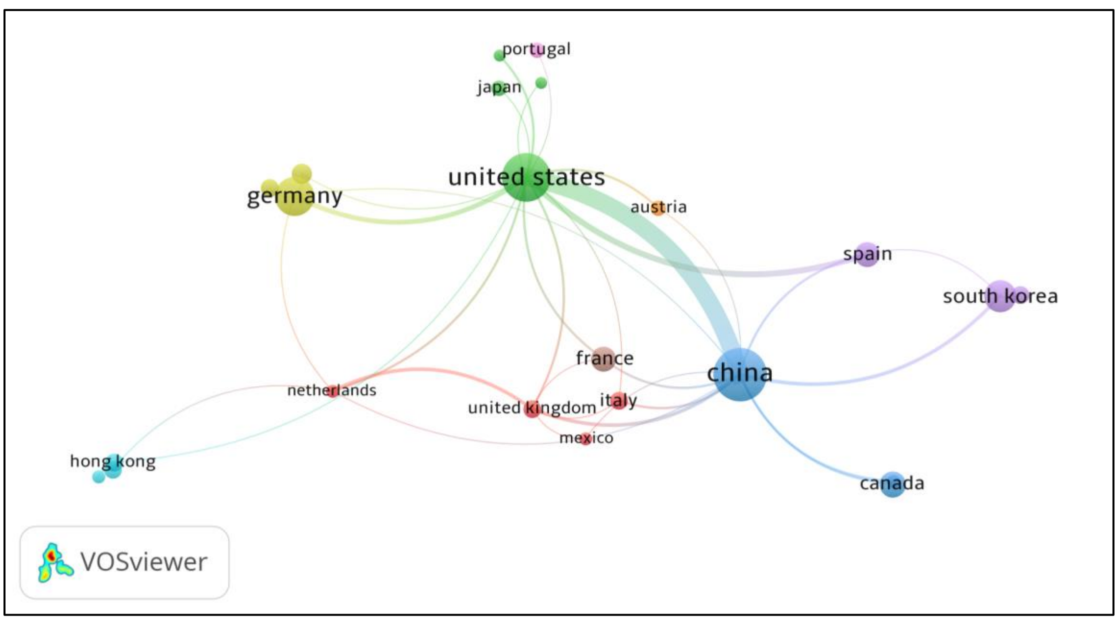

Figure 13: Network analysis based on Country wise citation

5. CONCLUSION

This paper discussed a brief bibliometric review of the inertial sensors-based position estimation systems that used sensor fusion as their base. Different analyses were carried out and results are indicated. Well known Scopus database is used for doing the database search. Initial search is carried out with keyword Position Estimation and inertial measurement unit. Total 345 articles are found published till year 2020. Maximum papers are published in the journals and conference proceedings. Year wise publication analysis indicates that the number of publications are increasing every year indicating the importance and applications of the considered topic. China and United States of America are the most contributing counties in the position estimation research work. Network analysis is also carried out using the VOSviewer, an open-source network analysis tool

References

[1] Motlagh, H. D. K., Lotfi, F., Taghirad, H. D., & Germi, S. B. (2019, November). Position Estimation for Drones based on Visual SLAM and IMU in GPS-denied Environment. In *2019 7th International Conference on Robotics and Mechatronics (ICRoM)* (pp. 120-124). IEEE.

[2] Engel, J., Stückler, J., & Cremers, D. (2015, September). Large-scale direct SLAM with stereo cameras. In *2015 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)* (pp. 1935-1942). IEEE.

[3] Balamurugan, G., Valarmathi, J., & Naidu, V. P. S. (2016, October). Survey on UAV navigation in GPS denied environments. In *2016 International conference on signal processing, communication, power and embedded system (SCOPES)* (pp. 198-204). IEEE.

[4] Wanli, X., Shuo, B., & Zhun, L. (2014, September). The state estimation of UAV based on UKF. In *2014 IEEE Workshop on Advanced Research and Technology in Industry Applications (WARTIA)* (pp. 402-405). IEEE.

[5] Kakillioglu, B., Wang, J., Velipasalar, S., Janani, A., & Koch, E. (2019, November). 3D Sensor-Based UAV Localization for Bridge Inspection. In *2019 53rd Asilomar Conference on Signals, Systems, and Computers* (pp. 1926-1930). IEEE.

[6] Eling, C., Klingbeil, L., & Kuhlmann, H. (2015). Real-time single-frequency GPS/MEMS-IMU attitude determination of lightweight UAVs. *Sensors*, *15*(10), 26212-26235.

[7] Vissiere, D., Martin, A., & Petit, N. (2007, July). Using magnetic disturbances to improve IMU-based position estimation. In *2007 European Control Conference (ECC)* (pp. 2853-2858). IEEE.

[8] Rady, S., Kandil, A. A., & Badreddin, E. (2011, December). A hybrid localization approach for uav in gps denied areas. In *2011 IEEE/SICE International Symposium on System Integration (SII)* (pp. 1269-1274). IEEE.

[9] Kumar, G. A., Patil, A. K., Patil, R., Park, S. S., & Chai, Y. H. (2017). A LiDAR and IMU integrated indoor navigation system for UAVs and its application in real-time pipeline classification. *Sensors*, *17*(6), 1268.

[10] Elmenreich, W. (2007, May). A review on system architectures for sensor fusion applications. In *IFIP International Workshop on Software Technolgies for Embedded and Ubiquitous Systems* (pp. 547-559). Springer, Berlin, Heidelberg.

[11] Kottath, R., Narkhede, P., Kumar, V., Karar, V., & Poddar, S. (2017). Multiple model adaptive complementary filter for attitude estimation. *Aerospace Science and Technology*, *69*, 574-581.

[12] Narkhede, P., Joseph Raj, A. N., Kumar, V., Karar, V., & Poddar, S. (2019). Least square estimation-based adaptive complimentary filter for attitude estimation. *Transactions of the Institute of Measurement and Control*, *41*(1), 235-245.

[13] Poddar, S., Narkhede, P., Kumar, V., & Kumar, A. (2017). PSO aided adaptive complementary filter for attitude estimation. *Journal of Intelligent & Robotic Systems*, *87*(3), 531-543.

[14] Narkhede, P., Poddar, S., Walambe, R., Ghinea, G., & Kotecha, K. (2021). Cascaded Complementary Filter Architecture for Sensor Fusion in Attitude Estimation. *Sensors*, *21*(6), 1937.

[15] Tripathi, K., Narkhede, P., Kottath, R., Kumar, V., & Poddar, S. (2016, October). Design considerations of orientation estimation system. In *2016 5th International Conference on Wireless Networks and Embedded Systems (WECON)* (pp. 1-6). IEEE.

[16] Mac, T. T., Copot, C., De Keyser, R., & Ionescu, C. M. (2018). The development of an autonomous navigation system with optimal control of an UAV in partly unknown indoor environment. *Mechatronics*, *49*, 187-196.

[17] Zhao, H., & Wang, Z. (2011). Motion measurement using inertial sensors, ultrasonic sensors, and magnetometers with extended kalman filter for data fusion. *IEEE Sensors Journal*, *12*(5), 943-953.

[18] Alatise, M. B., & Hancke, G. P. (2017). Pose estimation of a mobile robot based on fusion of IMU data and vision data using an extended Kalman filter. *Sensors*, *17*(10), 2164.

[19] Olivares-Mendez, M. A., Campoy, P., Mellado-Bataller, I., & Mejias, L. (2012, June). See-and-avoid quadcopter using fuzzy control optimized by cross-entropy. In *2012 IEEE International Conference on Fuzzy Systems* (pp. 1-7). Ieee.

[20] Lee, T., Shin, J., & Cho, D. (2009, July). Position estimation for mobile robot using in-plane 3-axis IMU and active beacon. In *2009 IEEE International Symposium on Industrial Electronics* (pp. 1956-1961). IEEE.

[21] Zhang, S. (2019). Exploring imu attitude and position estimation for improved location in indoor environments.

[22] Angelino, C. V., Baraniello, V. R., & Cicala, L. (2012, July). UAV position and attitude estimation using IMU, GNSS and camera. In *2012 15th International Conference on Information Fusion* (pp. 735-742). IEEE.

[23] Mondragón, I. F., Campoy, P., Martinez, C., & Olivares-Méndez, M. A. (2010, May). 3D pose estimation based on planar object tracking for UAVs control. In *2010 IEEE International Conference on Robotics and Automation* (pp. 35-41). Ieee.

[24] Mason, F., Chiariotti, F., Capuzzo, M., Magrin, D., Zanella, A., & Zorzi, M. (2020, July). Combining LoRaWAN and a new 3D motion model for remote UAV tracking. In *IEEE INFOCOM 2020-IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)* (pp. 412-417). IEEE.

[25] Tang, S. H., Kojima, T., Namerikawa, T., Yeong, C. F., & Su, E. L. M. (2015, July). Unscented Kalman filter for position estimation of UAV by using image information. In *2015 54th Annual Conference of the Society of Instrument and Control Engineers of Japan (SICE)* (pp. 695-700). IEEE.

[26] Arreola, L., De Oca, A. M., Flores, A., Sanchez, J., & Flores, G. (2018, June). Improvement in the UAV position estimation with low-cost GPS, INS and vision-based system: Application to a quadrotor UAV. In *2018 International Conference on Unmanned Aircraft Systems (ICUAS)* (pp. 1248-1254). IEEE.