Soft Computing
https://doi.org/10.1007/s00500-022-07037-4

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A review on quantum computing and deep learning algorithms and their applications

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Accepted: 9 March 2022

Abstract
In this paper, we describe a review concerning the Quantum Computing (QC) and Deep Learning (DL) areas and their applications in Computational Intelligence (CI). Quantum algorithms (QAs), engage the rules of quantum mechanics to solve problems using quantum information, where the quantum information is concerning the state of a quantum system, which can be manipulated using quantum information algorithms and other processing techniques. Nowadays, many QAs have been proposed, whose general conclusion is that using the effects of quantum mechanics results in a significant speedup (exponential, polynomial, super polynomial) over the traditional algorithms. This implies that some complex problems currently intractable with traditional algorithms can be solved with QA. On the other hand, DL algorithms offer what is known as machine learning techniques. DL is concerned with teaching a computer to filter inputs through layers to learn how to predict and classify information. Observations can be in the form of plain text, images, or sound. The inspiration for deep learning is the way that the human brain filters information. Therefore, in this research, we analyzed these two areas to observe the most relevant works and applications developed by the researchers in the world.

Keywords Quantum computing · Deep learning · Neural networks · Fuzzy logic · Robotic · Medicine · Intelligent · Control

1 Introduction

Nowadays, many intelligent algorithms have been proposed to solve complex problems, some are based on nature Baskaran et al. (2015), evolution Valdez (2020), brain behavior Krizhevsky et al. (2012), physics Rere et al. (2015), etc; which can be found in the literature, it is calculated there are more than 100 different algorithms, and improved algorithms for finding the best results on the complex problems. However, it is not our aim to analyze all existent methods. Instead, our approach will be on the quantum and deep learning algorithms and their applications. Therefore, we have selected the most relevant applications in this work. Although, we have worked with different algorithms in different ways, for example, with neural networks, fuzzy logic, evolutionary computing, QA and DL have demonstrated be two areas in Computational Intelligence to solve several problems as pattern recognition, optimization problems and can be combined with other methods to improve the performance. Therefore, we focused with the applications about quantum and deep learning algorithms.

Quantum computing works with machines that use the properties of quantum physics to store data and perform computations. This can be extremely advantageous for certain tasks where they could vastly outperform even our best supercomputers. In Montiel-Ross (2020) was made a review of quantum-inspired population-based metaheuristics, in this work, the authors reviewed which quantum-inspired metaheuristics could be translated to be used in the existing quantum computers based on the circuit model programming paradigm. Also, in Montiel-Ross et al. (2019), was proposed the quantum-inspired Acromyrmex evolutionary algorithm as a highly efficient global optimization method for complex systems.

Communicated by Oscar Castillo.

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Published online: 07 April 2022

A review of quantum neural networks is shown in Zhao and Wang (2021), where the authors observed that the quantum neural networks are higher storage capacity and computational efficiency compared to its classical counterparts. Also, in Beer et al. (2020), was proposed a truly quantum analogue of classical neurons, which form quantum feedforward neural networks capable of universal quantum computation.

In Figure 1, is appreciated the domain which belong deep learning. In the figure, we can observe the relationship with machine learning and the artificial intelligence and DL is shown as a sub-field of artificial intelligence, and DL is a specialization of Machine Learning. Therefore, DL represents the advance stage of machine learning which mainly uses neural networks for learning and prediction of data. It is a group of different algorithms. These are used to design complex systems that can take any type of problems and give predictions. It uses the deep graph with numerous processing layers, made up of many linear and nonlinear conversions, (Schmidhuber (2015), Shinde and Shah (2018)).

The main contribution in this paper, is to visualize the evolution that QC and DL algorithms have had in the last years. For this reason, we made several queries in Scopus and Web of Science to validate in the best way the obtained results. After, we collected the data in plain text to generate the clusters, networks and relations of works around the world with specific queries of the analyzed applications. To achieve obtain the graphics and presented results corresponding to queries, the VosViewer software was used in this research. VOSviewer is a software tool for constructing and visualizing bibliometric networks. These networks may for instance include journals, researchers, or individual publications, and they can be constructed based on citation, bibliographic coupling, co-citation, or co-authorship relations (Perianes-Rodriguez et al. (2016), Van Eck and Waltman (2014)). The parameters used in VosViewer to build the networks, clusters and relations presented in the paper are shown in Table 1.

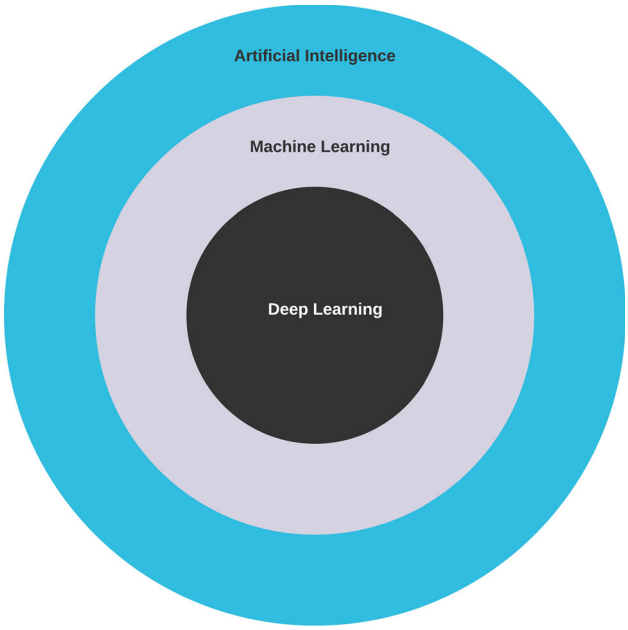

Fig. 1 Domains of deep learning, machine learning and artificial intelligence

This paper is organized as follows: in Section 1 a brief introduction about of main contribution is presented, Section 2 describes with detail the literature review analyzed in the paper, Section 3 shows the Applications with Quantum Computing Algorithms, in Section 4 the Applications with Deep Learning are presented, and the following Section presents the conclusions and future works and finally the conclusions in the last section are included.

2 Literature review

In this section, we made an exhaustive review about the topics described above. In this case, the consulted papers were collected from the Scopus database. Also, we made a search in Web of Science (WoS) to analyze the published journals papers with these two areas. In WoS, we made queries with the topic 'quantum computing'. With this query, were obtained as result from WoS 33,230 journal papers. However, is a big number of works with difficulty for analyzing. But, with this query is possible to understand the areas, quantity of paper by areas, authors and countries developing works with quantum computing as is shown in Figure 2, where, it can be appreciated the number of papers by areas. The Figure only shows the first 10 areas.

Also, we made a query from WoS search is with the topic 'Deep Learning', and were found 86,829 papers, that represent a major number of works with respect to QC. But, this is because the search was very general. Therefore, in the other section, we made specific queries to filter and refine in the best way this data. Figure 3, shows the areas with the higher number of published journal papers, where we can highlight the number of works in the area

Table 1 Parameters of VosViewer Software

Parameter	Value
Random start	1
Iterations	1000
Initial step size	1
Step size reduction	0.75
Step size convergence	0.001
Random seed	0

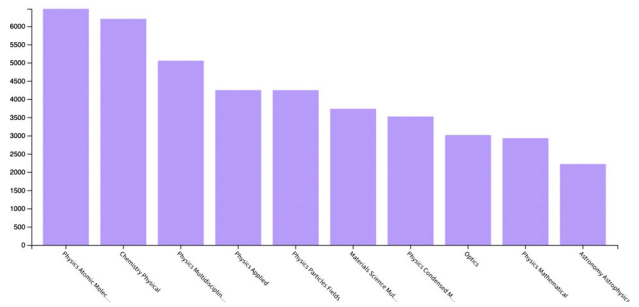

Fig. 2 Topic 'quantum computing'. collected data from WoS

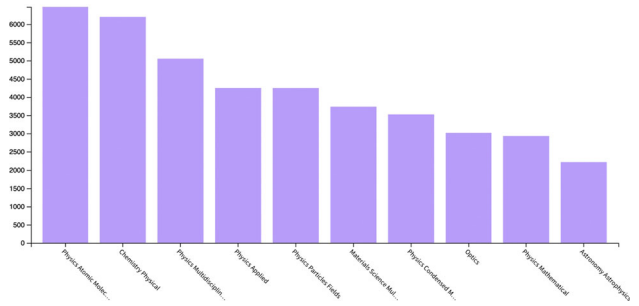

Fig. 3 Topic 'deep learning'. collected data from WoS

Engineering Electrical Electronic with more than 20,000 papers. Also, this figure only shows the first ten areas.

In this part, we presented related works about these two topics (QC and DL) algorithms. The source of collected data were reviewed in Scopus database. The search was made with the topic 'Quantum Computing Algorithms', the obtained results were 5785 papers in total. However, we are presenting a brief description only of the most relevant and recent works in this area. But, with the topic search above described is possible to find at any time the updated documents. Also, we presented a review about applications using Quantum Computing Algorithms. In this case, we decide to include applications based in Computational Intelligence, such has neural networks, fuzzy logic, intelligent control, robotic, medicine, etc.

Before doing the separate queries, with the topics of QC and DL. A query was made in the Scopus database with the two topics together; this was, to know the authors who in the last 10 years have been working in this field of computational intelligence. Figure 4 shows the result of this query.

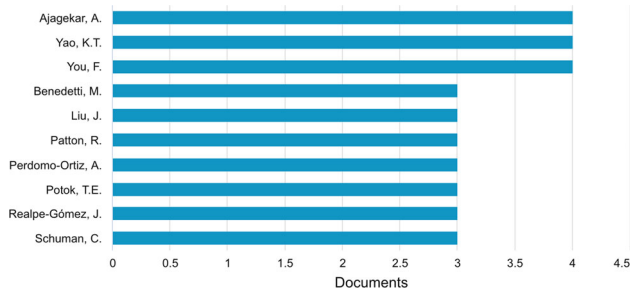

Fig. 4 Scopus authors working with QC and DL algorithms

From Scopus, with the topic QC and DL we made a query to know the classification of works according to type of document. In Figure 5 it can be appreciated, the types of work carried out in the last 10 years. In Figure 6 it can be noted in that the numbers of papers developed to date is increasing every day.

In a recent work, Pathak et al. (2022), presented an Algorithm of Quantum Computing During Pandemic Situation of COVID-19. Further, this work presents fundamental about quantum properties such as superposition, entanglement, and quantum programming tools such as Qiskit (IBM), pyQuil (Google), etc. In Potempa and Porebski (2022) the authors Comparing Concepts of Quantum and Classical Neural Network Models for Image Classification Task. The comparative results of two models: classical and quantum neural networks of a similar number of training parameters, indicate that the quantum network, although its simulation is time-consuming, overcomes the classical network it has better convergence and achieves higher training and testing accuracy. On the other hand, an interesting work was proposed for Enhancing Security Using Quantum Computing. Were, the authors, developed quantum algorithms using qubit that run faster than classical algorithms and these algorithms reduce the time complexity and also it is impossible for the attackers to attack Peelam and Johari (2022), with this work is highlighting the importance for using quantum algorithms in security problems in the last years. Other use of QC can be seen in Ong and Tan (2022), where the authors proposed a work using a quantum circuit program generation with a genetic algorithm for the Open Quantum Assembly Language. In other research, was proposed a Supervised Machine Learning Strategies for Investigation of Weird Pattern Formulation from Large Volume Data Using Quantum Computing, in this work, Quantum machine learning accelerated the supervised, unsupervised, and

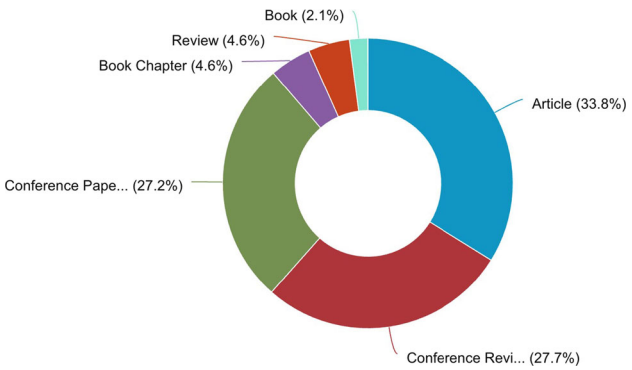

Fig. 5 Document types from Scopus database

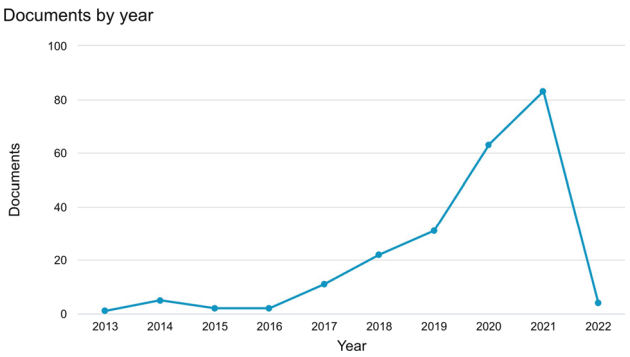

Fig. 6 Documents from Scopus database in the last 10 years

reinforcement learning methods obtained better results than the classical machi Nivelkar and Bhirud (2022).

In Xiao et al. (2021) was proposed a stochastic quantum program synthesis framework based on Bayesian optimization, where Quantum computers and algorithms offered an exponential performance improvement over some NP-complete programs which cannot be run efficiently through a Von Neumann computing approach. On the other hand, a classical simulation of the Quantum Approximate Optimization Algorithm was presented, in this work Medvidović and Carleo (2021), was developed A neural-network of the many qubit wave function, focusing on states relevant for the Quantum Approximate Optimization Algorithm. A practical application can be seen in Dalyac et al. (2021) where CA was used for hard industrial optimization problems. The case study in the field of smart-charging of electric vehicles. Also, an important application in the cryptography area was presented in Gaj (2018).

Other important and recent works can be seen in Singh et al. (2021a), Wang et al. (2021), Yunakovsky et al. (2021), Gao et al. (2021), Huber et al. (2021), Kulkarni et al. (2021), Ajagekar and You (2021), Alberts et al. (2021), Medvidović and Carleo (2021), Singh et al. (2021b), Im et al. (2021) Liu et al. (2021).

3 Applications with quantum computing algorithms

In this section, we presented the most relevant applications in Medicine, Intelligent Control and Robotic. In each area, we made a brief description about the analyzed works. Also, in this part, we are presenting the most cited paper in each field. Table 2 shows the 10 most cited works in the medicine area using QC.

In Table 3, the 10 most cited works in the area of intelligent control with QC is presented. In this table is shown the difference with respect to the medicine area, where the number of citations is bigger than intelligent control.

Finally, in Table 4 is shown the most cited works in robotic using QC. Here, it is shown that the number of citations is greater than the intelligent control topic, but less than that of medicine.

3.1 Medicine quantum computing

In this section, a review with QA algorithms applied to medicine are shown. We used the tool VosViewer Perianes-Rodriguez et al. (2016) to appreciate the formed networks and relations in medicine. From Scopus database, was made a query to calculate the network, relations, clusters with the topic'Medicine Quantum Computing'. We found 114 linked papers considering title, abstract and keyword. The collected data from Scopus, were used in VosViewer to obtain in graph form the obtained results. First, we create a map based on bibliographic data from Scopus.

The data were introduced in a csv format. The type of analysis was by Co-occurrence, the counting method was full counting. Finally, the measure unit used was by keywords with a minimum number of occurrences equal to 2. Where, we obtained 1675 keywords, which 292 meet the threshold. For each of the 292 keywords, the total strength of the co-occurrence links with other keywords was calculated. The keywords with the greatest total link strength were selected. In total 292 keywords were selected to obtain the final results. In Fig. 8, is shown the network, relations, clusters and links in a form graph of this query using data from Scopus. Figure 7 shows the citations in the last years. In this figure, we can appreciate how the number of citations has increased significantly each year (Fig. 8).

Also, in this section, are presented a brief description about relevant works with the analyzed topic.

In Boev et al. (2021), the authors developed a method for solving genome assembly tasks with the use of quantum and quantum-inspired optimization techniques. Within this method, we present experimental results on genome assembly using quantum annealers both for simulated data and the φX 174 bacteriophages. The results pave a way for a significant increase in the efficiency of solving bioinformatics problems with the use of quantum computing technologies.

Also, in Thomasian and Adashi (2021), a qualitative review of the medical cybersecurity literature was presented with collation of federal and international legal documents, policy reports, industry frameworks, cyber-breach analyses, and scientific journal papers. On the other hand, fuzzy logic with quantum computing was used in Kumar et al. (2020), in this the authors proposed a health analytics system by forming a knowledge repository of

Table 2 10 most cited works in medicine with QC

Title	Year	Citations
Quantum computers	2010	1922
Linear optical quantum computing with photonic qubits Kok et al. (2007)	2007	1656
Functional nanomaterials for phototherapies of cancer Cheng et al. (2014)	2014	1599
Quantum information with Rydberg atoms Saffman et al. (2010)	2010	1395
Fano resonances in photonics Limonov et al. (2017)	2017	673
Creation of a six-atom 'Schrödinger cat' state Leibfried et al. (2006)	2006	664
Artificial intelligence in healthcare: Past, present and future Jiang et al. (2017)	2017	655
Macromolecular modeling with Rosetta Das and Baker (2008)	2008	639
Quantum computing with trapped ions Häffner et al. (2008)	2008	588
Optical quantum computing O'Brien (2007)	2007	576

Table 3 10 most cited works in intelligent control with QC

Title	Year	Citation
Multivariable system identification based on double quantum particle swarm optimization and big data Han and Yuan (2014a)	2014	23
Quantum Artificial Fish Swarm Algorithm Zhu and Jiang (2010)	2010	18
A review on application of particle swarm optimization in association rule mining Ankita et al. (2013)	2013	15
An Atomic-Array Optical Clock with Single-Atom Readout Madjarov et al. (2019)	2019	14
Quantum soft computing in control process design: Quantum genetic algorithms and quantum neural network approaches Ulyanov (2004)	2004	12
Relay selection scheme based on quantum differential evolution algorithm in relay networks Gao et al. (2017)	2017	9
An alert correlation method based on improved cluster algorithm Peng et al. (2008)	2008	9
The design of reversible gate and reversible sequential circuit based on DNA computing Song et al. (2008)	2008	9
Quantum-inspired swarm evolution algorithm Huang et al. (2007)	2007	9
Analog quantum computing (AQC) and the need for time-symmetric physics Werbos and Dolmatova (2016)	2016	8

Table 4 10 most cited works in robotic with QC

Title	Year	Citation
Natural products for drug discovery in the twenty-first century: Innovations for novel drug discovery Thomford et al. (2018)	2018	301
Evolving connectionist systems: The knowledge engineering approach Kasabov (2007)	2007	265
Human-competitive results produced by genetic programming Koza (2010)	2004	207
Applications of Clifford's Geometric Algebra	2013	88
Smart Machining Process Using Machine Learning: A Review and Perspective on Machining Industry Kim et al. (2018)	2018	92
Use machine learning to find energy materials Wei et al. (2017b)	2017	53
Quantum robot: Structure, algorithms and applications Dong et al. (2006)	2006	35
The genesis of neurosurgery and the evolution of the neurosurgical operative environment: Part II—Concepts for future development, 2003 and beyond Liu et al. (2003)	2003	29
Morphogenic neural networks encode abstract rules by data Resconi and der Wal (2002)	2002	24
AIR-Chem: Authentic Intelligent Robotics for Chemistry Li et al. (2018)	2018	21

patient's symptoms and medicines dosage to prescribe the precise quantum of medicine to cure an ailment and also prevent drug abuse. Also, in this field, Bianconi and Mohseni (2020), an Infrared detection and imaging are key enabling technologies for a vast number of applications, ranging from communication, to medicine and astronomy, were proposed using quantum computing. In big data applied to medicine have been developed some works with QC, for example, in the healthcare industry, various sources for big data include hospital records, medical records of

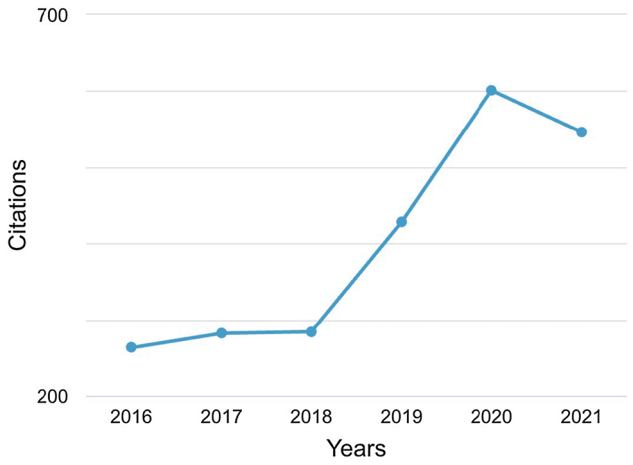

Fig. 7 Scopus citations with the topic medicine quantum computing

patients, results of medical examinations, and devices that are a part of internet of things. The authors used QC to manage this quantity of data Dash et al. (2019).

3.2 Intelligent control quantum computing applications

In the same way that the previous topic, in this section, a review with QC algorithms applied to intelligent control are presented. Also, was used the tool VosViewer Perianes-Rodriguez et al. (2016) to distinguish the formed networks and relations in intelligent control. From Scopus database, was made a query to calculate the network, relations, clusters with the topic 'Intelligent Control Quantum Computing'. We found 141 linked papers considering title, abstract and keyword. The collected data from Scopus, were used in VosViewer to obtain in graph form the obtained results. First, we create a map based on bibliographic data from Scopus. The data were introduced in a csv format. The type of analysis was by Co-occurrence, the counting method was full counting. Finally, the measure unit used was by keywords with a minimum number of occurrences equal to 2. Where, we obtained 1329 keywords, which 301 meet the threshold. For each of the 301 keywords, the total strength of the co-occurrence links with other keywords was calculated. The keywords with the greatest total link strength were selected. In total 301 keywords were selected to obtain the presented results. In Fig. 9, is shown the network, relations, clusters and links in a form graph of this query using data from Scopus. Figure 10 shows the density of this network, highlighting with yellow color the area of quantum computing and intelligent control with more strength that other analyzed keywords. Figure 11 shows the citations in the last years from Scopus. In this figure, we can appreciate how the number of citations has increased significantly each year. Also, in this section, are presented a brief description about relevant works with the analyzed topic. In Guan et al. (2020)

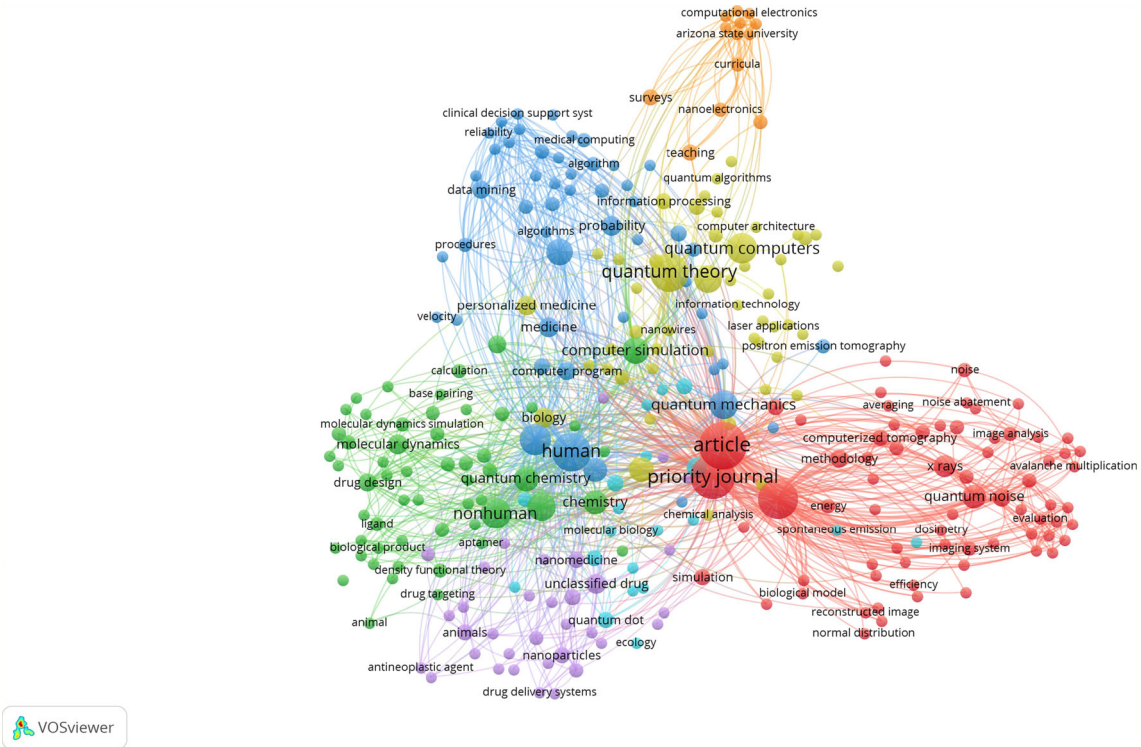

Fig. 8 Network with the topic medicine quantum computing

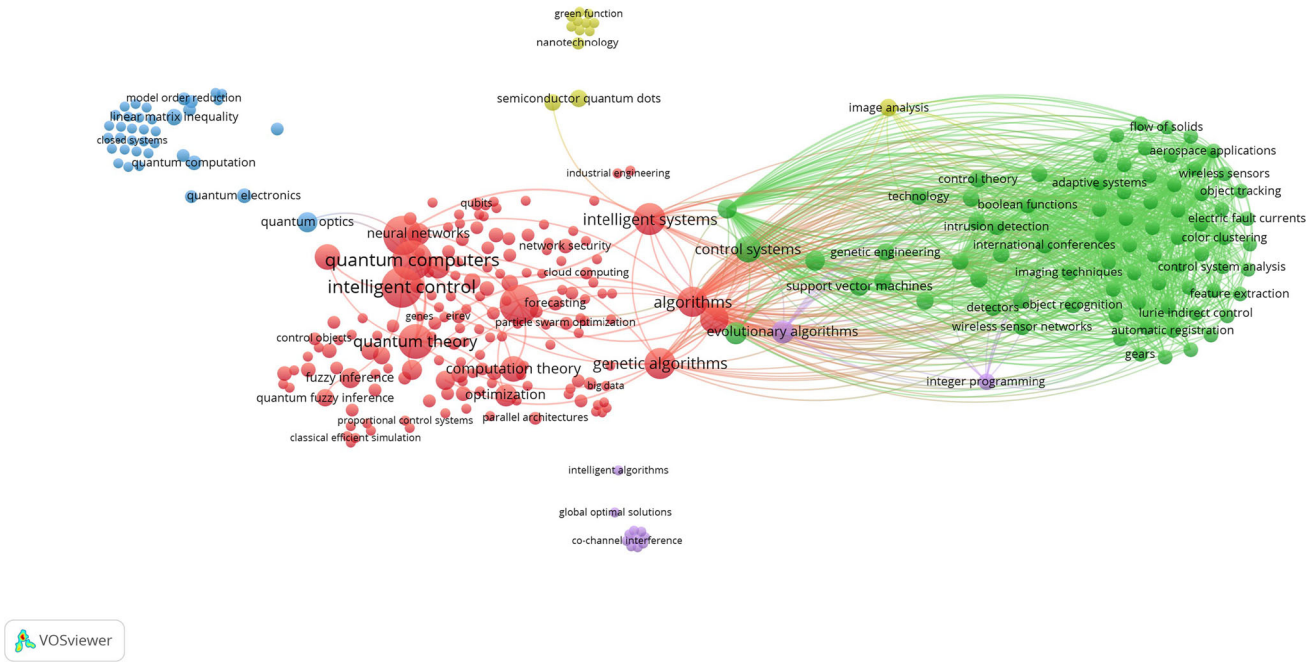

Fig. 9 Network with the topic intelligent control quantum computing

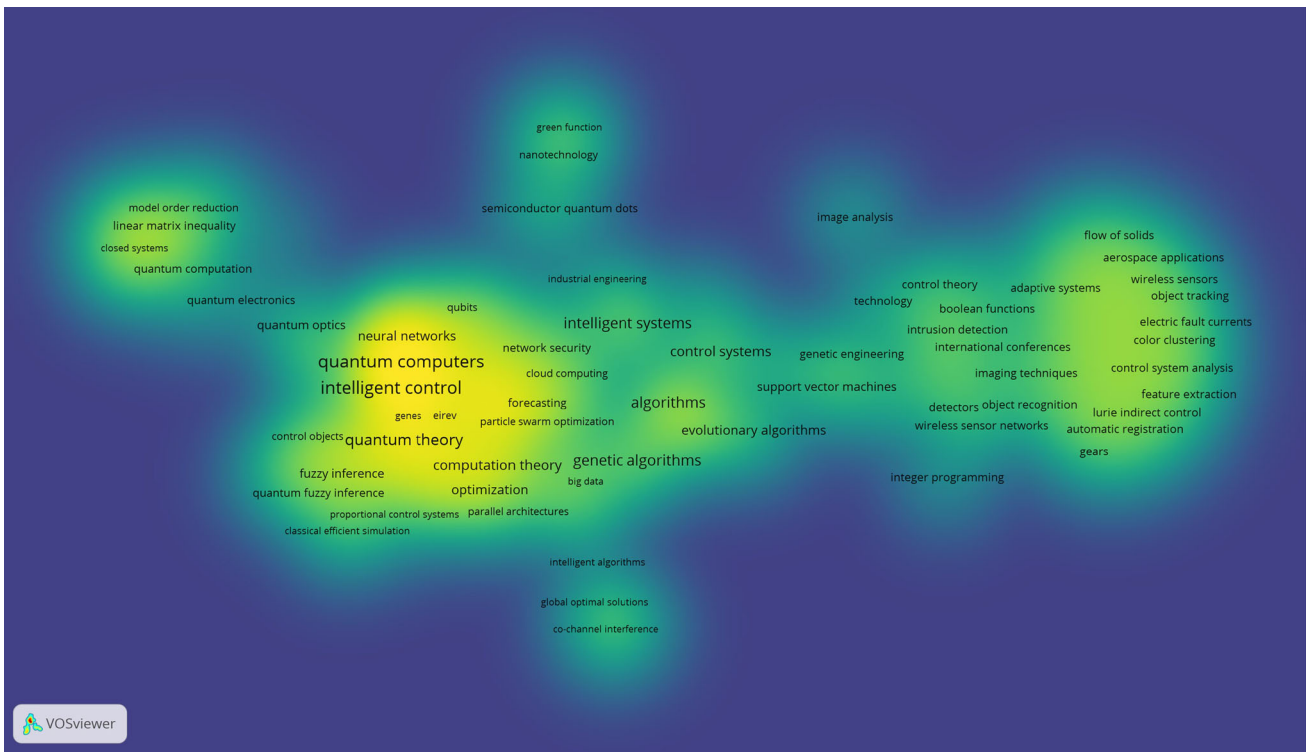

Fig. 10 Density with the topic intelligent control quantum computing

proposed new Lyapunov control scheme for quantum systems using a Particle Swarm Optimization algorithm. Also, in Barchatova et al. (2015) was proposed an Intelligent robust control system based on quantum KB-self-organization. The authors, considered Quantum soft computing and Kansei/affective engineering technologies in this research. On the other hand, Mohanty and Rout (2015) presented a motion control method for mobile robots in indoor environments based on color object detection using quantum computing. Also, Han and Yuan

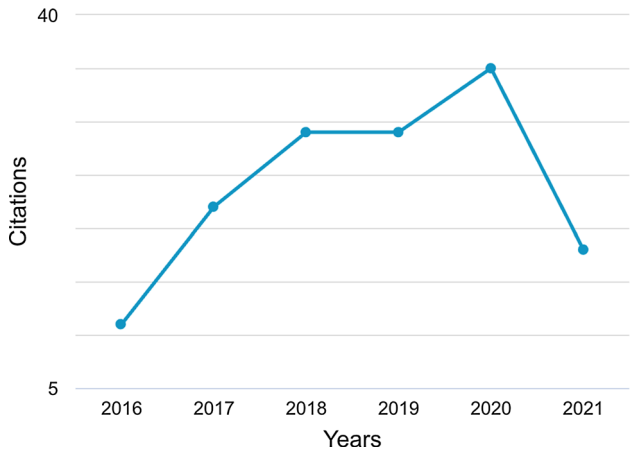

Fig. 11 Citations from Scopus Scopus citations with the topic 'Intelligent Control Quantum Computing'

(2014), proposed a Multivariable system identification based on double quantum particle swarm optimization and big data, in this case, the authors used an optimization method combined with quantum computing. Finally, in this section, we presented the application of an adaptive quantum particle swarm optimization algorithm for optimal dispatching of cascaded hydro power stations proposed by Zhang et al. (2012)

3.3 Robotic control quantum computing applications

Finally, in this section, a review with QC algorithms applied to Robotic are presented. Also, was used the tool VosViewer Perianes-Rodriguez et al. (2016) to distinguish the formed networks and relations in Robotic. From Scopus database, was made a query to calculate the network, relations, clusters with the topic'Robotic Control Quantum Computing'. We found 93 linked papers considering title, abstract and keyword. The collected data from Scopus, were used in VosViewer to obtain in graph form the obtained results. First, we create a map based on bibliographic data from Scopus. The data were introduced in a csv format. The type of analysis was by Co-occurrence, the counting method was full counting. Finally, the measure unit used was by keywords with a minimum number of occurrences equal to 2. Where, we obtained 1013 keywords, which 197 meet the threshold. For each of the 197 keywords, the total strength of the co-occurrence links with other keywords was calculated. The keywords with the greatest total link strength were selected. In total, 197 keywords were selected to obtain the final results. In Fig. 12, is shown the network, relations, clusters and links in a form graph of this query using data from Scopus. Figure 13 shows the overlay visualization to appreciate clearly how are distributed each one the keywords. In Fig. 14 the density of this network is presented, highlighting with yellow color the area of quantum computing and robotic with more strength that other analyzed keywords. Figure 15 shows the citations in the last years from Scopus. In this figure, we can appreciate how the number of citations has increased significantly each year.

Also, in this section are presented some important applications with robotic using QC. Atchade-Adelomou et al. (2021) proposed a quantum computing approach in mobile robot order picking and batching problem solver optimization, the authors developed a quantum algorithm to minimize the distance traveled in warehouses and distribution centers where order picking is applied. Also, in this field A New Quantum-computing based Algorithm for Robotic Arms and Rigid Bodies' Orientation was proposed by Zioui et al. (2021). Also, in Post Quantum Secure Command and Control of Mobile Agents Inserting quantum-resistant encryption schemes in the Secure Robot Operating System Varma et al. (2020). On the other hand, in Korenkov et al. (2020) quantum software engineering supremacy in Intelligent robotics was developed. Also, in Ulyanov (2020) Quantum fuzzy inference based on quantum genetic algorithm: Quantum simulator in intelligent robotics.

4 Applications with deep learning algorithms

In this section, we presented a review about applications using Deep Learning Algorithms. In this case, we decide to include applications based in Computational Intelligence, such has neural networks, fuzzy logic, etc. Also, in this section, we are presenting the most cited paper in each field. Table 5 shows the 10 most cited works in the medicine area using DL. Here, is observed how in the last years, the number of citations is increasing in this field.

In Table 6, are presented the most cited works in intelligent control with DL. Also, is shown as in the last years this topic is highly used by the researchers.

Finally, in Table 7, are presented the most cited works in robotic with DL. Also, in this topic the number of citations is increasing in the last years.

4.1 Medicine deep learning applications

Also, in this section, a review with DL algorithms applied to Medicine are presented. Also, was used the tool VosViewer Perianes-Rodriguez et al. (2016) to distinguish the formed networks and relations in medicine. From Scopus database, was made a query to calculate the network, relations, clusters with the topic'Robotic Control Quantum Computing'. We found 1011 linked papers considering

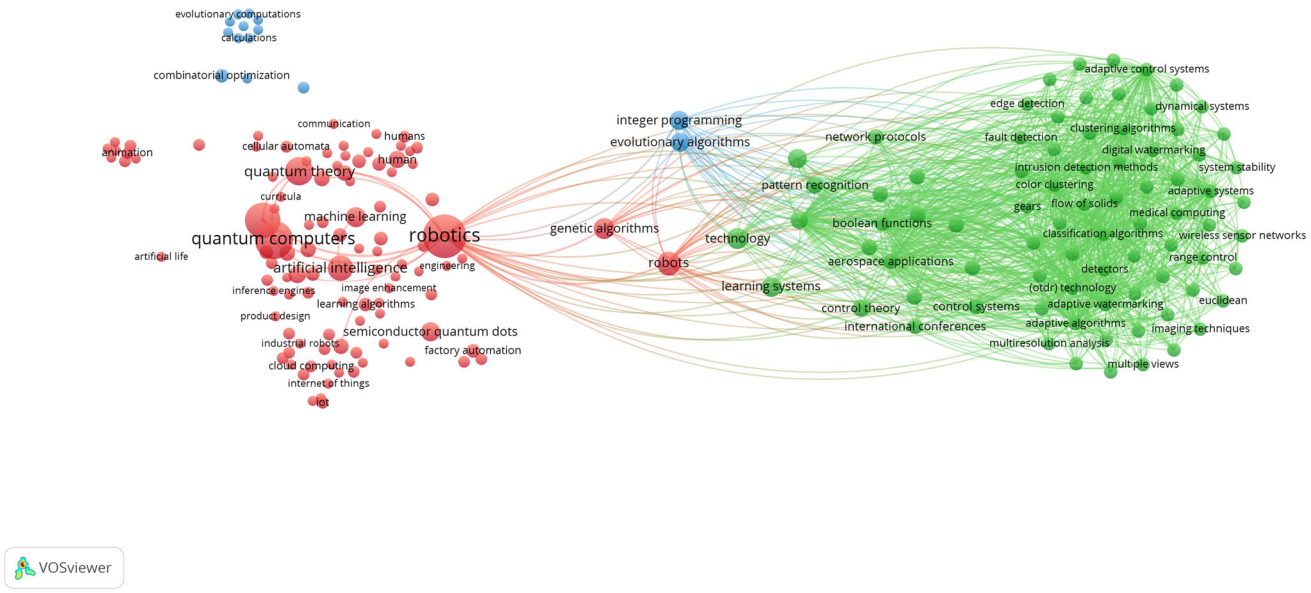

Fig. 12 Network with the topic robotic quantum computing

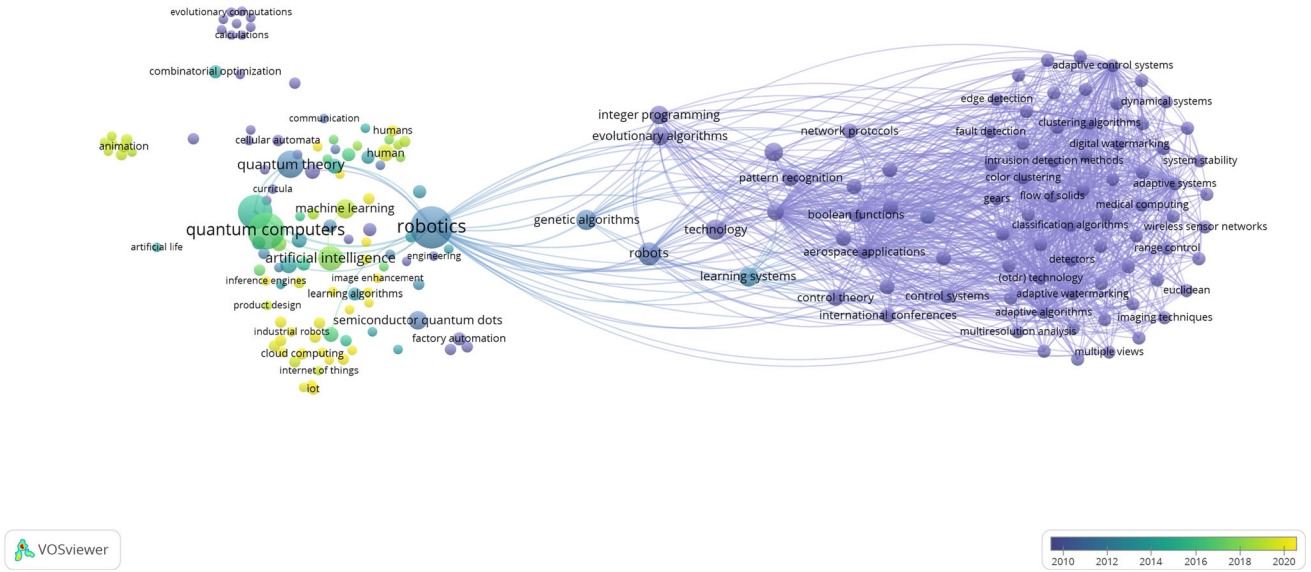

Fig. 13 Overlay with the topic robotic quantum computing

title, abstract and keyword. The collected data from Scopus, were used in VosViewer to obtain in graph form the obtained results. First, we create a map based on bibliographic data from Scopus. The data were introduced in a csv format. The type of analysis was by Co-occurrence, the counting method was full counting. Finally, the measure unit used was by keywords with a minimum number of occurrences equal to 2. Where, we obtained 7782 keywords, which 2355 meet the threshold. For each of the 2355 keywords, the total strength of the co-occurrence links with other keywords was calculated. The keywords with the greatest total link strength were selected. In total 1000 keywords were selected to obtain the final results. In Fig. 16, is shown the network, relations, clusters and links in a form graph of this query using data from Scopus. In Fig. 17 the density of this network is presented, highlighting with yellow color the area of deep learning and human with more strength that other analyzed keywords. Figure 18 shows the citations in the last years from Scopus. In this figure, we can appreciate how the number of citations has increased significantly each year. Also, in this section are presented some applications with deep learning techniques as, neural networks, machine learning, convolutional neural networks, etc., applied to medicine.

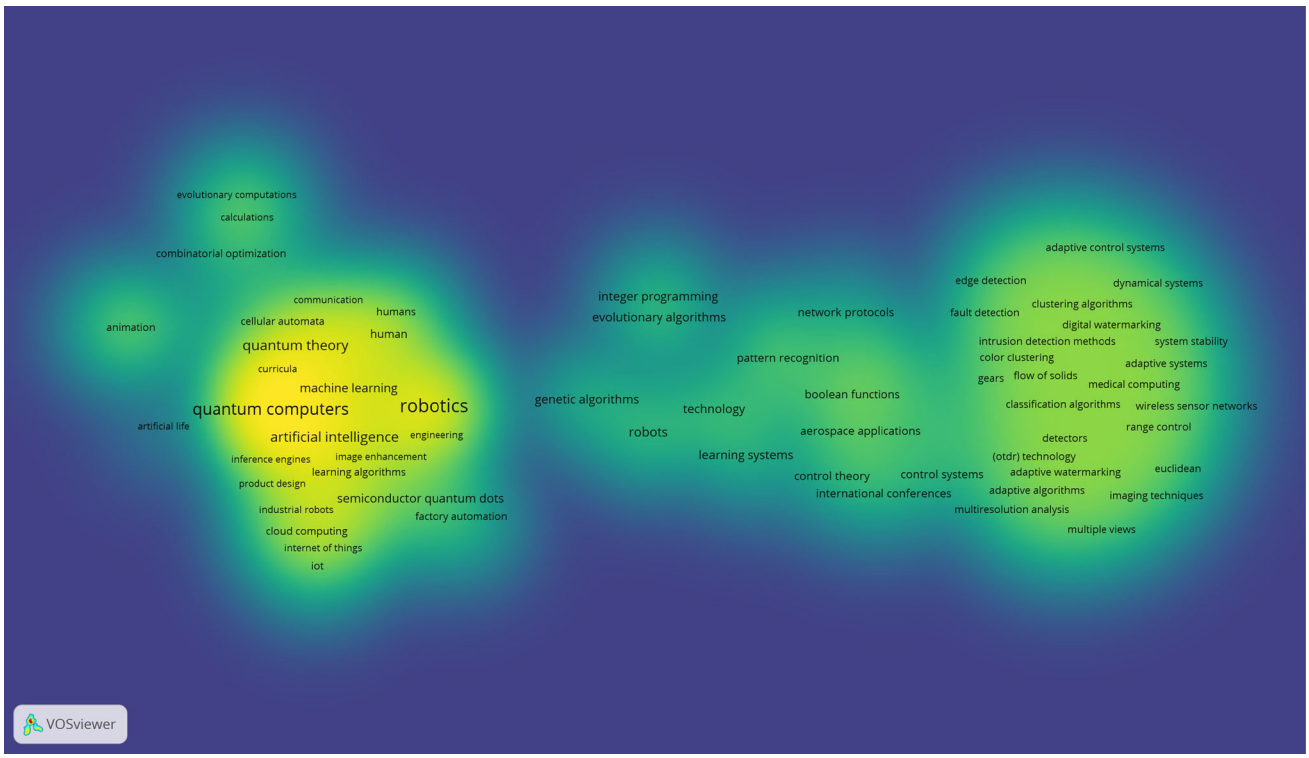

Fig. 14 Density with the topic robotic quantum computing

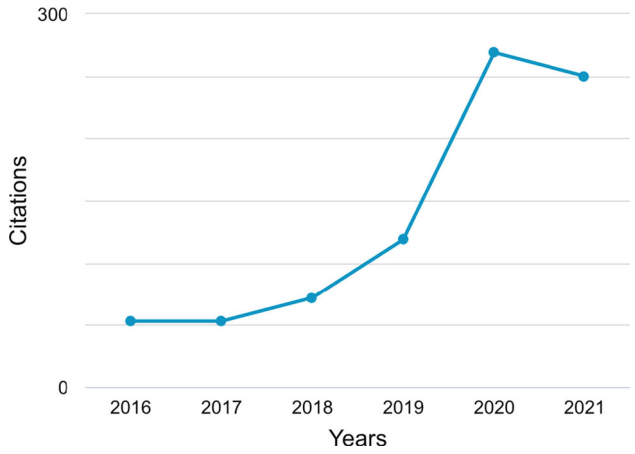

Fig. 15 Scopus citations with the topic'Robotic Quantum Computing'

Nowadays, several web medical applications evolved in the field of medicine, there is need for an intelligent and efficient extraction technique. Therefore, neural networks, machine learning can be used to improve the obtained results with other classical techniques. For example, in Deepika and Radha (2022) was presented a study of Abstract-Based Classification of Medical Journals Using Machine Learning Techniques. Other relevant application using deep learning is presented in Gaxiola et al. (2018), in this work, the authors used modular neural networks for iris recognition. The authors used the human iris database improved with image preprocessing methods. Also, a recent work in the medical area with deep learning techniques is presented by Varela-Santos and Melin (2021). In this case, the authors used neural networks for classifying coronavirus based on its manifestation on chest X-rays using texture features. In González et al. (2015), Fuzzy logic with the optimization method gravitational search was used to optimize the architecture of a modular neural networks in echocardiogram recognition. In the same way, the authors presented a work but using type-2 fuzzy logic with pattern recognition with modular neural networks González et al. (2016). On the other hand, an overview of deep learning in medical imaging was presented by Lundervold and Lundervold (2019). In this work, the authors review the deep artificial neural networks, machine learning models to image analysis to natural language processing.

4.2 Intelligent control deep learning application

Also, in this section, a review with DL algorithms applied to Medicine are presented. Also, was used the tool VosViewer Perianes-Rodriguez et al. (2016) to distinguish the formed networks and relations in medicine. From Scopus database, was made a query to calculate the network, relations, clusters with the topic'Robotic Control Quantum Computing'. We found 1160 linked papers considering

Table 5 10 most cited works in medicine with DL

Title	Year	Citations
High-performance medicine: the convergence of human and artificial intelligence Topol (2019)	2019	962
Opportunities and obstacles for deep learning in biology and medicine Ching et al. (2018)	2018	574
Learning a variational network for reconstruction of accelerated MRI data Hammernik et al. (2018)	2018	404
Deep learning in medical imaging: General overview Lee et al. (2017)	2017	393
Artificial intelligence in medicine Hamet and Tremblay (2017)	2017	340
Artificial Intelligence in Precision Car-Diovascular Medicine Krittanawong et al. (2017)	2017	283
Deep learning algorithms for human activity recognition using mobile and wearable sensor networks: State of the art and research challenges Nweke et al. (2018)	2018	264
Predicting cancer outcomes from histology and genomics using convolutional networks Mobadersany et al. (2018)	2018	253
Review of deep learning algorithms and architectures Shrestha and Mahmood (2019)	2019	244
Artificial Intelligence in Cardiology Johnson et al. (2018)	2018	231

Table 6 10 most cited works in intelligent control with DL

Title	Year	Citations
State-of-the-Art Deep Learning: Evolving Machine Intelligence Toward Tomorrow's Intelligent Network Traffic Control Systems Fadlullah et al. (2017)	2017	413
Collaborative filtering and deep learning-based recommendation system for cold start items Wei et al. (2017a)	2017	327
Deep learning for intelligent wireless networks: A comprehensive survey Mao et al. (2018)	2018	234
Optimized Structure of the Traffic Flow Forecasting Model with a Deep Learning Approach Yang et al. (2017)	2017	132
An Intelligent Traffic Load Prediction Based Adaptive Channel Assignment Algorithm in SDN-IoT: A Deep Learning Approach Tang et al. (2018)	2018	128
Deep learning with a long short-term memory networks approach for rainfall runoff simulation Hu et al. (2018)	2018	117
Deep Reinforcement Learning for Building HVAC Control Wei et al. (2017c)	2017	113
Multiagent learning: Basics, challenges, and prospects Tuyls and Weiss (2012)	2012	93
Human-like autonomous car-following model with deep reinforcement learning Zhu et al. (2018)	2018	88
Deep learning algorithm for autonomous driving using GoogLeNet	2017	85

Table 7 10 most cited works in robotic control with DL

Title	Year	Citations
Efficient Processing of Deep Neural Networks: A Tutorial and Survey Sze et al. (2017)	2017	1049
Deep reinforcement learning: A brief survey Arulkumaran et al. (2017)	2017	619
Deep reinforcement learning for robotic manipulation with asynchronous off-policy updates Gu et al. (2017)	2017	483
Deepfruits: A fruit detection system using deep neural networks Sa et al. (2016)	2016	428
Robots that can adapt like animals Cully et al. (2015)	2015	414
A Machine Learning Approach to Visual Perception of Forest Trails for Mobile Robots Giusti et al. (2016)	2016	347
Pointpillars: Fast encoders for object detection from point clouds Lang et al. (2019)	2019	332
Dex-Net 2.0: Deep learning to plan Robust grasps with synthetic point clouds and analytic grasp metrics Mahler et al. (2017)	2017	329
DeepVO: Towards end-to-end visual odometry with deep Recurrent Convolutional Neural Networks Wang et al. (2017)	2017	290
Modelling uncertainty in deep learning for camera relocalization Kendall and Cipolla (2016)	2016	239

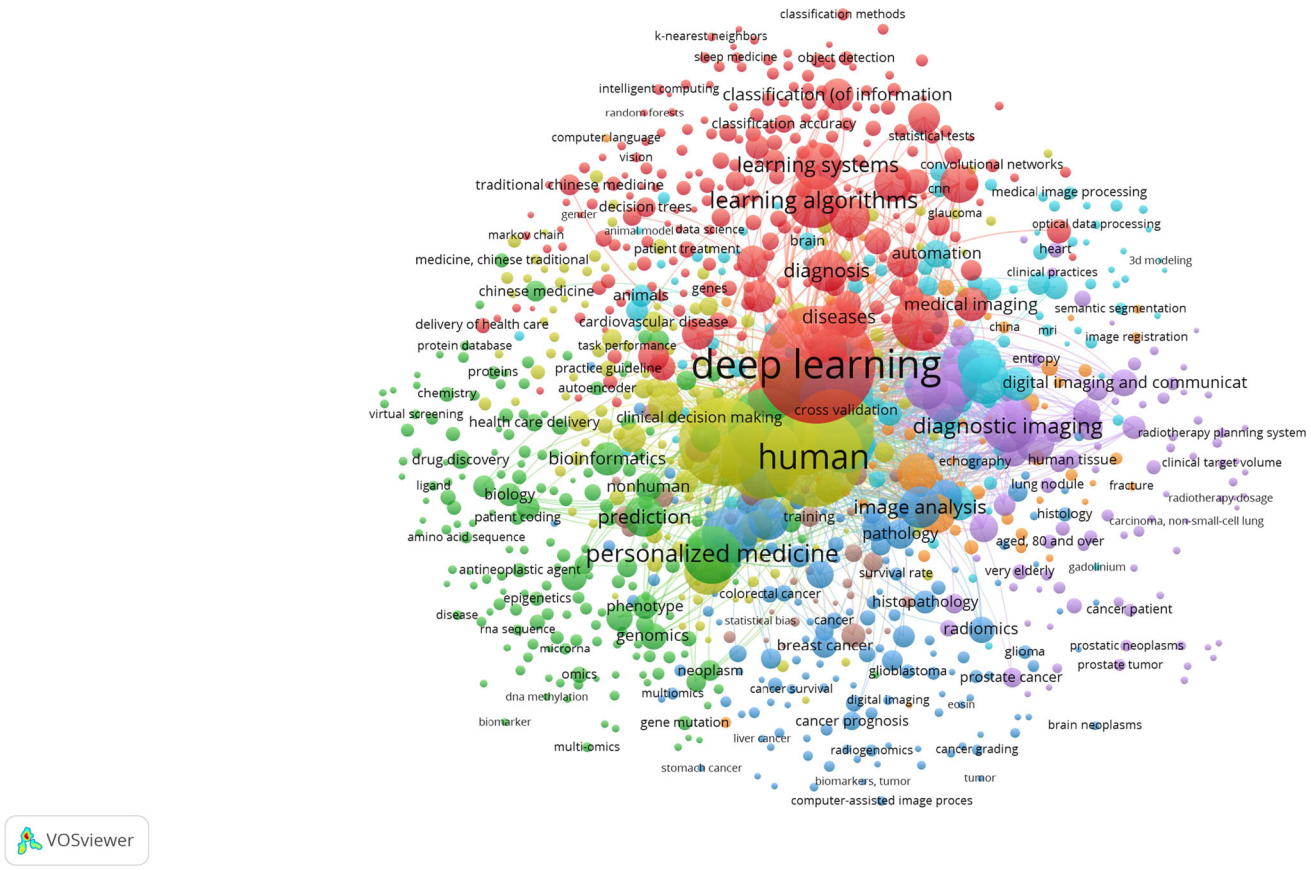

Fig. 16 Network with the topic medicine deep learning algorithms

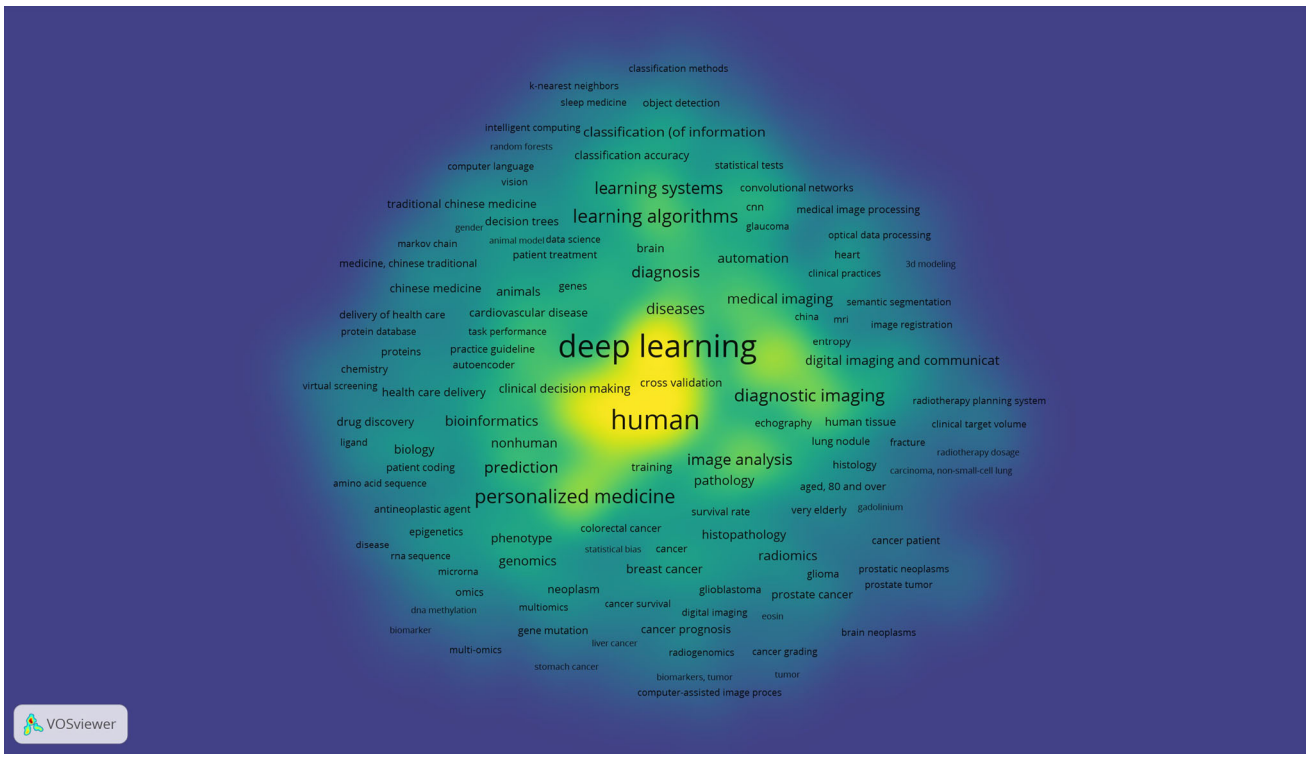

Fig. 17 Density with the topic medicine deep learning algorithms

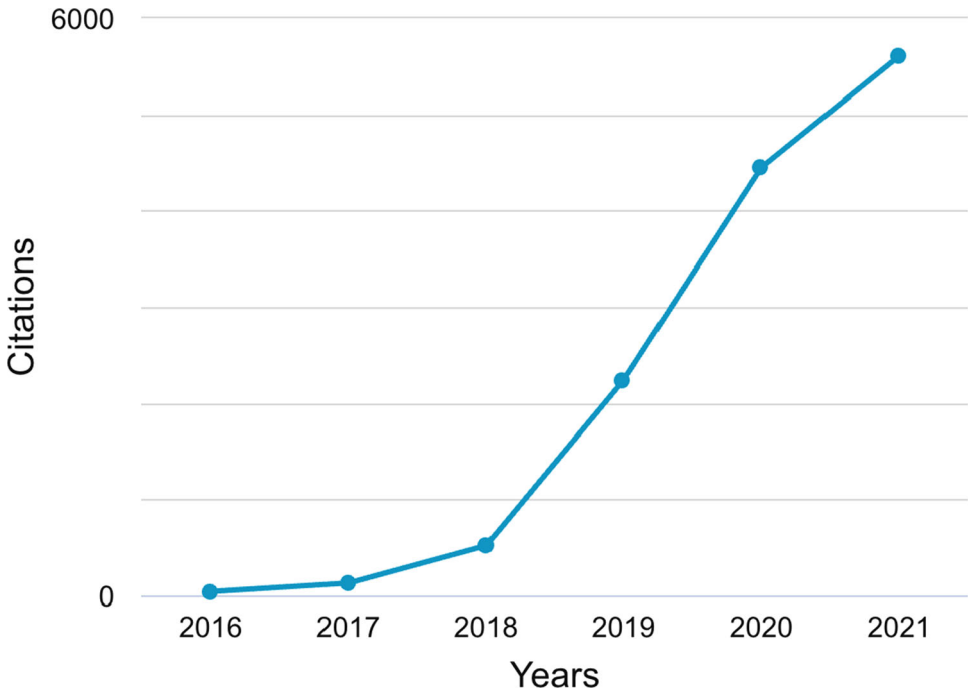

Fig. 18 Scopus citations with the topic 'Medicine Deep Learning Algorithms'

title, abstract and keyword. The collected data from Scopus, were used in VosViewer to obtain in graph form the obtained results. First, we create a map based on bibliographic data from Scopus. The data were introduced in a csv format. The type of analysis was by Co-occurrence, the counting method was full counting. Finally, the measure unit used was by keywords with a minimum number of occurrences equal to 2. Where, we obtained 8721 keywords, which 2131 meet the threshold. For each of the 2131 keywords, the total strength of the co-occurrence links with other keywords was calculated. The keywords with the greatest total link strength were selected. In total 1000 keywords were selected to obtain the final results. In Fig. 19, is shown the network, relations, clusters and links in a form graph of this query using data from Scopus. In Fig. 20 the density of this network is presented, highlighting with yellow color the area of intelligent control and deep learning with more strength that other analyzed keywords. Figure 21 shows the citations in the last years from Scopus. In this figure, we can appreciate how the number of citations has increased significantly each year.

4.3 Robotic deep learning applications

Also, in this section, a review with DL algorithms applied to Medicine are presented. Also, was used the tool VosViewer Perianes-Rodriguez et al. (2016) to distinguish the formed networks and relations in medicine. From Scopus database, was made a query to calculate the network, relations, clusters with the topic'Robotic Control Quantum Computing'. We found 516 linked papers considering title, abstract and keyword. The collected data from Scopus, were used in VosViewer to obtain in graph form the obtained results. First, we create a map based on bibliographic data from Scopus. The data were introduced in a csv format. The type of analysis was by Co-occurrence, the counting method was full counting. Finally, the measure unit used was by keywords with a minimum number of occurrences equal to 2. Where, we obtained 4010 keywords, which 990 meet the threshold. For each of the 990 keywords, the total strength of the co-occurrence links with other keywords was calculated. The keywords with the greatest total link strength were selected. In total, 990 keywords were selected to obtain the final results. In Fig. 22, is shown the network, relations, clusters and links in a form graph of this query using data from Scopus. In Fig. 23 the density of this network is presented, highlighting with yellow color the area of deep learning and learning algorithms with more strength that other analyzed keywords. Figure 24 shows the citations in the last years from Scopus. In this figure, we can appreciate how the number of citations has increased significantly each year.

In this field, we can see many works applying robotics with deep learning methods. Therefore, in this section are presented the most relevant and recent in this area. For example, in Wu et al. (2019) implemented a robot to make an automatic choreography system based on the deep learning technology. On the other hand, King and Hwang (1989). The authors proposed a ring VLSI systolic architecture for implementing neural networks with applications

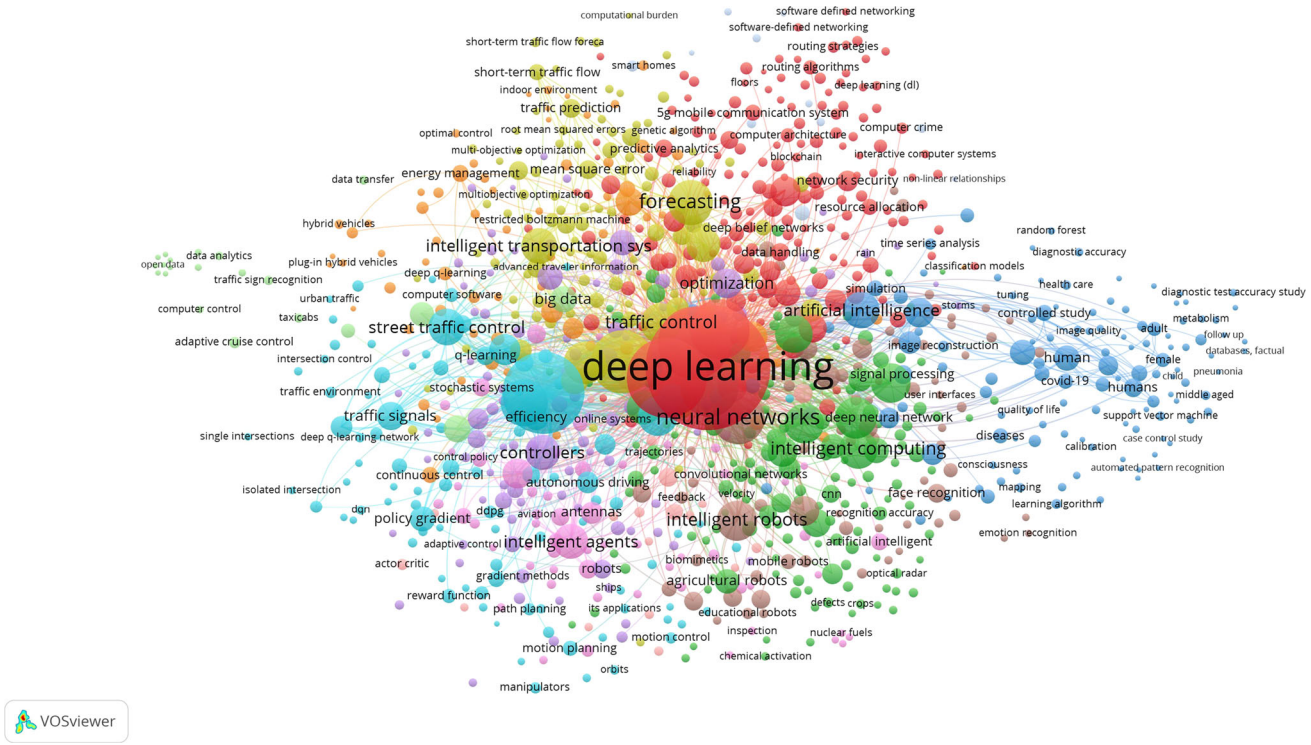

Fig. 19 Network with the topic 'intelligent control deep learning algorithms'

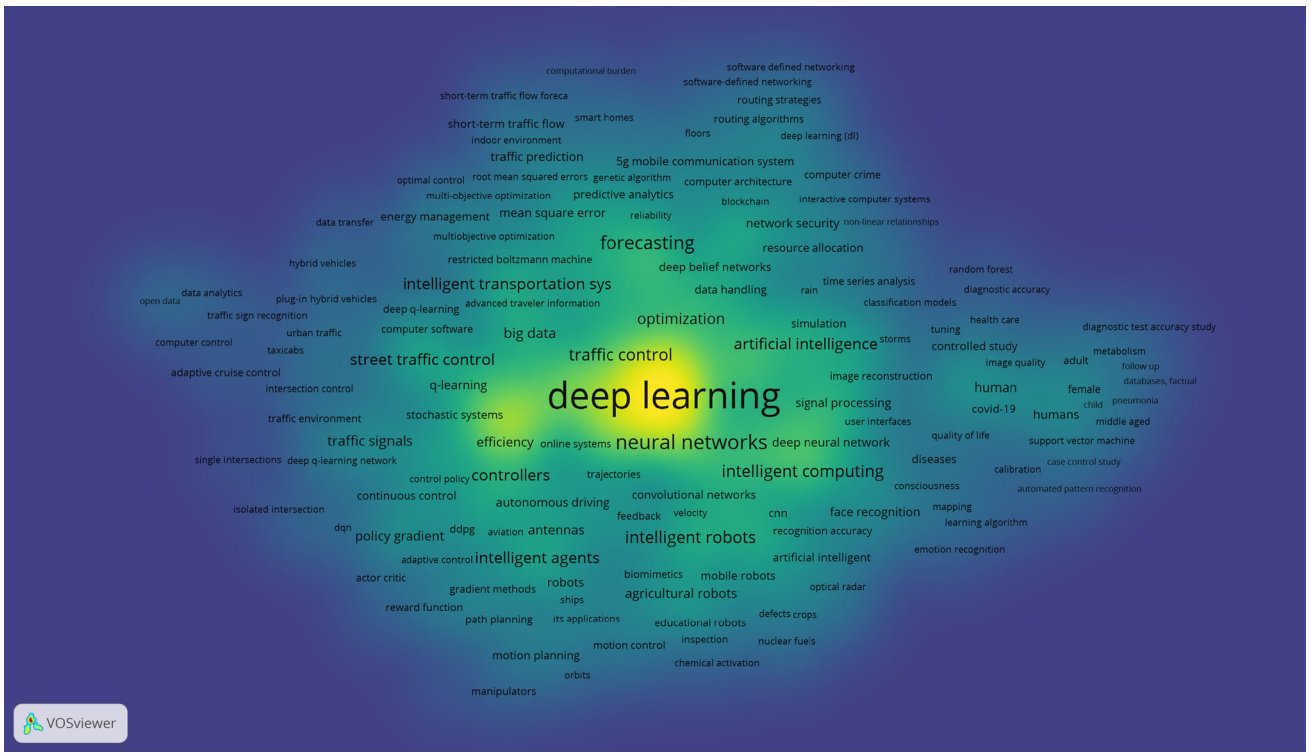

Fig. 20 Density with the topic 'intelligent control deep learning algorithms'

to robotic processing. Also, Liao et al. (2021) proposed an unsupervised fault detection and recovery for intelligent robotic rollators using deep neural networks. The experiments under several conditions confirmed that the method,

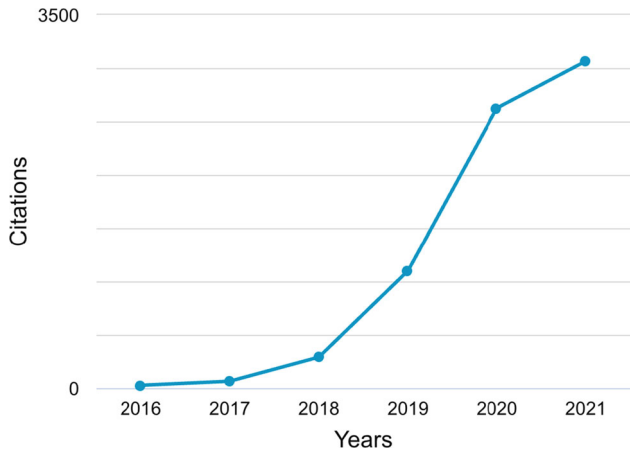

Fig. 21 Scopus citations with the topic 'Intelligent Control Deep Learning Algorithms'

which leverages machine learning-enhanced algorithms, exhibits reliable performance. Also, Chen et al. (2020) proposed a robotic device capable of introducing needles and catheters into deformable tissues such as blood vessels to draw blood or deliver fluids autonomously. Robotic cannulation is driven by predictions from a series of deep convolutional neural networks that encode information from multimodal image sequences to guide real-time serving. Also, in Alzubaidi et al. (2021) was made a review about applications in robotic with deep learning, convolutional neural networks architectures, challenges, etc. In this study, the authors attempt to provide a more comprehensive survey of the most important aspects of Deep Learning and including those enhancements recently added to the field.

5 Conclusions

After performing an analysis from Scopus, an undertaking an exhaustive study about the applications and importance of Quantum Computing and Deep Learning; we can conclude that these areas have achieved an important advancement in the last years. We can observe, the increment of number of citations, for example, in Scopus, the tendency is developed every day more works based on these two fields of the computational intelligence. Also, we have found, the networks, clusters, and built relationships around the world by many researches that are working with the analyzed topics. As future works, other topics of WoS, Google Scholar, or other databases can be analyzed with this software to compare the number of citations or relevance considering other sources. Also, specific queries with

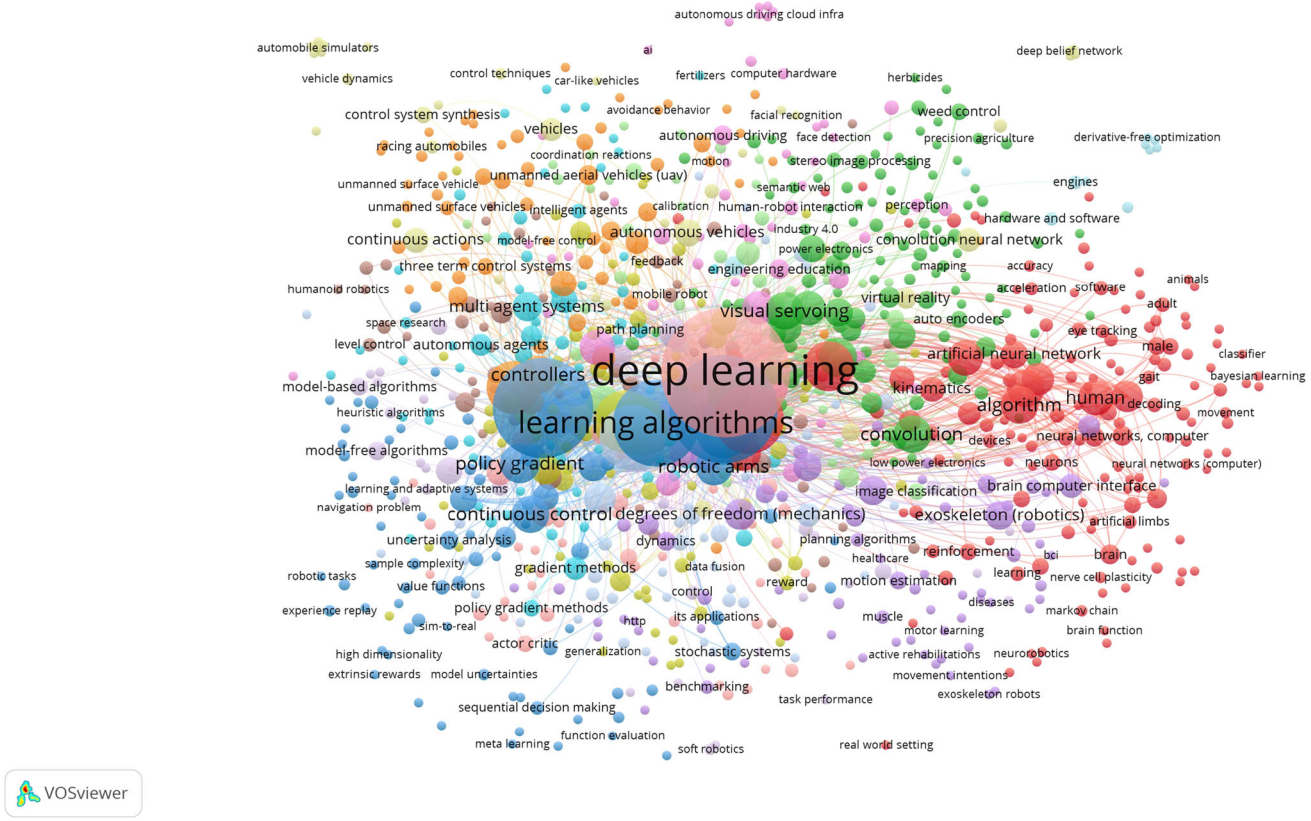

Fig. 22 Network with the topic 'robotic deep learning algorithms'

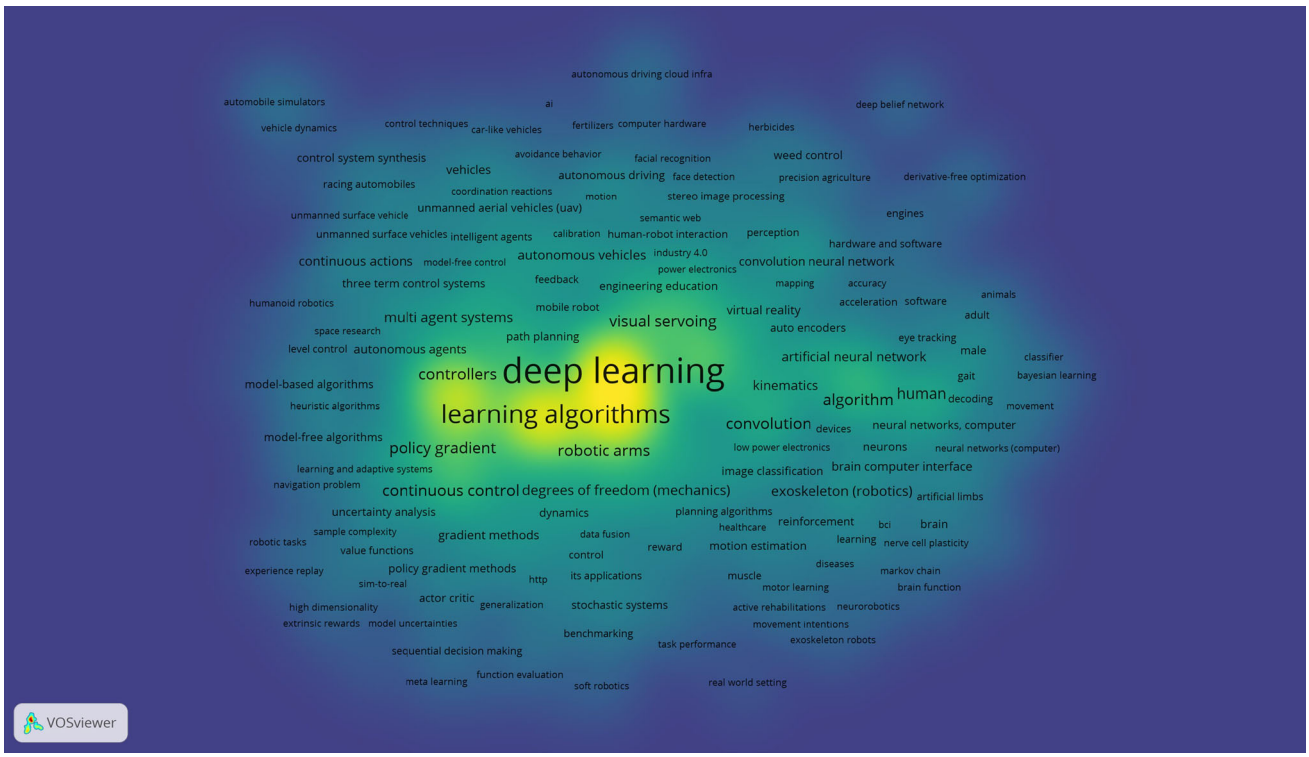

Fig. 23 Density with the topic 'robotic deep learning algorithms'

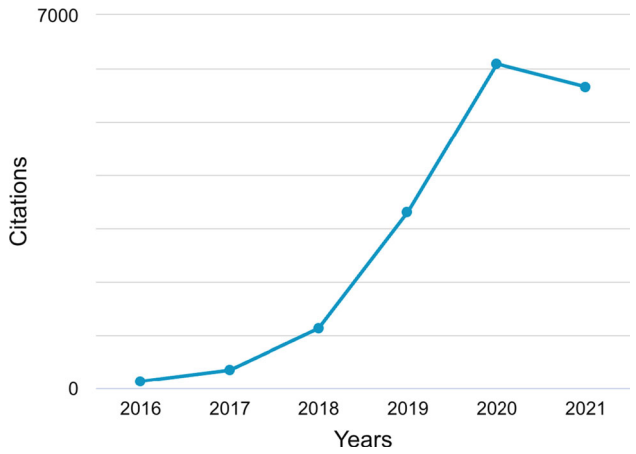

Fig. 24 Scopus citations with the topic 'Robotic Deep Learning Algorithms'

other bibliometric software such as CiteSpace, Zhang et al. (2010), that is a free software for visualizing and analyzing trends and patterns in the scientific literature can be used. The relevance of the review is that with this paper, the researchers can observe the trends for using QC and DL in several areas. However, the paper can serve as reference to make other queries, with other topics from different databases. Also, the same searches can be explored to view the updated information about the analyzed topics in this review. Although, only were reviewed medicine, robotic and intelligent control to make the research, the paper can be extended with other important areas. We decided to explore these areas because we have some works in computational intelligence with these topics.

Acknowledgements The authors would like to thank CONACYT and Tecnológico Nacional de Mexico/Tijuana Institute of Technology for the support during this research work.

Author contribution Conceptualization, F.V. and P.M.; methodology, F.V.; software, F.V.; validation, F.V. and P.M.; formal analysis, P.M.; investigation, P.M.; resources, P.M.; writing—original draft preparation, F.V. and P.M.; writing—review and editing, P.M.; visualization, F.V.; supervision, F.V. and P.M.; project administration. All authors have read and agreed to the published version of the manuscript.

Funding This paper did not receive funding.

Data availability Not applicable

Declarations

Conflict of interest All the authors in the paper have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed Consent Statement Not applicable

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