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OVERVIEW

Application-Based Review of Soft Computational Methods to Enhance Industrial Practices Abetted by the Patent Landscape Analysis

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Received: 3 July 2024 | **Revised:** 29 August 2024 | **Accepted:** 9 September 2024

Edited by: Tianrui Li, Associate Editor and Witold Pedrycz, Editor-in-Chief

Funding: The authors received no specific funding for this work.

Keywords: applications | patent landscape | productivity | soft computing | technology

ABSTRACT

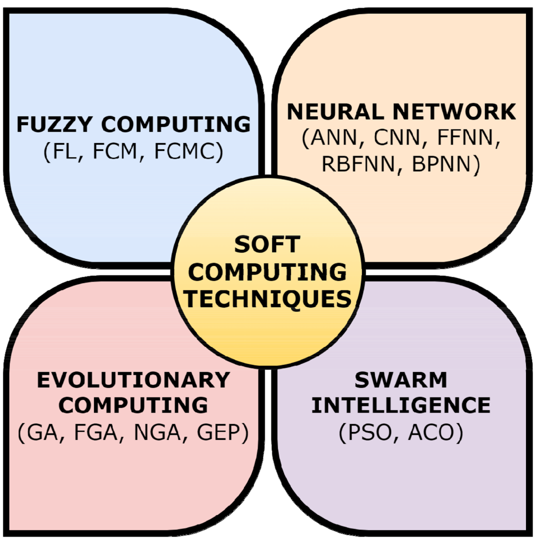
Soft computing is a collective methodology that touches all engineering and technology fields owing to its easiness in solving various problems while comparing the conventional methods. Many analytical methods are taken over by this soft computing technique and resolve it accurately and the soft computing has given a paradigm shift. The flexibility in soft computing results in swift knowledge acquisition processing and the information supply renders versatile and affordable technological system. Besides, the accuracy with which the soft computing technique predicts the parameters has transformed the industrial productivity to a whole new level. The interest of this article focuses on versatile applications of SC methods to forecast the technological changes which intend to reorient the progress of various industries, and this is ascertained by a patent landscape analysis. The patent landscape revealed the players who are in the segment consistently and this also provides how this field moves on in the future and who could be a dominant country for a specific technology. Alongside, the accuracy of the soft computing method for a particular practice has also been mentioned indicating the feasibility of the technique. The novel part of this article lies in patent landscape analysis compared with the other data while the other part is the discussion of application of computational techniques to various industrial practices. The progress of various engineering applications integrating them with the patent landscape analysis must be envisaged for a better understanding of the future of all these applications resulting in an improved productivity.

Abbreviations: ACO, ant colony optimization; AI, artificial intelligence; ANFIS, adaptive neuro-fuzzy inference system; ANN, artificial neural network; BLR, binary logistic regression; BN, Bayesian network; BPNN, back propagation neural network; CART, classification and regression trees; CNN, convolution neural network; CT, DT, classification tree, decision tree; EC, evolutionary computation; FCM, fuzzy cognitive maps; FCMC, fuzzy C-means clustering; FFNN, feed-forward neural network; FGA, fuzzy-genetic approach; FL, fuzzy logic; FORM, first-order reliability method; GA, genetic algorithm; G-ANN, gray-artificial neural networks; GBM, gradient-boosting machine; GEP, gene expression programming; GP, Gaussian processes; H & SC, hard and soft computing; HFNS, hybrid fuzzy neural system; KNN, K-nearest neighbor; LR, logistic regression; MARS, multivariate adaptive regression splines; NGA, neural-genetic algorithm; NGS, neuro-genetic system; PCA, principle component analysis; PSO, particle swarm optimization; RBFNN, radial basis functional neural network; RF, random forest; SC, soft computing; SI, swarm intelligence; SVM, support vector machines.

1 | Introduction

Soft Computing (SC) is an advanced learning technique that uses the motion and perception combination for its learning. SC places itself in a key position by paving the way for advanced knowledge processing. SC techniques are known for their interactive knowledge processing with humans, the environment, and other AI platforms while they are characterized by advantages like self-organizing, emergent, and reflective techniques which exchange their ideas with bio-information processing (Ovaska et al. 1999; Kaushal, Khehra, and Sharma 2018). The benefits of SC techniques include a highly flexible knowledge acquisition by learning from a broad range of data, representing its knowledge by patterns and symbols, and processing the acquired knowledge through the pattern-symbol interface. This results in the development of low-cost intelligent systems that can handle any set of data and render very efficient outputs. The SC variants perform calculations without any mathematical techniques for the problem. It is categorized under intelligence computing; wherein complex problems are resolved effectively and work similarly to the human brain (Saridakis and Dentsoras 2008; Moridian et al. 2022; Aydilek 2018). The SC techniques are completely adaptive which eases the getting of output for various applications containing different parameters. This in turn expands the scope of usage of the SC techniques in versatile industrial domains. Not only major industrial applications but also various minor sub-domains of the applications are using SC techniques to improve their productivity lately (Lasheen and Abdel-Salam 2018; Abdolrasol et al. 2021). Scheme 1 depicts the classification of SC techniques and their subclassifications.

Most of the SC techniques are a combination of the techniques which combines the cognition and consciousness in various aspects so that the SC technique learns from its experience, generalizes itself into various industrial fields where direct human intervention is impossible and they also simulate complex biological processes through parallel computer architecture. All these unique characteristics of the SC techniques combined with their ability to self-tuning through experimental data exposed them to various industrial applications involving large data to be optimized (Ali et al. 2022; Hurwitz et al. 2015; Marcinkevičs and Vogt 2023). The utilization of various soft computational methods in the industries has been dealt with meagerly in most of the recently published articles. The future prediction of SC techniques utilization of SC methods has not been made in any of the literature using the patent landscape analysis. Accordingly, some important service and manufacturing sectors like medical, construction, aeronautical, power, communication, mechanical, transportation, automation, and robotics were taken for analysis. In all the above industries, the role of SC methods has been discussed and consolidated along with the probable sub-domains in which the SC techniques were applied. Various published literature works were considered, and the accuracy of the SC technique used in each article has been given for all the application areas. The accuracy given for each technique specifies the rate with which any SC method can predict the output responses for a given specific set of input parameters. It could be very well understood that the higher accuracy specifies a higher reliability of the SC technique adopted for the application. Additionally, a patent landscape analysis was also performed to predict the progress pathway of the SC methods in various countries and industries.



SCHEME 1 | Soft computing techniques.

2 | Application of SC Techniques

2.1 | Medical Industry

The physical changes caused by the dysfunction in behavior affect human beings physically as well as mentally (Sarafino and Smith 2011). This leads to disorders in terms of thinking ability and affects their socio-physical behavior (Kaur and Sharma 2019). Physical disorders are the primary source of most health-oriented issues (The Banyan n.d.). The association of SC proved that the approximation, uncertainty, and processing of the captured images are processed better when compared to the hard computing method (Kaur and Sharma 2017; Zadeh 1996). Fuzzy can handle the rate of truth while comparing with the accurate values to state whether it is false or true so it can be used for effective handling of imprecise (Zadeh 1988). A neural network can be utilized with other methods for the perfect prediction of anomalies (Smith 1993). Naturally inspired computing is used to derive novel algorithms that are used to detect medical anomalies (Fister Jr et al. 2013). Stochastic thinking contributes to reckoning standards for haphazard variables (Ikeda, Tanaka, and Amari 2004). Deep learning is gaining more popularity in the medical field owing to its accuracy (LeCun, Bengio, and Hinton 2015; Litjens et al. 2017).

The SC method is used for versatile medical applications and it is most effective for diagnosing disease (Kannan and Vasanthi 2019; Mittal et al. 2019), for optimization of the query (Sharma et al. 2013; Panahi and Navimipour 2019; Sharma, Singh, and Singh 2018), selecting features (Sayed, Hassanien, and Azar 2019; Rao et al. 2019), for scheduling tasks (Akbari, Rashidi, and Alizadeh 2017; Prakash and

Vidyarthi 2015), analyzing sentiments of human (Hussein and Mohamed 2018; Onan and Korukoğlu 2017), for analyzing the balance stock (Göçken et al. 2019) as well as the prediction of crop specifically for a medical purpose (Sethy et al. 2018; Deepa and Ganesan 2018) in case of using other techniques which may be little tedious. Hybrid SC techniques along with nature-inspired methods are playing a vital role nowadays. Some of them are Gray colored wolf based technique for optimization (Mirjalili, Mirjalili, and Lewis 2014), Crow behavior-inspired searching technique derived algorithm (Zolghadr-Asli, Bozorg-Haddad, and Chu 2018), Hawks based derived algorithm for optimization (Debruyne and Kaur 2016), an Artificial method of feeding based algorithm for birds (Lamy 2019), Ants, as well as lion, inspired algorithms for optimization (Mirjalili 2015), Snake inspired technique for optimization (Naghdiani and Jahanshahi 2017), Spot by hyena method for optimization (Dhiman and Kumar 2019), Elephant deriving the steering for optimization (Wang, Deb, and Coelho 2015), Penguins emperor derived from the colony (Harifi et al. 2019), Whale behavior-based algorithm for optimization (Mirjalili and Lewis 2016). Most of these techniques are used for the identification of the various psychological behaviors of human beings.

The fuzzy technique is used to predict psychiatric problems (Ahmadi et al. 2018). Fuzzy is combined with other techniques to enhance the diagnosis with DNN—D. Neural Network-based technique (Liu et al. 2017), DBN—D. Belief Network-based method (Faust et al. 2018), RBM—R. Boltzmann Machine-based technique (Liao, Jin, and Pavel 2016), as well as the CNN—Convolutional Neural Network-based method (Lakhani and Sundaram 2017) for image and video and audio analysis. Advanced Deep learning techniques are effectively addressing the issues in the medical field too (Litjens et al. 2017). Likewise, in the medical field, it is used in versatile ways. The major identity is the capability of this technique to resolve sophisticated medical issues, therein which demands accuracy at the smallest level. The following Table 1 depicts the various ways SC is employed in the medical field.

The landscape analysis is carried out for SC in medicine shown in the following table. Figure 1 reveals a few parameters for assessing, United States is quite a dominant player in using SC for medical applications. The dominant applicant or major individual player is "Z advanced computing Inc.", they have filed 9 patent applications in this domain. Gradually the year-wise filing patents showed sinusoidal motion, the reason might be based on the need for this technique. Recently, SC is getting hybrid with Artificial Intelligence (AI) and data analytics to show superior performances. The other observation concerning the country is, the consideration parameter is none of the other countries followed by the United States is not in the nearby count, it might be because of the technical experts' availability in this domain. United States is good in the medical field as well as in software, along they understood the nuances of using SC feasibly. The total count is 169 as per the record for the keyword EN_ALL: ("Soft computing" "Medicine"). In addition, only one application by count was considered which is being filed as multiple applicants from different countries.

2.2 | Construction and Civil Engineering Industries

Civil engineering glitches have been frequently considered by noteworthy levels of difficulty, they are normally approached as well as resolved by merging numerous practitioners' knowledge and skill, including instinct, past know-how, rational reasoning, analytical elaborations, as well as physical sense. The SC chief applications are to pertinent structural as well as earthquake issues as depicted in Figure 2a. Precisely, fuzzy computing, swarm intelligence, and evolutionary computing, along with the neural networks, are worked out in hybrid combinations and have been analyzed by targeting to inspect their ability along with the restrictions in optimization glitches modeling, and simulation (Falcone, Lima, and Martinelli 2020).

2.2.1 | Seismic Vulnerability

Seismic vulnerability valuation of prevailing buildings has been of prodigious concern around the globe. SC played a very good in predicting the seismic and its associated issues created by natural calamities. Figure 2b covers the entire pathway of construction industry to assess the seismic vulnerability with the aid of SC and hybrid techniques including AI and others (Harirchian et al. 2021).

Figure 2c depicts the growth of the construction industry over the period by the specific usage of ANN and FL for various aspects.

2.2.2 | Underground Excavations

SC technique is effectively employed in underground excavations which are given in the following Figure 2d, various techniques for its assessing parameters such as tunneling, grouting, drilling, excavation, rock breaking, and so on (Zhang et al. 2020). Maintenance parameters are the major areas in which SC methodologies are used to optimize the process parameters. Techniques like ANFIS, RNN, RBN, LR, MARS, and a few other techniques are reported in various research works with an appreciable level of accuracy (Jude Hemanth and Anitha 2014). The landscape analysis is carried out for SC in the civil industry shown in the following table.

Figure 2e reveals a few parameters for assessing, United States and India are quite a dominant player using SC for civil applications. The dominant applicant or major individual player is "The research foundation for the state university of New York", they have filed three patent applications in this domain. Gradually the year-wise filing patents showed sinusoidal motion, the reason might be based on the need for this technique. Recently, SC is getting hybrid with AI and data analytics to show superior performances.

2.3 | Aeronautical and Aerospace Industries

Aerospace and aeronautical system involves various complex problems including various components and structures. For

TABLE 1 | Various applications of soft computing in the medical field.

S. no.	Description	Technique	Accuracy	References
1	Observing as well as assessing the individual risk	FL, NN, GA	95%	(Yardimci 2015)
2	Data forecasting analytics	SC	90%	(Dhamodaran and Balmoor 2019)
3	Percept people's emotion	CNN	85%	(Das et al. 2021)
4	Classifying the ECG signals	ANFIS	82%	(Nazmy, El-Messiry, and Al-Bokhity 2005)
5	Swallow able imaging capsule for diagnosis	NFS	76%	(Kodogiannis 2004)
6	Differentiating normal/ glaucomatous eye	ANFIS	80%	(Huang, Chen, and Huang 2007)
7	Analyzing the US kidney images	HFNS	77%	(Raja, Madheswaran, and Thyagarajah 2008)
8	Identifying tumors in the images	HFNS	79%	(Benamrane, Freville, and Nekkache 2005)
9	Diagnosis of breast cancer	FGA	74%	(Peña-Reyes and Sipper 1999)
10	Prognosis of brain tumors	FL & GA	69%	(Das and Bhattacharya 2009)
11	Epilepsy risk level from EEG signals	FL & GA	83%	(Harikumar, Sukanesh, and Bharathi 2004)
12	Forecast the lung sounds	NN & GA	73%	(Guler, Polat, and Un 2005)
13	Analyze mammograms	NGA	70%	(Verma and Zhang 2007)
14	Classifying as well as detecting any abnormalities	FL, NN, GA	94%	(Benamrane, Aribi, and Kraoula 2006)
15	Hypertension identification	SC	89%	(Srivastava et al. 2013)
16	Medical informatics	SC	91%	(Kobashi et al. 2016)
17	Diabetic foot evaluation	SC	83%	(Gururajarao et al. 2019)
18	Attribute selection for survival analysis	SC	78%	(Pattaraintakorn, Cercone, and Naruedomkul 2005)
19	Development of objective functions	SC	74%	(Fathi et al. 1995)
20	Data mining of medical info	SC	84%	(Karegowda and Jayaram 2009)
21	Image can be assessing of breast of ductal proliferative lesions	SC	68%	(Hwang et al. 2007)
22	Medical decision support systems	FCM	78%	(Habib and Akram 2019; Chou, Cheng, and Chang 2007)
23	Envisaging TB	SC	71%	(Rupali and Jyoti 2016; Kim, Song, and Woo 2007)
24	Ischemic stroke modeling	SC	92%	(Przelaskowski et al. 2007)
25	MRI sharpness metric assessment	FL	89%	(Simi, Edla, and Joseph 2018)
26	Identify the severity of depression	SC	68%	(Thanathamathee 2014)
27	Multi-detector computed tomography (MDCT) image analysis	SC	89%	(Kobashi, Nyúl, and Udupa 2016)

(Continues)

TABLE 1 | (Continued)

S. no.	Description	Technique	Accuracy	References
28	Medical image processing	SC	88%	(Kobashi, Nyúl, and Udupa 2016; Xiao, Ho, and Salih 2007; Jude Hemanth and Anitha 2014; Costin and Rotariu 2011; Mehta et al. 2003; Bhansali and Mehta 2021; Sinha, Tuteja, and Saxena 2020)

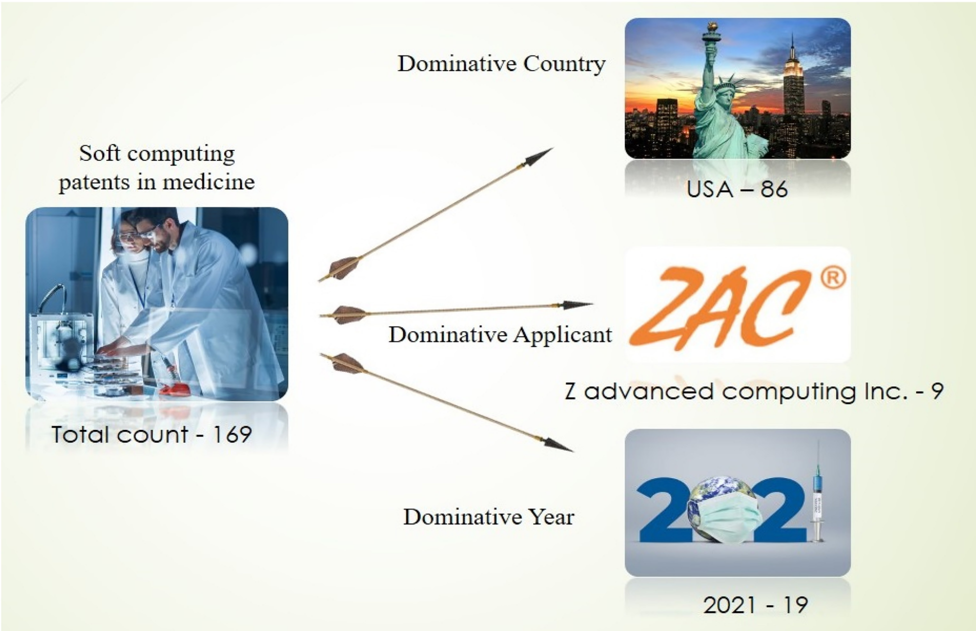


FIGURE 1 | Applications of SC in medicine (patentscope n.d.-a).

instance, the design of aircraft wing structures involves various parameters which are to be optimized critically for the better aeroacoustics and aerodynamics. A few of the subdomains of aerospace in which SC techniques play a significant role include aerodynamic heating, thermal strains, structural deformation, airflow condition, and computation and control systems. In various research works, the aircraft landing and control have been taken as a study and were optimized using SC techniques for a fail-safe landing. Further, SC techniques were also applied in some critical areas of aeronautical including aircraft sensor management, flight control, multidisciplinary aerospace design, and satellite data processing (Hajela 2002; D'Angelo and Rampone 2016, 2014; Chafouk et al. 2007). The followings Table 2 depicts the SC used in the aerospace domains and sub-domains.

The landscape analysis is carried out for SC in the aero industry shown in the following Figure 3a which reveals a few parameters for assessing, United States is quite a dominant player using SC for aero applications. The dominant applicant or major individual player is "Automotive Tech International Inc." they have filed 26 patent applications in this domain. Gradually the year-wise filing patents showed sinusoidal motion, the reason might be based on the need for this technique. Recently, SC is getting hybrid with AI and data analytics to show superior performances. Another observation concerning the country is, the consideration parameter is none of the other countries followed by the United States is not at all for consideration, it might be because of the technical experts' availability in this domain. United States is at a greater height in the aerospace field a well-known fact as well as in software, along with understanding the nuances of using SC feasibly.

2.4 | Communication Systems

The application of SC techniques in wireless communication systems like mobile and antennas has become common lately owing to the number of imprecision and uncertainty associated with them. Growing access points, continuously changing channels of propagation, random user mobility, and variations in network load led to the improper functioning of the wireless networks. SC techniques take the numerous factors and parameters into account and optimizes the output for a smooth communication. SC techniques are widely used in various communication sub-domain such as wireless wide area networks, wireless personal area networks, radio link systems, and wireless local area networks (Krishnamoorthy et al. 2020; Marriwala 2020; Gaykar, Nalini, and Joshi 2021). The followings Table 3 depicts the SC used in the communication systems domain.

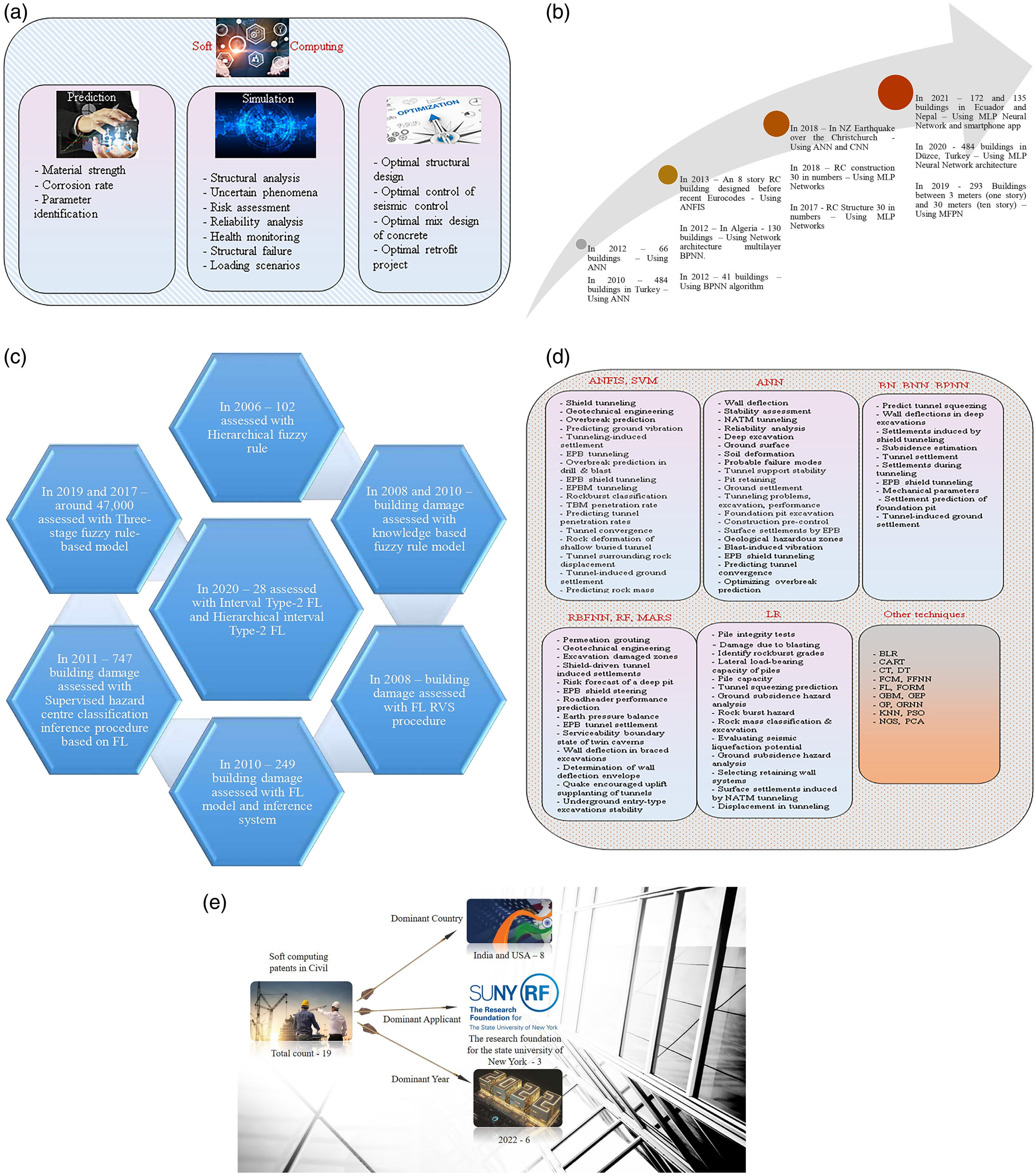


FIGURE 2 | (a) Soft computing civil derivatives (Falcone, Lima, and Martinelli 2020). (b) Progress of construction industry since 2012, (c) Growth in the construction industry using ANN and FL (Harirchian et al. 2021). (d) Soft Computing in Underground Elxcavations (Dhamodaran and Balmoor 2019). (e) Landscape Analysis soft computing in Civil Engineering applications (Oosterom, Babuska, and Verbruggen 2002; patentscope n.d.-b).

The landscape analysis is carried out for SC in the communication system shown in the Figure 3b which reveals a few parameters for assessing, United States is quite a dominant player using SC for the communication system. The dominant applicant or major individual player is "Automotive tech international Inc." they have filed 35 patent applications in this domain. Gradually the year-wise filing patents showed sinusoidal motion, the reason might be based on the need for this technique. Recently, SC is getting hybrid with Artificial Intelligence and data analytics to show superior performances.

TABLE 2 | Various applications of soft computing in the aeronautical and aerospace field.

S. no.	Description	Technique	Accuracy	References
1	Multidisciplinary aerospace design	FL, GA	86%	(Hajela 2002)
2	Aerospace structure defect classification	SC	81%	(D'Angelo and Rampone 2016)
3	Diagnosis of aerospace structure defects	SC	79%	(D'Angelo and Rampone 2014)
4	Data validation in aerospace systems	SC	76%	(Chafouk et al. 2007)
5	Fault detection in gas turbine engines	SC	70%	(Uluyol, Kim, and Nwadiogbu 2006)
6	Suspended lubrication inaccurate machining of Al6061	FL	82%	(Ooi, Sayuti, and Sarhan 2015)
7	Gas turbine diagnostics	SC	74%	(Verma, Roy, and Ganguli 2006)
8	Multi-spectral satellite imaging	SC	69%	(Starks and Kreinovich 1999)
9	Parameter design of aerospace Al alloy weldment	SC	83%	(Jhang 2011)
10	Aircraft sensor supervision as well flight control rule reconfiguration	SC	79%	(Oosterom, Babuska, and Verbruggen 2002)
11	Forecast of cutting speed and surface roughness in wire EDM	SC	89%	(Saha et al. 2008)
12	NDTs are extremely critical in the aerospace system	GA	82%	(D'Angelo and Palmieri 2020)
13	Design of quiet and efficient aircraft propellers and maneuver control of a satellite	SC	78%	(Drack and Zadeh 2006)
14	Space applications	SC	76%	(Berenji 1996)
15	Surface roughness forecast for the milling of ELI material	SC	92%	(Karkalos, Galanis, and Markopoulos 2016)
16	Type-2 fuzzy granular for aero applications	FL	86%	(Castillo et al. 2016)
17	Concentration in a sparsely populated vicinity	SC	81%	(Yeganeh et al. 2017)
18	Forecast surface hardness of thin-film coating	FL	88%	(Zalnezhad, Sarhan, and Hamdi 2013a)
19	Intelligent synthesis environment for future aerospace systems	SC	69%	(Noor and Venneri 2008)
20	Optimization of non-traditional turning processes	SC	91%	(Sofuoğlu et al. 2019)
21	Multi-hole drilling path optimization for aero products	SC	95%	(Abidin, Ab Rashid, and Mohamed 2019)
22	Aerospace structural for damage detection	AI	87%	(Das, Sahu, and Parhi 2020)
23	Intelligent optimization technique in EDM	SC	92%	(Ming et al. 2016)
24	Forecast of coating adhesion strength on aerospace alloy	FL	90%	(Zalnezhad, Sarhan, and Hamdi 2012)
25	Identification for the residual useful life of capacitors	NFS	91%	(Jamshidi and Alibeigi 2017)
26	Surface hardness of hard-anodized aerospace AL7075-T6 alloy	FL	92%	(Zalnezhad, Sarhan, and Hamdi 2013b)
27	Process parameters for composite	SC	88%	(Yadav and Yadava 2015)
28	SR-30 turbojet engine	SC	80%	(Watanabe et al. 2006)
29	Bridgeless SEPIC converter for PMBLDC motor drive	SC	90%	(Meena Devi and Premalatha 2018)

(Continues)

TABLE 2 | (Continued)

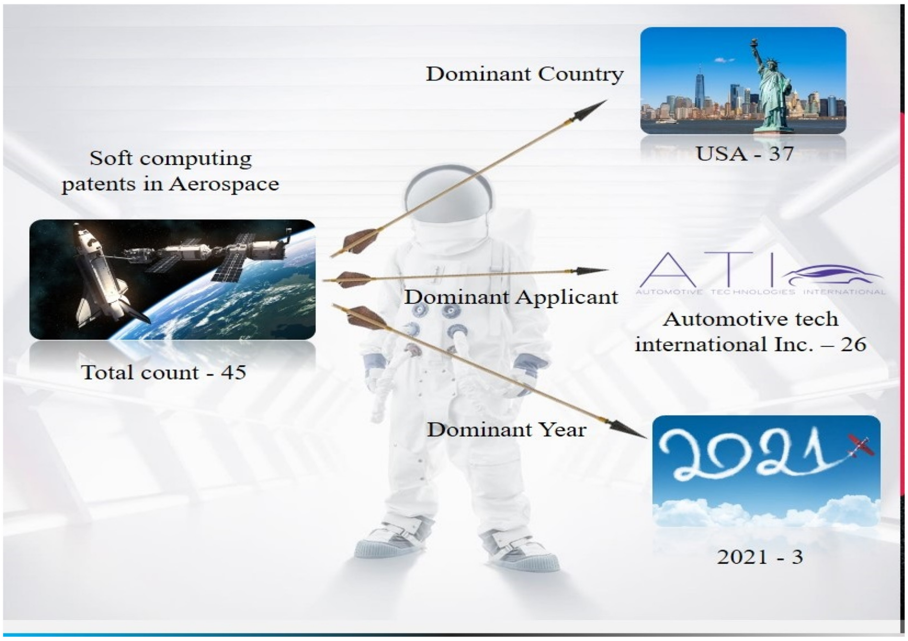
S. no.	Description	Technique	Accuracy	References
30	Autopilot design	FL, GA	78%	(Babaei, Mortazavi, and Moradi 2011)
31	Machinability analysis and advanced machining of hybrid MMC	ANFIS	92%	(Manikandan et al. 2019)
32	Conventional control techniques for high-frequency	SC	85%	(Khalid and Dwivedi 2013)
33	Electron beam welding of aerospace alloy	ANN	90%	(Choudhury and Chandrasekaran 2020)
34	Security control for energy management architecture of hybrid emergency power system for more-electric aircrafts	SC	82%	(Kamal, Mendis, and Wei 2018)
35	Design optimization of aerospace platforms	SC	79%	(Drack 2006)
36	Automatic assembly sequence planning for the aerospace industry	GA	81%	(Xin, Jianzhong, and Yujun 2017)
37	Aerospace design	GA	76%	(Anderson 2003)
38	Assessing the microgravity vicinity quality on the ISS	SC	68%	(Jules, Lin, and Weiss 2001)
39	Visual anomaly detection	SC	72%	(Domínguez and Klinko 2003)
40	Blending the forecasting technique for storing reliability parameters	G-ANN	74%	(Wang et al. 2013)
41	Automatic fluid level controller	SC	77%	(Pal, Kumar, and Kumar 2015)
42	Electro-dynamic shaker for testing vibration	FC	78%	(Rana 2011)
43	Space shuttle during the lift-off process	SC	70%	(Dominquez and Klinko 2007)
44	Non-natural feel control column for a motion-based simulation	H&SC	79%	(Raza and Zeir 2005)
45	Forecast the fretting fatigue life of space alloy	FL	83%	(Zalnezhad et al. 2012)
46	Fluid dynamics	SC	81%	(Le Clainche 2019)
47	Force recovery technique for hypersonic shock tunnel tests	SC	65%	(Pallekonda et al. 2018)
48	Unsteady aerodynamics of flapping aerofoils studies	SC	68%	(Kurtulus 2011)
49	Performance predictions of using new Nano-lubrication in end-milling	ANFIS	89%	(Sayuti, Sarhan, and Hamdi 2014)
50	Space link quality prediction for small satellites	SC	67%	(Preindl et al. 2009)

Another observation concerning the country is, the consideration parameter is none of the other countries followed by the United States is not at all in the picture, it might be because of the technical experts' availability in this domain. United States is good in a communication system as well as in software, along with they understood the nuances of using SC feasibly.

2.5 | Power Systems and Related Industries

Modern-day power systems including smart grids, hybrid power systems, and solar-based technologies are facing advancements in their field rapidly. However, due to the high steady-state error and power oscillation problems, the power output of these systems faces a major setback. The efficiency of the power systems largely depends on the communication infrastructure and background information that contains a huge amount of data. SC techniques are highly capable of handling these data for maximizing the power output by iterating among the large data. Various researchers found that the use of SC techniques resulted in very small power oscillations at steady state and good convergence rates. In most power systems operation and control, SC techniques render a reactive power compensation, voltage stability, and high performance of the systems (Latif et al. 2020; Bhattacharyya and Karmakar 2020; Guchhait, Banerjee, and Mukherjee 2020; Suganyadevi, Vasanth, and

(a)



(b)

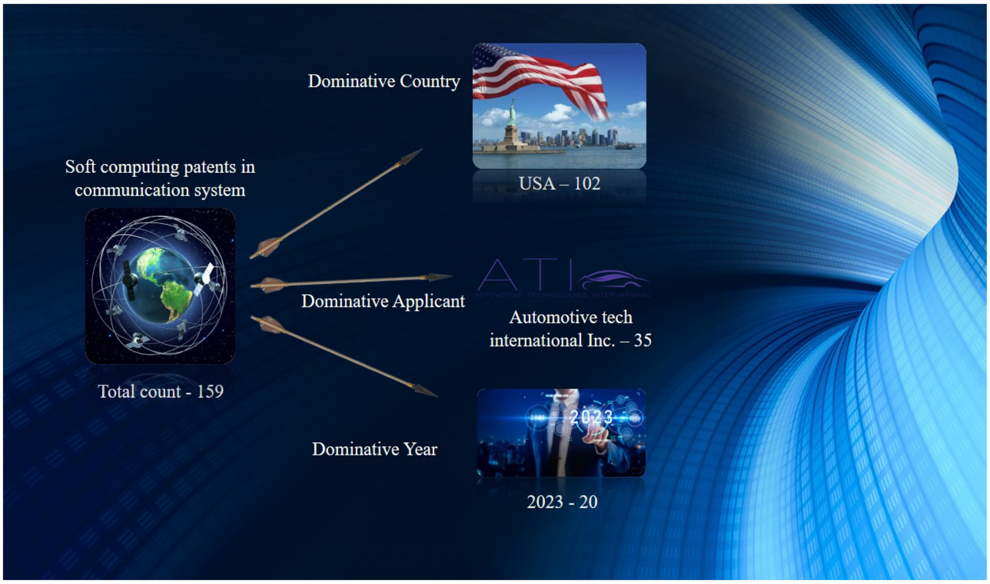


FIGURE 3 | (a) Landscape Analysis soft computing techniques in Aerospace (patentscope n.d.-c). (b) Landscape analysis soft computing in communication system (patentscope n.d.-d). (c) Landscape Analysis soft computing in power systems (patentscope n.d.-e). Landscape Analysis soft computing in (d) Automation (patentscope n.d.-f), (e) Robotics (patentscope n.d.-g).

Viswanathan 2020). Accordingly, Table 4 depicts the use of SC techniques in various power system sub-domains.

Figure 3c reveals a few parameters for assessing, United States is quite a dominant player using SC for the power system domain. The dominant applicant or major individual player is "Automotive tech international Inc." they have filed 32 patent applications in this domain. Gradually the year-wise filing patents showed sinusoidal motion, the reason might be based on the need for this technique, also reveals in the last decade it is a complete slowdown in this domain-based application filing. Recently, SC is getting hybrid with AI and data analytics to show superior performances. Another observation for the country is, the consideration parameter is none of the other countries followed by the United States is not at all in the picture, it might be because of the technical experts' availability in this domain along with they understood the nuances of using SC feasibly.

2.6 | Automation and Robotics

Robotics and automation are another rapidly growing industry that faces day-to-day challenges in terms of demands warranting advancements. The use of SC techniques in hard and soft

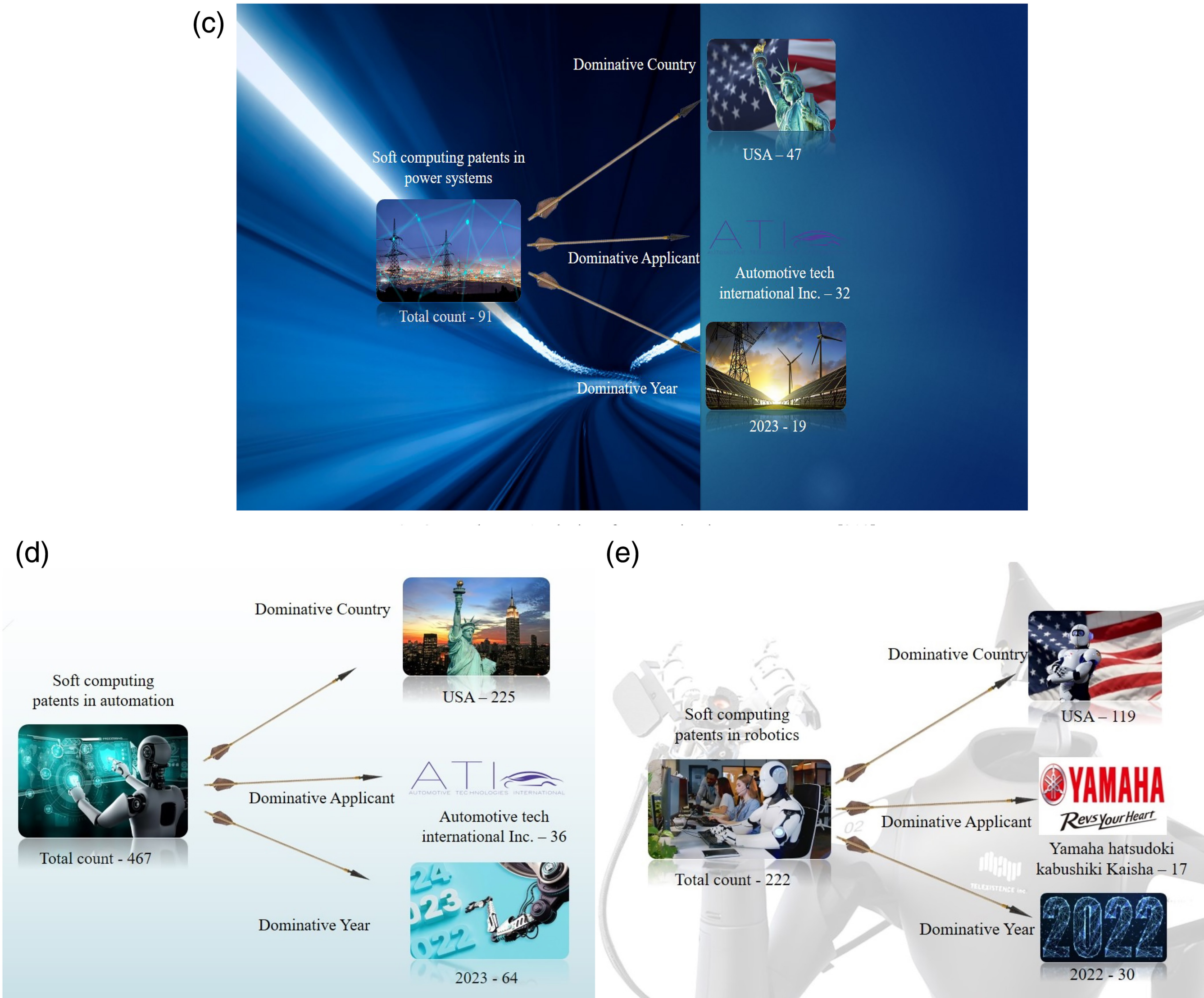


FIGURE 3 | (Continued)

robotics and various fields of automation such as agriculture, manufacturing and so on makes them reliable, adaptive, and productivity-oriented. The following Table 5 depicts the SC used in the automation and robotics domain.

Figure 3d reveals a few parameters for assessing the automation domain, United States is quite a dominant player using SC. The dominant applicant or major individual player is "Automotive Tech International Inc." They have filed 30 patent applications in this domain. Gradually the year-wise filing patents showed sinusoidal motion, the reason might be based on the need for this technique. Recently, SC has become a hybrid with Artificial Intelligence and data analytics to show superior performances. Another observation concerning a country is, that the consideration parameter is none of the other countries followed by the United States is not at all in the picture, it might be because of the technical experts' availability in this domain along with their understanding of the nuances of using SC feasibly in automation.

Figure 3e reveals a few parameters for assessing the robotics domain, United States is quite a dominant player using SC. The dominant applicant or major individual player is "Yamaha hatsudoki kabushiki Kaisha" they have filed 17 patent applications in this domain. Gradually the year-wise filing patents showed sinusoidal motion, the reason might be based on the need for this technique. Recently, SC is getting hybrid with AI and data analytics to show superior performances. Another observation concerning a country is, the consideration parameter is none of the other countries followed by the United States is not at all in the picture, it might be because of the technical experts' availability in this domain along with they understood the nuances of using SC feasibly in robotics.

2.7 | Transportation Industries

To handle the need for smart transportation systems, the aid of SC techniques for handling large-scale data and complex features has become an imminent necessity. Major transportation buzz areas like smart vehicles, driverless cars, smart signals, traffic prediction, and intelligent road inspection are taken care of by the SC techniques to maximize their output (Sarkar and Biswas 2021; Wang et al. 2016). Table 6 depicts the use of SC techniques in various sub-domains of the transportation systems.

TABLE 3 | Various applications of soft computing in Communication systems.

S. no.	Description	Technique	Accuracy	References
1	Performance examination of bio-signal technique in sea vicinity	SC	72%	(Krishnamoorthy et al. 2020)
2	Error control coding for software defined radios	SC	77%	(Marriwala 2020)
3	Detection of straggler node in disseminated vicinity	SC	81%	(Gaykar, Nalini, and Joshi 2021)
4	Smart energy meter monitoring and control	ANN	86%	(Kumari and Geethanjali 2020)
5	Bio-signal processing in the ocean environment	SC	75%	(Krishnamoorthy et al. 2020)
6	Nonlinear channel equalizers in wireless communication	NN	83%	(Ingle and Jatoth 2020)
7	Saving energy mechanism	PSO	81%	(Ming et al. 2020)
8	Network management	SC	79%	(Rath, Pati, and Pattanayak 2018)
9	Intelligent vehicular ad-hoc network	SC	83%	(Rath and Pattanayak 2017)
10	Mobile ad-hoc network gateway identification	SC	75%	(Mishra, Verma, and Kumar 2017)
11	Antenna designing	SC	82%	(Choudhury, Thomas, and Jha 2015)
12	Evaluation for FIR filter	SC	79%	(Sinha and Choubey 2017)
13	Enhancements of cognitive radio networks	FL	81%	(Darney and Jacob 2019)
14	Dual-function radar-communication	NN	85%	(Anjali and Prabha 2019)
15	Secure communication	FL	84%	(Soleimanizadeh and Nekoui 2021)
16	Channel equalization	SC	86%	(Parida, Panda, and Singh n.d.)
17	Scheduler for a cyber-physical system	ANFIS	81%	(Padmajothi and Iqbal 2020)
18	Enhanced power line communication	ANFIS	88%	(Acakpovi et al. 2021)
19	Enchaining the free-space optical communications performance	SC	83%	(Kazaura et al. 2006)
20	Robust voice activity detector for wireless	SC	87%	(Beritelli, Casale, and Cavallaero 1998)
21	Performance analysis of wired and wireless LAN	SC	84%	(Bansal, Gupta, and Malhotra 2010)
22	Multiuser detection techniques for SDMA–OFDM wireless	SC	81%	(Bagadi 2014)
23	Location prediction of mobility management	SC	84%	(Parija et al. 2013)
24	In network systems including wireless	SC	87%	(Rath and Pati 2018)
25	Channel allocation in cellular networks	SC	79%	(Rajagopalan and Mala 2012)

(Continues)

TABLE 3 | (Continued)

S. no.	Description	Technique	Accuracy	References
26	Simulating the performance parameter wireless and wired	SC	80%	(Sukhroop, Singla, and Singla 2012)
27	Phase synchronization in communication systems	SC	82%	(Drake and Prasad 1999)
28	Channel assignment problem in mobile cellular	PSO	89%	(Malar Dhas and Rajesh 2012)
29	Power control in CDMA networks	SC	77%	(Tsagkaris et al. 2005)
30	Intelligent handoff of mobile terminals	SC	84%	(Chou, Liu, and Wu 2006)

TABLE 4 | Various applications of soft computing in power systems.

S. no.	Description	Technique	Accuracy	References
1	Load frequency regulation	SC	79%	(Latif et al. 2020)
2	Optimal power generation scheduling	SC	81%	(Lolla et al. 2021)
3	Monitoring the condition as well as diagnostics	SC	84%	(Malik, Iqbal, and Yadav 2020)
4	High step-up boost converters	SC	86%	(Basha and Rani 2020)
5	Power-point chasing method underneath non-uniform solar irradiation	SC	76%	(Ali et al. 2020)
6	Planning strategy for reactive power	SC	83%	(Bhattacharyya and Karmakar 2020)
7	Prediction of power	SC	88%	(Kumar, Pal, and Tripathi 2020)
8	LF control of hybrid power method	SC	78%	(Pandey et al. 2020)
9	Power quality problems for grid-connected PV	SC	82%	(Pragathi, Nayak, and Poonia 2020)
10	Economic load dispatch problem	SC	84%	(Singh and Singh 2020)
11	Reactive power compensation of a hybrid power system model	SC	76%	(Guchhait, Banerjee, and Mukherjee 2020)
12	Optimal allocation of distributed generation units	PSO	86%	(Hantash, Khatib, and Khammash 2020; Gupta, Pandey, and Vais 2020)
13	Optimization techniques for load frequency control	SC	78%	(Prajapati et al. 2020)
14	Improvement of voltage profile for large-scale	SC	83%	(Abdillah, Setiadi, and Sulistyo 2020)
15	Time series forecasting	SC	88%	(Hendikawati 2020)
16	Automatic tracking tilt angle of PV	SC	84%	(Mamodiya and Tiwari 2020)
17	Fault diagnosis in transmission line	SC	89%	(Singh, Ansari, and Kalam 2020; Rahman and Suleman n.d.)

(Continues)

TABLE 4 | (Continued)

S. no.	Description	Technique	Accuracy	References
18	Measurement of voltage stability	SC	83%	(Suganyadevi, Vasanth, and Viswanathan 2020)
19	Fault diagnosis system	SC	81%	(Mandaogade and Ingole 2020)
20	Grid-connected PV module to augment power quality problems	SC	86%	(Pragathi et al. 2021)
21	Distributed generation systems—condition monitoring	SC	89%	(Qaiser et al. 2021)
22	Enhance the voltage profile as well as loss reduction	SC	76%	(Yadav and Jain 2020)
23	Simulation as well as the design of three-level cascaded inverter	SC	72%	(Bilhan and Sunter 2020)
24	Control method for mitigation of voltage perturbations	SC	83%	(Manitha and Nair 2020)
25	LV ride along with control of doubly fed induction generator using air	SC	86%	(Maheswari, Indumathi, and Parvathy 2021)
26	Current harmonics mitigation in the industry	ANN	88%	(Karthikeyan et al. 2020)
27	Augmenting auto-healing of smart distribution network	SC	81%	(Jafari et al. 2020)
28	Digital adaptive controllers with intelligent system for switched reluctance motor	SC	83%	(Meenakshi, Kumar, and Ramsanjay n.d.)
29	Maximizing power point chasing using perturb and observe	FL & ANFIS	84%	(Mahdi et al. 2020)
30	Improved control design strategy for PV	FL	86%	(Bisht, Kumar, and Sikander 2020)

TABLE 5 | Various applications of soft computing in automation and robotics.

S. no.	Description	Technique	Accuracy	References
1	Automation of the cutting-speed control process	FL	83%	(Titov and Nasser 2015)
2	Automation as well as process control of contrary osmosis system	SC	81%	(Zilouchian and Jafar 2001)
3	Developing automation strategies from material indeterminacies	SC	85%	(Dickey 2017)
4	Advanced power plant start-up automation	H&SC	77%	(Kamiya et al. 1999)
5	Assembly sequence generation and its automation	SC	87%	(Bahubalendruni and Biswal 2016)

(Continues)

TABLE 5 | (Continued)

S. no.	Description	Technique	Accuracy	References
6	Automation of knowledge work	SC	79%	(Ryjov 2016)
7	Behavior-based robotics	SC	71%	(Hoffmann 2003)
8	Swarm robotics	SC	69%	(Osaba et al. 2020)
9	Intelligent control and mobile robotics	SC	74%	(Castillo and Pedrycz 2010)
10	Development of a fuzzy logic over the mobile robotic	FL	78%	(Mucientes et al. 2007)
11	Application in various robotic systems	SC	76%	(Saxena and Saxena 2013)
12	Advanced intelligent robotics and mechatronics	SC	80%	(Ulyanov et al. 2000)
13	Strategies for autonomous field robotics	SC	79%	(Tunstel et al. 2003)
14	Intelligent control systems in micro-nano-robotics	SC	73%	(Panfilov et al. 2000)
15	Robotic arm movement optimization	SC	78%	(Kumar, Rani, and Banga 2017)
16	Cognitive intelligent robust control system	FL	77%	(Ulyanov and Reshetnikov 2017)
17	Intelligent task planner for cloud robotics	FL	74%	(Khan et al. 2020)
18	Swarm robotics based on virtual pheromones	NN	71%	(Song et al. 2020)
19	Robotics control based on learning-inspired spiking	NN	70%	(Bing et al. 2018)
20	Consequences for rehabilitation robotics	ANN	68%	(Khoshdel and Akbarzadeh 2018; Rittenhouse et al. 2006)
21	Nature-inspired optimization algorithms for robotics	FL	73%	(Valdez et al. 2019)

Figure 4 reveals a few parameters for assessing, United States is quite a dominant player using SC for the transportation domain. The dominant applicant or major individual player is “Automotive tech international Inc.” they have filed 35 patent applications in this domain. Gradually, the year-wise filing patents showed sinusoidal motion, the reason might be based on the need for this technique. Recently, SC is getting hybrid with Artificial Intelligence and data analytics to show superior performances. Another observation concerning a country is, the consideration parameter is none of the other countries followed by the United States is not at all in the picture, it might be because of the technical experts' availability in this domain along with they understood the nuances of using SC feasibly.

2.8 | Manufacturing Industries

The manufacturing industries face continuous upgradation to smart manufacturing technologies to meet the customized batch production needs and flexibility demands in manufacturing systems. Many researchers analyze the probability of optimizing the operations like self-perception, operations optimization, intelligent manufacturing decisions, and dynamic reconfiguration of the manufacturing systems using the SC techniques like cloud computing, neurocomputing, fuzzy, Internet of Things, and so on (Bhuvaneswari et al. 2021; Priyadharshini et al. 2022; Gowtham et al. 2024). In recent research works, it was stated that the abetting of SC techniques

TABLE 6 | Various applications of soft computing in Transportation.

S. no.	Description	Technique	Accuracy	References
1	Resolving the two-stage travel issue for fixed costs	SC	85%	(Cosma, Pop, and Zelina 2019)
2	Transportation management through a new distance measure	FL	83%	(Sarkar and Biswas 2021)
3	Fractional transportation problem	FL	86%	(Bharati 2019)
4	Solve unbalanced triangular fuzzy transportation problems	FL	81%	(Muthuperumal, Titus, and Venkatachalapathy 2020)
5	Prioritizing transportation demand management measures	FL	87%	(Pamucar et al. 2020)
6	Fully intuitionistic fuzzy transportation problem	FL	86%	(Mahmoodirad, Allahviranloo, and Niroomand 2019)
7	Intelligent transportation systems	SC	80%	(Wang et al. 2016)
8	Modeling transportation problems	SC	88%	(Lucic 2002)
9	A decision support system for modern international containers	SC	86%	(Liu et al. 2010)
10	Life-cycle charge assessment tools in travel system	SC	87%	(Chen 2007)
11	Transportation infrastructure asset managing	SC	83%	(Flintsch 2002)
12	Fixed cost versatile item in solid transport issue	FL	85%	(Gupta, Kaur, and Kumar 2016; Yang and Liu 2007)
13	Technique for bike-sharing repositioning	SC	82%	(Caggiani and Ottomanelli 2012)
14	Helicopter offshore transportation	GA	74%	(Romero, Sheremetov, and Soriano 2007)
15	Priority-based encoding with new operators for the fixed charge	GA	82%	(Lotfi and Tavakkoli-Moghaddam 2013)
16	Sustainability evaluation of transportation policies	SC	80%	(Rossi, Gastaldi, and Gecchele 2014)
17	Solid vehicle transport issue with Type-2 variables using fuzzy	FL	85%	(Liu et al. 2014)
18	Transportation designing using modified S-curve	FL	83%	(Peidro and Vasant 2011)
19	Crucial transportation designing during disaster management	FL	81%	(Zheng and Ling 2013)
20	Enhancing traffic signal optimization	SC	89%	(Angulo et al. 2011)
21	Evaluating alternative-fuel busses for public transportation	FL	84%	(Erdoğan and Kaya 2016)
22	Enhanced routing protocols for vehicular network	SC	88%	(Haoxiang and Smys 2019)

FIGURE 4 | Landscape analysis soft computing in transportation (patentscope n.d.-h).

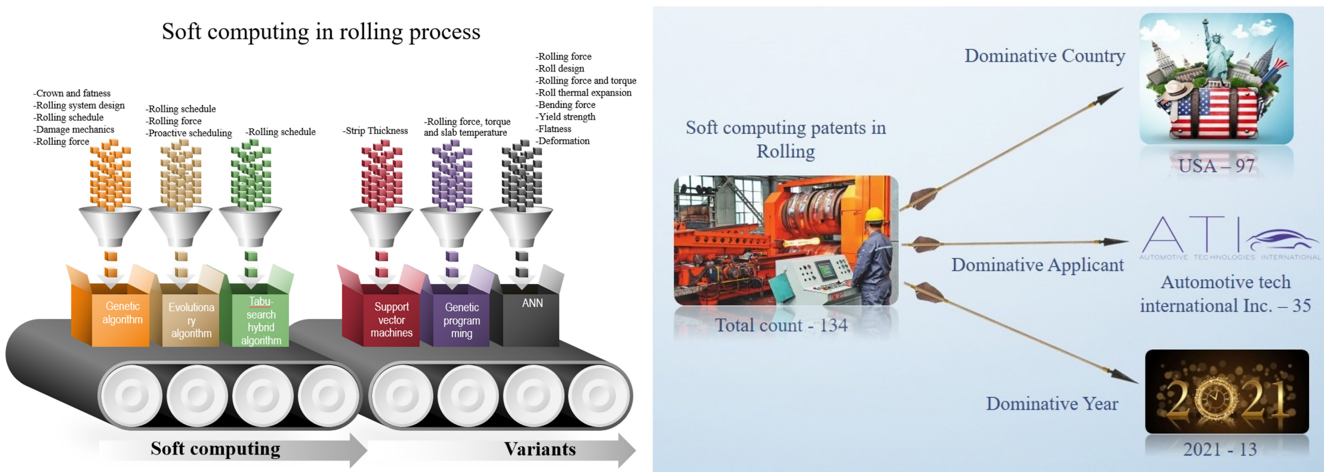


FIGURE 5 | Use of SC in the rolling process (a) Schematic and uses (Hu et al. 2021), (b) Landscape Analysis (patentscope n.d.-i).

with the manufacturing systems is an integral part of Industry 4.0 which transforms traditional manufacturing environment to smart and self-managed environment through analytics and proactive capabilities (Wan et al. 2020; Sanchez, Exposito, and Aguilar 2020). The following Figure 5a depicts the SC is used in the rolling process.

Figure 5b reveals a few parameters for assessing, United States is quite a dominant player using SC for the rolling machining domain. The dominant applicant or major individual player is "Automotive tech international Inc." they have filed 35 patent applications in this domain. Gradually, the year-wise filing patents showed sinusoidal motion, the reason might be based on the need for this technique. Recently, SC is getting hybrid with AI and data analytics to show superior performances. Another observation to a country is, the consideration parameter is none of the other countries followed by the United States is not at all in the picture, it might be because of the technical experts' availability in this domain along with they understood the nuances of using SC feasibly.

3 | Summary and Conclusion

From all the above discussions, it could be deduced that the emergence of SC techniques is a new paradigm in computational techniques that combines cognitiveness and consciousness in various aspects. The use of SC techniques opens various avenues in various technologies, and it paves the way for the improvement of majorly used in various regards. The United States is quite a dominant player in the usage of SC techniques for various domains. The domain's growth is not considerable inconsistency, owing to the growth of similar technologies like artificial intelligence, deep learning, machine learning, and other similar techniques in the past few decades. The considerable dominant company is "Automotive Tech International Inc." in utilizing this technique at the maximum level. The year landscape reveals in the last decade they followed the sinusoidal trend might be because this technique would be older compared with other similar new trends. India has shown significant growth in recent years by using SC. The growing technology automation and robotics patent applications are more than the journals therein, which reveals that the technology is accelerating. The closer observation of the utilization of the SC technique is which is utilized by the sub-domain and sub-sub-domain effectively while comparing over the border domain. The accuracy level depicts which technique should be adopted for the specific application as well as the scope for further acceleration in the specific domain.

Despite their high applicability, SC techniques are highly data-driven approaches and hence larger the data more accurate will be the technique. But the algorithms and models to handle such a large data are very limited and even if available the reliability and accuracy of the model is not satisfactory. Hence developing a high-quality model to handle such data sets to predict the closest possible responses is of vital importance. SC techniques are also characterized with some other inherent disadvantages such as extraction of knowledge, and uncertainty and interpretability of the model. To dodge these shortcomings, a prior knowledge of the background physical engineering process and the human expertise on the learning is significant. So, to conclude the SC scope is better for the accelerating domain than the grown domain. Further, hybridization is more suitable for this SC technique with artificial intelligence, deep learning, machine learning as well as data analytics considered a very good scope. In the manufacturing sector, the SC might be good for additive manufacturing which is not covered in this article. The journal writers may focus on writing reviews for sub-domains instead of writing for the board's various applications of SC, which increases the scope of publications.

Author Contributions

S. Tamilselvan: data curation (equal), formal analysis (equal), software (lead). **G. Dhanalakshmi:** investigation (equal), software (equal), visualization (lead). **D. Balaji:** conceptualization (lead), formal analysis (lead), visualization (equal), writing – original draft (lead). **L. Rajeshkumar:** formal analysis (equal), methodology (lead), supervision (lead), writing – review and editing (lead).

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Related Wires Articles

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