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A research agenda of AI-based analog circuit fault diagnosis with bibliometric analysis

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Abstract. Analog circuit fault identification is crucial for preserving regular operation. Methods based on artificial intelligence (AI) provide excellent accuracy in fault identification. AI-based techniques have been used widely in recent years, displaying remarkable variety and complexity. Therefore, in order to have a clearer understanding of the issues in this area, it is necessary to summarise and classify the techniques. In this article, various AI-based fault detection techniques are displayed, and bibliometrics is used to show the trend and citations. The relationships, significant writers, and journals will first be discussed in this article, after which some key pieces of literature will be displayed. The key findings and conclusions, clarification of the current issues, and a summary of the present and foreseeable research trends are all included in the last section.

Keywords: analogy circuit, fault diagnosis, deep learning, machine learning, bibliometric analysis.

1. Introduction

Electric engineering places a lot of emphasis on diagnosing analogue circuit faults in order to ensure a smooth operation and cut down on wasteful losses. Deep learning and machine learning have both seen increased application recently. AI-based techniques can significantly increase the efficiency and accuracy of fault identification over conventional ones. As a result, AI-based fault detection techniques like the Support Vector Machine (SVM), Extreme Learning Machine (ELM), Particle Swarm Optimization (PSO), Generative Adversarial Networks (GAN), Wavelet Transform (WT), Back-Propagation (BP), Neural Network (NN), and Fuzzy Logic are becoming increasingly popular. To facilitate the further study and research, it is vital to describe given the complexity and diversity of the approaches.

In recent studies, methods in this sector have been compiled, however the majority of them are not complete. Some have outlined the procedures and introduced the fundamental elements of typical methodologies, but the trend has not been researched and is only applicable to the diagnosis of motors [1]. There is no classification of methods in other articles, which discuss the theory of defect diagnosis methods and explain their contributions [2]. In other studies, the primary phases of fault diagnosis using various techniques were discussed, but no comparisons were conducted [3]. In recent years, some have counted the volume of publications and usage of AI approaches generally, but no comprehensive analysis has been done on the connections between these methods [4]. In order to make insightful

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deductions from the earlier works, it is crucial to examine them using bibliometrics. A number of thorough reviews will also be examined and used as a guide for this review.

Analyzing analogue circuit fault diagnosis techniques is the goal of this paper, which also serves as a resource for future engineering studies. There are five sections in the article. The research methodology will be presented in the second section to demonstrate the framework and criteria for gathering and evaluating the literature. In the third section, bibliometrics techniques will be used to demonstrate the trend and connections between analogue circuit fault diagnosis techniques, significant authors, and journals. Several key pieces of literature will be shown in the fourth section. The key conclusions and findings will be presented in the last section, along with a summary of the current issues and the direction that research is headed in the coming years.

2. Research methodology

2.1. Databases, keywords, and inclusion criteria

The research from the Web of Science database served as the foundation for the methods utilised to find the studies pertinent to this study. The selection of keywords that enable the identification of all articles that are pertinent to the study objectives is a crucial problem when performing database queries. Studying the most often occurring keywords in articles that are pertinent to the topic under consideration is one technique to deal with this problem. The relevant articles' keywords were divided into two groups as follows:

- Keywords relating to the research object, such as "Analog circuit" and "circuit failure diagnosis," are included in Group A.
- Keywords related to the research methodology, such as "deep learning," "machine learning," and "neural network," are included in Group B.

Each keyword from group A and group B was combined to run the queries, and publications were deemed relevant if the title, abstract, or keywords had at least one term from each group. Sort the articles after retrieval by reading the abstract and skimming the text. The study subjects and research techniques should closely resemble the selected keywords. The time frame for publishing was left unrestricted. Review articles were also taken out of the retrieval results. Ultimately, 106 papers in all were included in the collection for additional investigation.

2.2. Analysis tools

For the aims of the descriptive statistics provided in Section 3, the pertinent information from the 106 papers in the sample was saved in a Microsoft Excel spreadsheet. Vos viewer was used to determine the relationships between the network of author collaborations (Section 3) and the various analogue circuit fault diagnose (ACFD) subjects (Section 4).

3. Descriptive results

3.1. Trend of publications in time

Figure displays the papers on ACFD's publication trend. The graphic shows that the increasing trend multiplies the number of publications. Although there was no restriction on the publishing date, the first pertinent paper was published in 1992 (Figure 1), making ACFD a relatively new area of study. From 1997 to 2010, the publication pattern remained fairly consistent at one to four works per year. The number rose to 6 in 2011, and from then until 2020, it varied around 4 per year. The amount sharply raised to 16 in 2021. Although 2022 hasn't ended yet, based on the figures presented thus far, it is anticipated to be very high. Figure 1 illustrates that although the number of research publications on this subject varies, it generally exhibits a pattern of growth and had a significant increase to 16 in 2021. It is clear that methods using AI are progressively gaining popularity.

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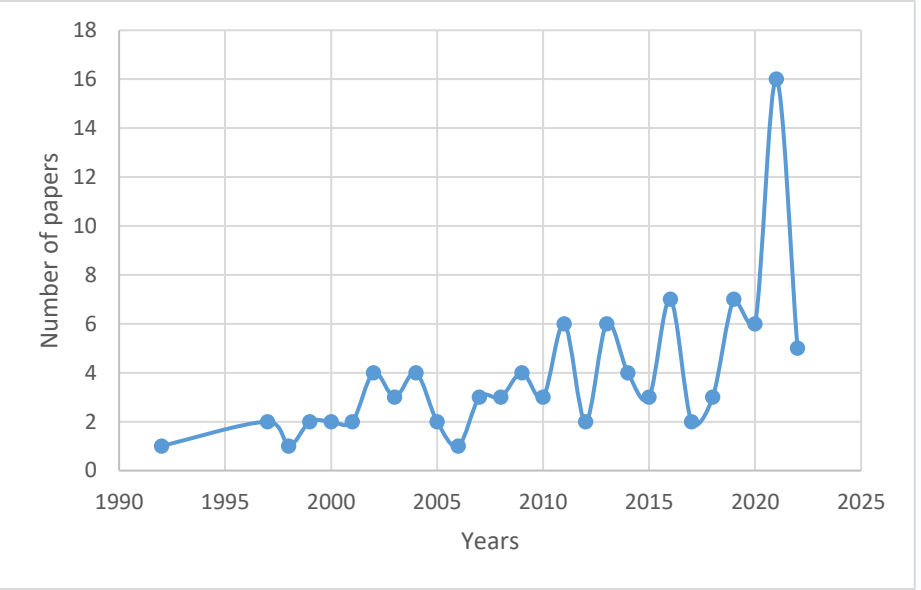

Figure 1. Publication trend.

3.2. Publication outlet

Table 1 displays the number of publications in the topic that have been published in various journals. Only journals with two or more publications are displayed in this graph. The Journal of Electronic Testing-Theory and Applications has the highest number of publications, which suggests that the journal gives this issue greater attention and may have more works of literature on the topic. Analog Integrated Circuits and Signal Processing, Metrology and Measurement Systems, and IEEE Transactions on Instrumentation and Measurement are a few further noteworthy periodicals.

Table 1. Publication outlet.

Journals	Number of articles	Citations	Total link strength
Journal of Electronic Testing-theory and Applications	10	188	76
Analog Integrated Circuits and Signal Processing	9	76	56
Metrology and Measurement Systems	8	100	41
IEEE Transactions on Instrumentation and Measurement	7	582	113
Circuits Systems and Signal Processing	5	45	44
Measurement	5	196	55
IEEE Access	4	80	25
Neural Computing & Applications	4	47	36
Electronics	3	7	15
IEEE Proceedings-circuits Devices and Systems	3	90	17

3.3. Authorship and collaborations

As can be seen in Table.2, the ACFD literature was written by a total of 262 distinct authors. While 16 writers (6.1%) published three or more papers on ACFD, the majority of authors (93.9%) only published one. The figure shows that He Yang has much more publications than other academics, which is noteworthy. He Yang may therefore be more knowledgeable about and have conducted comparatively more study on this issue. Zhang Chaolong, Aminian, F., Aminian, M., and Wang Youren are more noteworthy authors.

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Table 2. Authorship and collaborations.

Author	Number of articles	Citations	Total link strength
He Yigang	11	404	457
Zhang Chaolong	6	99	249
Aminian, F.	4	414	321
Aminian, M.	4	414	321
Wang Youren	4	75	124

The authors of the references are displayed in Figure 2 along with any co-citations. It is clear that He Yigang and Zhang Chaolong are two more than significant and knowledgeable authors in this area. Yuan Lifen, Tan Yanghong, and Xiang Shen are further noteworthy authors.

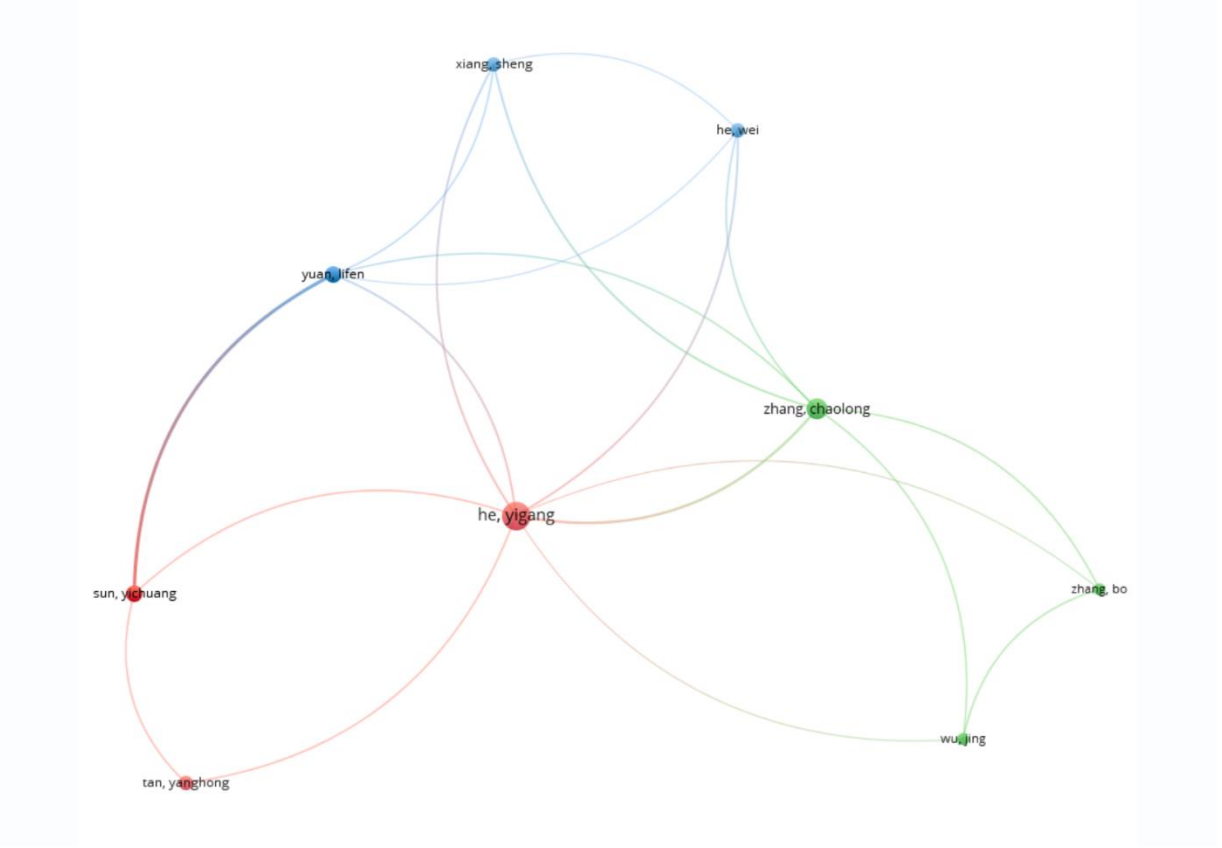

Figure 2. Author co-citations.

3.4. keywords

The keywords that appear more than three times in both the title and abstract are included in Table 3. It is clear that fault diagnostics, analogue circuits, neural networks, and wavelet transform are the keywords that appear the most frequently. The first two are study-related items, whereas the final two are study-related procedures. It is clear that wavelet transformation and neural networks are the most widely used techniques for fault detection in analogue circuits.

Table 3. keywords.

Keywords	Frequency	Total link strength
fault diagnosis	59	255
analog circuits	43	181
neural networks	16	63
neural network	14	51

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Table 3. (continued).

wavelet transform	10	44
fault detection	9	37
feature extraction	9	45
fault classification	6	33
convolutional neural network	5	27
support vector machine	5	17
artificial neural networks	4	12

3.5. Co-citation of keywords

The association between the terms that frequently appear in the title and abstract is shown in Figure 3. It is clear that the use of neural networks, wavelet transforms, SVM, and ELM are crucial techniques for addressing the issue of diagnosing analogue circuit faults. The approaches' feature extraction, algorithms, and optimization are the most problematic aspects.

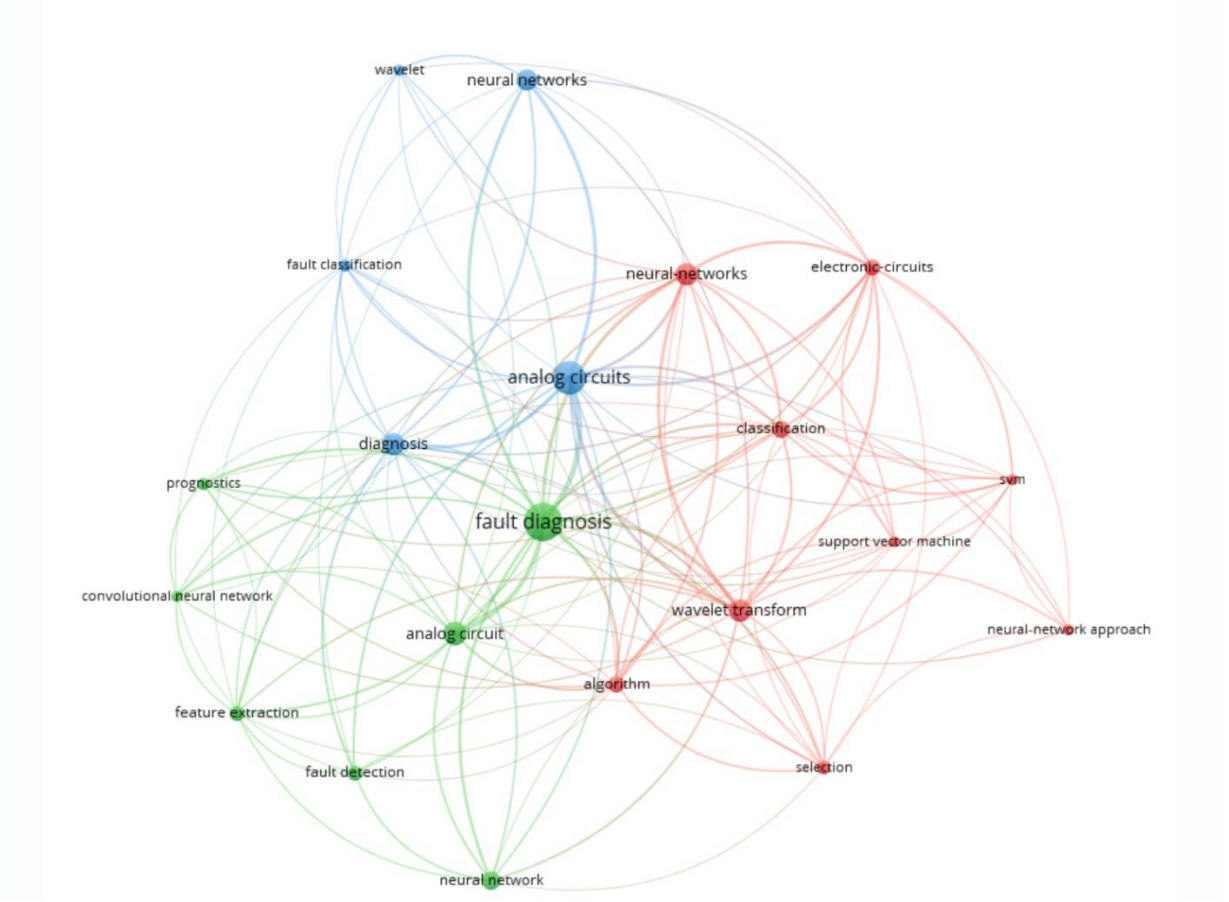

Figure 3. Co-citation of keywords.

3.6. Key articles

The key articles are displayed along with their co-citations in Figure.4. The documents Yuan (2010), Aminian (2007), Aminian (2000), and Aminian (2002) are reasonably significant and authoritative documents, as can be seen from the figure. These documents will be investigated in-depth below.

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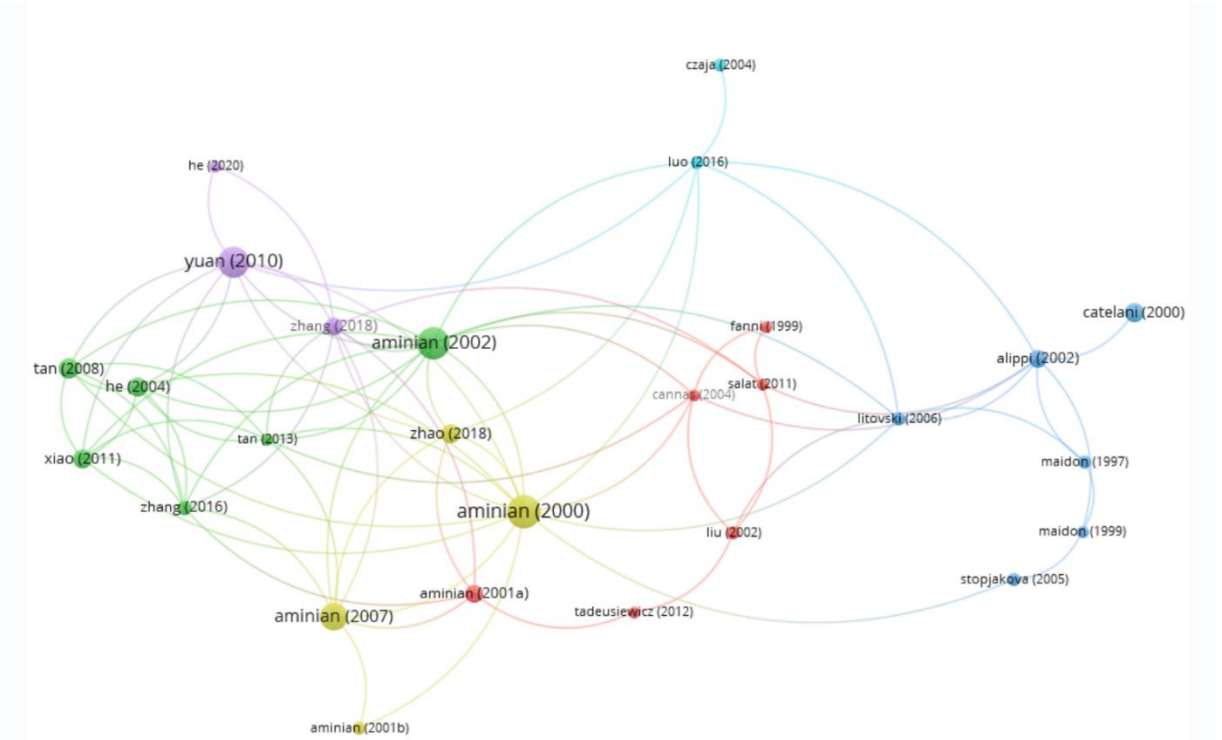

Figure 4. Key articles.

3.7. Methods

The research techniques applied in the literature sample are listed in Table.4. Deep learning, machine learning, and other methods make up the three main divisions. The table highlights the literature published since 2017 and displays how frequently they are used. Many articles also combine many methodologies, for example, WT and machine learning, deep learning and other method, etc.

Table 4. Methods.

Method	Frequency	Works since 2017
Deep Learning e.g., CNN, RNN, DNN, etc.	52	[2] [5–17]
Machine Learning e.g., PSO, SVM, PCA, etc.	18	[9] [18–24]
Else e.g., WT, Encoding, etc.	12	[25–27]
Combined method e.g., WT+deep learning, etc.	21	[11] [22]

4. Review of key literature

This section will explore the important literature that is commonly quoted and displayed in 3.6. The use of Wavelet Transform (WT) for Principal Component Analysis (PCA) and Back Propagation (BP) in training neural networks was pioneered by Aminian (2000). The results demonstrate that the system outperforms conventional BP techniques and requires a substantially smaller network. In order to improve the procedure, ltspice (software) was used to simulate certain circuits in 2002. According to the

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findings, features obtained from real circuits are more similar to one another and show greater fault class overlap than they do in ltspice simulations. In Aminian's 2007 experiment, neural networks were separated into numerous layers and made modular, significantly shrinking the size of the fault module while increasing feasibility and accuracy.

Y. He et al. (2004) used examples to assess the benefits and drawbacks of WT and BP [28]. Cannas et al. (2004) presented a diagnostic method based on the pre-test simulation at the same time (SBT) [29]. Following that, Yuan et al. (2010) created an optimization based on them, processing the data using an unique convolutional neural network variant and the backward difference strategy [30]. The neural network classifier's structure is simplified by preprocessing based on signal kurtosis and entropy.

In order to get over the dependence of feature extraction for conventional approaches, a Deep Belief Network (DBN) is developed. Zhao et al. (2018) explicitly suggested a thorough comparison analysis of two sample experimental circuits with various degrees of complexity in soft failure mode [31].Tan et al. (2013) suggested a support vector machine (SVM) and optimized the DBN structure using the QPSO approach [32].The results show that the method is more accurate at diagnosing faults in analogue circuits than other common methods. Additionally, Xiao & He (2011) presented the maximum class separability Kernel Principal Component Analysis (MCSKPCA) pre-processor, simplifying the architectures and lightening the load on neural networks' computational resources [33].

Furthermore, Alippi et al. (2002) improved the procedure of Catelani & Fort (2000), researching sensitivity-based and RBF approaches, and resolving the issue of fault diagnosis based on SBT in analogue electronic circuits [34][35].

It is clear that the two primary techniques for diagnosing analogue circuit faults are WT and BP. On the basis of this, optimization techniques like MCSKPCA, FFT, MLP, DBN, and QPSO been developed. RBF and sensitivity-based techniques are examples of complementary methodologies.

5. Conclusion and future work

Analog circuit fault detection is a necessary step that can increase system stability and decrease resource waste, given the costs of circuit failures and the loss to the system. In order to define the research area, categorise published studies, and compile current knowledge in the field of ACFD, this work presents a thorough literature review of 106 papers on ACFD.

Future research opportunities abound because ACFD is a relatively new area of study. According to the findings of this review, the following research recommendations (RR) can be developed as potential research areas for ACFD:

RR1: When examining the macro-themes examined in the literature, it was found that laboratory simulation (circuit design and optimization) received greater attention than real-world production applications (e.g. Aminian kept optimising network design without considering actual operation situation). Future research will be required to combine circuit diagnosis with production practise, take into account the real working environment and coordination with other systems, and address fault diagnosis dynamically and macroscopically.

RR2: Software simulation falls short of actual circuit measurement in quality [36]. The real-world scene has extra perturbations (also known as residual terms), which causes some discrepancy between the simulations' predictions and the actual outcomes. Since doing several actual tests would be difficult, it is essential to account for significant disturbance in simulations and perform practical verification of small samples to increase the reliability of simulations.

RR3: From a methodological perspective, combining AI techniques has become commonplace. Instead of being organised, several approaches are used in particular processing steps. For instance, Tan et al. (2013) used three approaches individually in data processing and network training[32]. The directions for future study are the development and coordination of various methodologies.

RR4: In terms of research topics, new energy has seen an increase in recent years [1,3]. The application of circuit fault diagnosis in this area holds promise for more intelligent operating environment detection, circuit stability assessment, and circuit design optimization.

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RR5: The quality of the data has a significant impact on the model's quality [34]. In the future, techniques to produce more accurate data for simulations will be investigated. Up until recently, EDA technologies have been employed to create artificial data [2]. Future research should focus on challenges such how to effectively and succinctly express routing data on a dataset, which data should be provided to the model, and how broadly the model can be used.

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