EDU REKHA INTERNATIONAL JOURNAL OF ARTS, LAW AND SOCIAL SCIENCE

Journal Homepage: https://edurekhapublisher.com/erijalss/

Volume- 2 Issue – 4 (July-August) 2026

ISSN: 3107-5169 (Online)

Frequency: Bimonthly

PAGES: 147-155

ARTICLE TITLE:

A Comprehensive Survey of Deep Learning Applications and Security in the Metaverse

Basma Mohamed[1*] & Mahmoud Almashad[2]

[1]Department of Information Systems, Giza Higher Institute for Managerial Sciences, Giza, Egypt

[2]Department of Accounting, Giza Higher Institute for Managerial Sciences, Giza, Egypt

ARTICLE HISTORY

RECEIVED
16-07-2026

ACCEPTED
20-07-2026

PUBLISHED
08-08-2026

Corresponding author:

Basma Mohamed

Department of Information Systems, Giza Higher Institute for Managerial Sciences, Giza, Egypt

Abstract

Deep learning is poised to play a pivotal role in shaping the future of the metaverse, a collective virtual shared space created by the convergence of virtually enhanced physical reality and physically persistent virtual reality. Its ability to learn from vast amounts of data and make complex decisions makes it an indispensable tool for creating immersive, intelligent, and personalized experiences within this digital realm. The metaverse is a collective virtual shared space created by the convergence of virtually enhanced physical reality and physically persistent virtual reality. It's a concept where users can interact with each other and their environment in a 3D virtual world. Image recognition, object detection, image segmentation, medical image analysis, natural language processing, speech recognition, healthcare and autonomous vehicles are a few examples of applications for deep learning. This survey provides an overview of various metaverse applications and outcomes, as well as an introduction to deep learning.

Keywords: Deep Learning; Metaverse; Artificial Neural Networks.

1. Introduction

A form of machine learning known as "deep learning" makes use of multiple-layer artificial neural networks to extract intricate patterns from data. These neural networks can process and analyze vast volumes of data to make deft decisions; they are inspired by the composition and operations of the human brain [1]. This is a relatively new method that has been extensively used in several classic artificial intelligence applications, including computer vision [2, 3], natural language processing [4], transfer learning [5], semantic parsing [6], and many more. The current growth in deep learning can be attributed to three key factors: the sharply higher processing power of chips (such as GPU units), the sharply lower cost of computing gear, and the notable advancements in machine learning techniques [7]. Numerous deep learning techniques have been thoroughly examined and deliberated in the past few years [8, 9, 10, 11]. Malashin et al. [10] explored the application of Long Short-Term Memory (LSTM) networks, a specialized type of recurrent neural network (RNN), in the field of polymeric sciences. LSTM networks have shown notable effectiveness in modeling sequential data and predicting time-series outcomes, which are essential for understanding complex molecular structures and dynamic processes in polymers, while Bian et al. [11] provided a comprehensive overview of ML optimization strategies, emphasizing their classification, obstacles, and potential areas for further study. Hypernetworks are a means by which Chauhan et al. [12] hope to spur additional progress in deep learning. The commonly used DL techniques, such as convolutional neural network (CNN), simple recurrent neural network (RNN), long short-term memory (LSTM), and gated recurrent unit (GRU), were succinctly described and their performances were compared by Mienye et al. [13] after reviewing the most recent DL-based study. A variational regularization method to inverse issues was examined by Duff et al. [14] with the usage of generative models. To support industry management and decision-making, Jauhar et al. [15] developed a framework for performance assessment and prediction based on Data Envelopment Analysis (DEA), Artificial Neural Networks, and Deep Learning (DL).

In order to improve the accuracy of future solar power generation predictions from renewable energy facilities, AlKandari et al. [16] presented a hybrid model that blends machine-learning techniques with the Theta statistical method. With a focus on dynamical system learning, Wang et al. [17] presented the physics-guided deep learning framework. In order to implement Wireless Sensor Networks (WSNs), Qiu et al. [18] investigated the revolutionary integration of deep learning applications. Researchers in the field were given a fresh viewpoint by Baradaran et al. [19], who categorized semi-supervised VAD algorithms based on the type of proxy job that they use to model normal data and then identify abnormalities. In order to forecast these yields, Chen et al. [20] investigated the use of sophisticated machine learning techniques, particularly Recurrent Neural Networks (RNN) and Long Short-Term Memory (LSTM) models. By examining how DL is applied to particular NDT applications and highlighting its benefits and drawbacks, Li et al. [21] sought to assess the state-of-the-art applications of DL algorithms in NDT. A comprehensive review of machine learning techniques used to address NP-hard Vehicle Routing Problems (VRPs) was presented by Bogyrbayeva et al. [22]. An extensive survey of machine learning and deep learning (ML and DL) for the healthcare system was provided by Rahman et al. [23], with a focus on critical state-of-the-art features, integration benefits, applications, prospects, and future guidelines.

A thorough analysis of the literature on the application of Machine Learning (ML) techniques in AM was provided by Karimzadeh et al. [24], with a focus on ML-based strategies for streamlining the manufacturing of FGMs. Wu et al. [25] developed a useful design tool for ceramic additive manufacturing and acquired fresh insights into the mechanical sciences regarding design for changing material conditions. The method suggested by Gupta et al. [26] effectively identifies users' emotions within the metaverse.

In order to investigate people's feelings on the metaverse in a user-generated context, Raghavan et al. [27] used machine learning sentiment analysis approaches utilizing Support Vector Machine, Doc2Vec, RNN, and CNN. With an emphasis on blockchain and machine learning (ML) solutions, Truong et al. [28] sought to conduct a detailed analysis of the security element of the Metaverse. The definitions, uses, and overall difficulties of DT and Metaverse were provided by Far et al. [29]. Choi et al. [30] provided future researchers with a thorough understanding of the security concerns associated with the various metaverse initiatives currently underway throughout the globe, as well as some of the most recent technological advancements and solutions employed to enhance security and quality of experience in the metaverse.

A unique Metaverse Security Architecture built on Zero-Trust principles was presented by Sharma et al. [31]. A thorough analysis of the metaverse's foundations, security, and privacy was provided by Wang et al. [32]. In an attempt to advance the metaverse community, Zhao et al. [33] suggested that in order to adequately address security and privacy concerns from a philosophical standpoint, it is necessary to utilize the new buckets effect. Blockchain technology and artificial intelligence should be combined in the metaverse, according to Ali et al. [34], to create more secure, quicker, and better healthcare facilities that offer a realistic experience online. From user apps to virtual services and the blockchain-enabled economic system, Truong et al. [35] explored how blockchain may enable the metaverse from many angles.

A thorough and in-depth analysis of every scenario of quantum implementation into a metaverse setting was suggested by Kwon et al. [36]. Peatchimuthu et al. [37] then offered extensive insights on the most recent developments in the metaverse realm in the context of cutting-edge technologies, security vulnerabilities and preventive measures specific to the metaverse and the research challenges pertaining to metaverse. They also proposed a hypothetical meta-stack framework to understand the various components in the metaverse realm. The explanation of the idea of the metaverse, its background, and its related advantages was the main goal of Bale et al. [38]. Sami et al. [39] outlined the current issues with each component, then suggested future lines of inquiry and possible fixes. After examining the fundamental features of the metaverse and the critical function of edge computing, Baidya et al. [40] looked into the different kinds of resources and the main problems and difficulties they faced.

2. Key Components of Deep Learning:

2.1. Artificial Neural Networks [41]: These networks process information in layers using networked nodes, or neurons.

2.2. Layers: Input, hidden, and output layers are the common layers seen in deep learning models.

2.3. Activation Functions [42]: The network can learn intricate associations thanks to the non-linearity these functions impart to it.

2.4. Back Propagation: This algorithm reduces the error between the expected and actual outputs by modifying the weights and biases of the network's links.

3. The Benefits of Deep Learning:

When compared to conventional machine learning methods, deep learning has the following important advantages:

3.1. Feature Learning:

a. **Automatic Feature Extraction [43]:** Without the requirement for human feature engineering, deep learning models are able to automatically extract the most pertinent features from raw data.

b. **Hierarchical Feature Representation [44]:** Complex relationships and patterns can be captured by deep learning models that are able to learn hierarchical representations of data.

3.2. Excellent Precision:

a. **State-of-the-Art Performance [45]:** On a variety of tasks such as speech recognition, image recognition, and natural language processing, deep learning models have demonstrated state-of-the-art performance.

b. **Continuous Improvement [46]:** As deep learning models are trained on additional data, they will be able to perform better over time.

3.3. Scalability:

a. **Managing Big Datasets [47]:** Deep learning models are well-suited for big data applications due to their ability to manage enormous datasets.

b. **Parallel Processing [48]:** Deep learning is appropriate for large-scale deployments since it can be parallelized to speed up training and inference.

3.4. Versatility:

a. **Broad Range of Applications [49]:** Deep learning has a wide range of applications, including natural language processing, medical diagnosis, and the analysis of images and videos.

b. **Adaptability [50]:** Deep learning models are easily modified to fit new tasks and domains.

3.5. End-to-End Learning:

a. **Direct Learning from Raw Data [51]:** Without the requirement for intermediary processing stages, deep learning models are able to learn directly from raw data.

b. **Simplified Workflow [52]:** This lowers the possibility of making mistakes and streamlines the workflow.

3.6. Representation Learning:

a. **Acquiring Valuable Representations [53]:** Deep learning models possess the ability to acquire valuable data representations that may be used to many tasks, including transfer learning.

b. **Enhancing Generalization [54]:** This may enhance the model's capacity for generalization.

4. Types of Deep Learning:

A branch of machine learning known as "deep learning" makes use of multiple-layered artificial neural networks to learn from data. Here are a few typical applications for deep learning:

4.1. Convolutional Neural Networks (CNNs) [55]:

a. They operate best in object recognition, natural language processing, and image and video analysis.

b. **How they operate:** CNNs are particularly good at processing grid-like data because they use convolutional layers to extract features from incoming data

4.2. RNNs, or recurrent neural networks [56]:

a. **Ideal for:** Speech recognition, natural language processing, and sequential data, such time series.

b. **How they function:** Recurrent neural networks (RNNs) handle sequential data and retain information from prior inputs thanks to feedback connections.

4.3. Networks with long short-term memory (LSTM)[57] are best suited to manage long-term dependencies in sequential data.

a. **How they function:** Long short-term memory (LSTM) is enhanced by the employment of gates, a unique kind of RNN, to regulate the information flow.

4.4. Generative Adversarial Networks (GANs) [58]:

a. **Most effective when:** Producing text, music, and visual data.

b. **How they function:** A discriminator network seeks to discern between produced and actual data, while a generator network generates new data.

4.5. Autoencoders [59]:

a. **Optimal for:** Feature extraction, dimensionality reduction, and unsupervised learning.

b. **How they operate:** Autoencoders are trained to recognize, compress, and rebuild input data while preserving its most crucial elements.

4.6. Deep Learning with Reinforcement [60]:

a. **Ideal for:** Acquiring decision-making skills in intricate settings.

b. **How they function:** By fusing reinforcement learning and deep learning, deep reinforcement learning enables agents to discover the best course of action by trial and error. Just a handful of the several varieties of deep learning algorithms exist. The particular task at hand and the properties of the data will determine which approach is best.

5. Important Metaverse Elements

The metaverse is an intricate ecology made up of various interdependent parts. Here are a few of the crucial components:

5.1. Virtual Worlds:

a. **Persistent Environments [61]:** These are online areas that run always, even when no one is using them.

b. **Immersive Experiences [62]:** Via realistic visuals, audio, and haptic input, virtual worlds seek to create immersive experiences.

c. **Social Interaction [63]:** In these virtual environments, users can communicate with one another and with virtual items.

5.2. Digital Avatars:

a. **User Representations [64]:** Avatars are personalized digital versions of users that can be altered to suit their unique tastes.

b. **Social Interaction [65]:** By allowing users to communicate with one another in the metaverse, avatars promote social interaction.

5.3. Blockchain Technology:

a. **Decentralization [66]:** Blockchain technology guarantees the decentralization of the metaverse, thereby impeding the control of the metaverse by a single entity.

b. **Ownership and Transactions [67]:** Digital asset ownership may be tracked via blockchain technology, which can also be utilized to make transactions easier within the metaverse.

5.4. The Differences Between Virtual and Augmented Reality:

a. **Merging Digital and Physical [68]:** AR projects digital data onto the physical world, whilst VR generates completely immersive virtual worlds.

b. **Enhanced Experiences:** By offering more realistic and interactive interactions, these technologies improve the metaverse experience.

5.5. The Internet of Things (IoT):

a. **Connected Devices [69]:** IoT devices can be used to improve user experiences and deliver real-time data by being integrated into the metaverse.

b. **Physical-Digital Integration [70]:** IoT can provide a link between the digital and physical realms, opening up new possibilities for people to engage with the metaverse.

5.6. Artificial Intelligence (AI):

a. **Intelligent Agents [71]:** Via AI, people can engage with intelligent agents and assign them tasks within the metaverse.

b. **Customized Experiences [72]:** By adjusting content and suggestions according to user preferences, AI may customize user experiences.

5.7. Interoperability:

a. **Connected Ecosystems [73]:** This feature makes it possible for various metaverse platforms to connect and communicate with one another, giving users a more seamless experience.

b. **Open Standards:** In order to achieve interoperability across various metaverse platforms, open standards are necessary.

6. The Metaverse's Benefits:

Numerous possible advantages of the metaverse exist, such as:

6.1. Strengthened Social Bonds:

a. **Virtual Communities [74]:** Even for individuals who live far apart, the metaverse can promote strong social bonds and communities.

b. **Inclusive Environments:** For those who struggle with social anxiety or disability, the metaverse can be a more accepting place.

6.2. New Economic Prospects:

a. **Digital Commerce [75]:** Companies can have a metaverse presence and sell products and services to a worldwide customer base.

b. **Job Creation [76]:** The metaverse is expected to lead to the creation of new positions in industries including AI development, virtual world design, and content production.

6.3. Innovative Training and Education:

a. Immersive Learning Experiences [77]: By offering captivating and immersive learning opportunities, the metaverse can enhance both the efficacy and enjoyment of education.

b. Practical Training [78]: In a secure and simulated setting, students can hone their skills in engineering design or medical operations.

6.4. Recreation and Amusement:

a. Virtual Experiences [79]: There are many different forms of entertainment available in the metaverse, such as social gatherings, concerts, and games.

b. Customized Experiences [80]: Individual preferences can be catered to by users while creating personalized metaverse experiences.

6.5. Research and Development:

a. Simulation and Testing [81]: By simulating experiments and testing new products in a virtual environment, scientists and engineers can make use of the metaverse.

b. Collaboration [82]: Across geographical boundaries, researchers can work together on projects in the metaverse.

6.6. Accessibility:

a. Overcoming Physical Restrictions [83]: People with physical restrictions can have access to experiences and possibilities through the metaverse.

b. Bridging Cultural Divides [84]: By giving people from all origins a common virtual place, the metaverse can aid in bridging cultural divides. The metaverse has the potential to completely change the way we work, learn, and interact with one another, even if it is still in its infancy.

7. Metaverse Types

The various metaverse types are as follows, each with special traits and uses:

7.1. Metaverse Based on Gaming [85]:

a. **Main Focus:** Interactive entertainment and gaming.

b. **Examples include** Roblox, Fortnite, and Minecraft.

c. **Elements** include social elements, multiplayer interactions, quests, challenges, and immersive virtual worlds.

Picture:

Fig 1: Roblox metaverse.

DOI: 10.5281/zenodo.21848867

7.2. Metaverse Built on Socials [32]:

a. **Main theme:** Human interaction and connection.
b. **Examples include** Decentraland, Meta's Horizon Worlds.
c. **Features include** social areas, events, virtual avatars, and chances to socialize.

Picture:

Fig 2: Meta's Horizon Worlds Metaverse.

7.3. Based on Commerce Metaverse [86]:

a. **Main theme:** Shopping and retail experiences; Roblox's virtual item marketplace and Decentraland's LAND marketplace are two examples
b. **Features:** Digital items, virtual currency, virtual storefronts, and product demonstrations.

Picture:

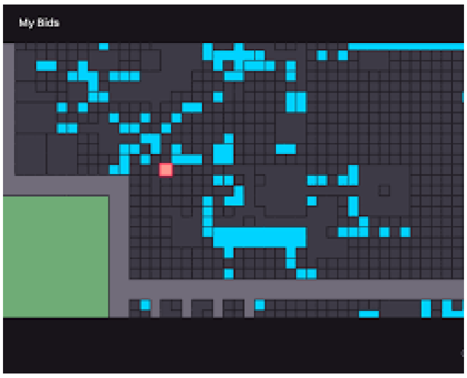

Fig 3: Decentraland's land marketplace.

7.4. A foundation in Education Metaverse [87]:

a. **Main objective:** Improving learning opportunities and experiences.
b. Engage and Immersive Learning are two examples.
c. **Features include** field trips, collaborative tools, virtual classrooms, and interactive learning opportunities.

Picture:

Fig 4: Engage metaverse.

7.5. Entertainment and Media Metaverse [88]:

a. **Main Ideas:** Taking part in interactive storytelling, exploring virtual entertainment spaces, going to virtual concerts, and interacting with media franchises in novel ways.
b. **Examples include** Roblox's virtual concerts and Meta's Horizon Venues.
c. **Features:** Live events, interactive storytelling, virtual spaces, and media material.

Picture:

Fig 5: Meta's horizon venues metaverse.

8. Deep Learning's Security Consequences in the Metaverse:

Although a very useful technique, deep learning poses new security risks in the metaverse.

8.1. Inverse Techniques:

a. **Poisoning Attacks[89]**: When malicious actors introduce tainted data into training sets, algorithms may react biasedly or produce inaccurate predictions.
b. **Evasion Attacks[90]:** By creating malicious inputs, adversaries can trick deep learning models and get around security precautions.

8.2. Privacy Concerns:

a. **Data Privacy [91]:** Since deep learning models frequently call for big datasets, data protection and privacy are major problems.
b. **Facial Recognition [92]:** If facial recognition technology is used in the metaverse improperly, it may result in privacy issues.

8.3. Theft of Intellectual Property:

a. **Model Theft [93]:** It is possible to steal and duplicate deep learning models, which can result in the theft of intellectual property and unapproved usage.

8.4. Fairness and Bias:

a. **Bias Amplification [94]:** Training data containing preexisting biases may be amplified or perpetuated by deep learning models, producing unfair or discriminating results.

8.5. Hardware Dependency:

a. **Hardware Vulnerabilities [95]:** The utilization of specialized hardware in deep learning may give rise to vulnerabilities that could be abused by malicious actors.

8.6. Strategies for Mitigation:

DOI: 10.5281/zenodo.21848867

a. **Sturdy Data Cleaning and Validation [96]:** To stop poisoning assaults, make sure that data is accurate and complete.
b. **Adversarial Training [97]:** Develop models that can withstand hostile attacks.
c. **Differential Privacy [98]:** By introducing noise into training data, you may safeguard user privacy.
d. **Frequent Model Auditing [99]:** Keep an eye out for bias and fairness problems in models at all times.
e. **Hardware Security mechanisms [100]:** Put robust security mechanisms in place to safeguard deep learning hardware.
f. **Frameworks for Law and Ethics [101]:** Establish precise legal and moral standards for the application of deep learning in the metaverse.

9. The following are some significant uses of deep learning in the metaverse:

a. **Image recognition [102]:** People, objects, and scenes in photos can be reliably identified by deep learning models.
b. **Natural language processing [103]:** These models are capable of producing and comprehending natural language, which makes them useful for tasks like sentiment analysis, text summarization, and machine translation.
c. **Speech recognition [104]:** Voice assistants and transcription services can be made possible by deep learning models that translate spoken words into text.
d. **Recommendation systems [105]:** These models make recommendations for goods or information based on the tastes and actions of the user.
e. **Medical image analysis [106-109]:** Deep learning models are useful for both medical image analysis and illness diagnosis.

10. Conclusion

In conclusion, deep learning is an incredibly potent technique that has transformed a wide range of industries. Deep learning models can address difficult issues by using artificial neural networks to learn intricate patterns from data. This paper provided an overview of various metaverse applications and outcomes, as well as an introduction to deep learning.

References

1. Le, Q., Miralles-Pechuán, L., Kulkarni, S., Su, J., & Boydell, O. (2020). An overview of deep learning in industry. *Data Analytics and AI*, 65-98.
2. Cireşan, D. C., Meier, U., & Schmidhuber, J. (2012, June). Transfer learning for Latin and Chinese characters with deep neural networks. In *The 2012 international joint conference on neural networks (IJCNN)* (pp. 1-6). IEEE.
3. Ren, J., & Xu, L. (2015, February). On vectorization of deep convolutional neural networks for vision tasks. In *Proceedings of the AAAI Conference on Artificial Intelligence* (Vol. 29, No. 1).
4. Bordes, A., Glorot, X., Weston, J., & Bengio, Y. (2012, March). Joint learning of words and meaning representations for open-text semantic parsing. In *Artificial intelligence and statistics* (pp. 127-135). PMLR.
5. Liou, C. Y., Cheng, W. C., Liou, J. W., & Liou, D. R. (2014). Autoencoder for words. *Neurocomputing*, *139*, 84-96.
6. Schmidhuber, J. (2015). Deep learning in neural networks: An overview. *Neural networks*, *61*, 85-117.
7. Krizhevsky, A., Sutskever, I., & Hinton, G. E. (2017). ImageNet classification with deep convolutional neural networks. *Communications of the ACM*, *60*(6), 84-90.
8. Schmidhuber, J. (2012, June). Multi-column deep neural networks for image classification. In *Proceedings of the 2012 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)* (pp. 3642-3649).
9. Khan, A., Sohail, A., Zahoora, U., & Qureshi, A. S. (2020). A survey of the recent architectures of deep convolutional neural networks. *Artificial intelligence review*, *53*, 5455-5516.
10. Malashin, I., Tynchenko, V., Gantimurov, A., Nelyub, V., & Borodulin, A. (2024). Applications of Long Short-Term Memory (LSTM) Networks in Polymeric Sciences: A Review. *Polymers*, *16*(18), 2607.
11. Bian, K., & Priyadarshi, R. (2024). Machine learning optimization techniques: a Survey, classification, challenges, and Future Research Issues. *Archives of Computational Methods in Engineering*, 1-25.
12. Chauhan, V. K., Zhou, J., Lu, P., Molaei, S., & Clifton, D. A. (2024). A brief review of hypernetworks in deep learning. *Artificial Intelligence Review*, *57*(9), 1-29.
13. Mienye, I. D., & Jere, N. (2024). Deep Learning for Credit Card Fraud Detection: A Review of Algorithms, Challenges, and Solutions. *IEEE Access*.
14. Duff, M. A. G., Campbell, N. D., & Ehrhardt, M. J. (2024). Regularising inverse problems with generative machine learning models. *Journal of Mathematical Imaging and Vision*, *66*(1), 37-56.
15. Jauhar, S. K., Raj, P. V. R. P., Kamble, S., Pratap, S., Gupta, S., & Belhadi, A. (2024). A deep learning-based approach for performance assessment and prediction: A case study of pulp and paper industries. *Annals of Operations Research*, 1-27.
16. AlKandari, M., & Ahmad, I. (2024). Solar power generation forecasting using ensemble approach based on deep learning and statistical methods. *Applied Computing and Informatics*, *20*(3/4), 231-250.
17. Yu, R., & Wang, R. (2024). Learning dynamical systems from data: An introduction to physics-guided deep learning. *Proceedings of the National Academy of Sciences*, *121*(27), e2311808121.
18. Qiu, Y., Ma, L., & Priyadarshi, R. (2024). Deep learning challenges and prospects in wireless sensor network deployment. *Archives of Computational Methods in Engineering*, 1-24.
19. Baradaran, M., & Bergevin, R. (2024). A critical study on the recent deep learning based semi-supervised video anomaly detection methods. *Multimedia Tools and Applications*, *83*(9), 27761-27807.
20. Li, Z., Wang, B., & Chen, Y. (2024). Incorporating economic indicators and market sentiment effect into US Treasury bond yield prediction with machine learning. *Journal of Infrastructure, Policy and Development*, *8*(9), 7671.
21. Li, Z., Wang, D., Zhu, T., Tao, Y., & Ni, C. (2024). Review of deep learning-based methods for non-

destructive evaluation of agricultural products. *Biosystems Engineering*, *245*, 56-83.
22. Bogyrbayeva, A., Meraliyev, M., Mustakhov, T., & Dauletbayev, B. (2024). Machine learning to solve vehicle routing problems: A survey. *IEEE Transactions on Intelligent Transportation Systems*.
23. Rahman, A., Debnath, T., Kundu, D., Khan, M. S. I., Aishi, A. A., Sazzad, S., ... & Band, S. S. (2024). Machine learning and deep learning-based approach in smart healthcare: Recent advances, applications, challenges and opportunities. *AIMS Public Health*, *11*(1), 58.
24. Karimzadeh, M., Basvoju, D., Vakanski, A., Charit, I., Xu, F., & Zhang, X. (2024). Machine learning for additive manufacturing of functionally graded materials. *Materials*, *17*(15), 3673.
25. Wu, C., Wan, B., Entezari, A., Fang, J., Xu, Y., & Li, Q. (2024). Machine learning-based design for additive manufacturing in biomedical engineering. *International Journal of Mechanical Sciences*, *266*, 108828.
26. Gupta, B. B., Gaurav, A., Chui, K. T., & Arya, V. (2024, January). Deep Learning-Based Facial Emotion Detection in the Metaverse. In *2024 IEEE International Conference on Consumer Electronics (ICCE)* (pp. 1-6). IEEE.
27. Natarajan, T., Pragha, P., Dhalmahapatra, K., & Veera Raghavan, D. R. (2024). Unveiling metaverse sentiments using machine learning approaches. *Kybernetes*.
28. Truong, V. T., & Le, L. B. (2024). Security for the Metaverse: Blockchain and Machine Learning techniques for intrusion detection. *IEEE Network*.
29. Far, S. B., & Rad, A. I. (2022). Applying digital twins in metaverse: User interface, security and privacy challenges. *Journal of Metaverse*, *2*(1), 8-15.
30. Choi, M., Azzaoui, A. E., Singh, S. K., Salim, M. M., Jeremiah, S. R., & Park, J. H. (2022). The future of metaverse: Security issues, requirements, and solutions. *Human-Centric Computing and Information Sciences*, *12*(60), 1-14.
31. Sharma, S., Singh, J., Gupta, A., Ali, F., Khan, F., & Kwak, D. (2024). User Safety and Security in the Metaverse: A Critical Review. *IEEE Open Journal of the Communications Society*.
32. Wang, Y., Su, Z., Zhang, N., Xing, R., Liu, D., Luan, T. H., & Shen, X. (2022). A survey on metaverse: Fundamentals, security, and privacy. *IEEE Communications Surveys & Tutorials*, *25*(1), 319-352.
33. Zhao, R., Zhang, Y., Zhu, Y., Lan, R., & Hua, Z. (2023). Metaverse: Security and privacy concerns. *Journal of Metaverse*, *3*(2), 93-99.
34. Ali, S., Abdullah, Armand, T. P. T., Athar, A., Hussain, A., Ali, M., ... & Kim, H. C. (2023). Metaverse in healthcare integrated with explainable AI and blockchain: enabling immersiveness, ensuring trust, and providing patient data security. *Sensors*, *23*(2), 565.
35. Truong, V. T., Le, L., & Niyato, D. (2023). Blockchain meets metaverse and digital asset management: A comprehensive survey. *Ieee Access*, *11*, 26258-26288.
36. Kwon, H. J., El Azzaoui, A., & Park, J. H. (2022). Metaq: A quantum approach for secure and optimized metaverse environment. *Hum.-Cent. Comput. Inf. Sci*, *12*, 42.
37. Venugopal, J. P., Subramanian, A. A. V., & Peatchimuthu, J. (2023). The realm of metaverse: A survey. *Computer Animation and Virtual Worlds*, *34*(5), e2150.
38. Bale, A. S., Ghorpade, N., Hashim, M. F., Vaishnav, J., & Almaspoor, Z. (2022). A comprehensive study on metaverse and its impacts on humans. *Advances in Human-Computer Interaction*, *2022*(1), 3247060.
39. Sami, H., Hammoud, A., Arafeh, M., Wazzeh, M., Arisdakessian, S., Chahoud, M., ... & Guizani, M. (2024). The metaverse: Survey, trends, novel pipeline ecosystem & future directions. *IEEE Communications Surveys & Tutorials*.
40. Baidya, T., & Moh, S. (2024). Comprehensive survey on resource allocation for edge-computing-enabled metaverse. *Computer Science Review*, *54*, 100680.
41. Kaveh, A. (2024). Applications of Artificial neural networks and machine learning in Civil Engineering. *Studies in computational intelligence*, *1168*.
42. Shamsipour, G., Fekri-Ershad, S., Sharifi, M., & Alaei, A. (2024). Improve the efficiency of handcrafted features in image retrieval by adding selected feature generating layers of deep convolutional neural networks. *Signal, image and video processing*, *18*(3), 2607-2620.
43. Hu, Y., Shi, W., & Yeh, C. H. (2024). Spatiotemporal convolution sleep network based on graph attention mechanism with automatic feature extraction. *Computer Methods and Programs in Biomedicine*, *244*, 107930.
44. Li, Z., Zhang, Q., Zhu, F., Li, D., Zheng, C., & Zhang, Y. (2023). Knowledge graph representation learning with simplifying hierarchical feature propagation. *Information Processing & Management*, *60*(4), 103348.
45. Al-Fraihat, D., Sharrab, Y., Alzyoud, F., Qahmash, A., Tarawneh, M., & Maaita, A. (2024). Speech recognition utilizing deep learning: A systematic review of the latest developments. *Human-centric Computing and Information Sciences*, *14*.
46. Noman, A. H. M., Mustaquim, S. M., Molla, S., & Siddique, I. M. (2024). Enhancing Operations Quality Improvement through Advanced Data Analytics. *Journal of Computer Science Engineering and Software Testing*, *10*(1), 1-14.
47. Wong, M. L., & Arjunan, T. (2024). Real-Time Detection of Network Traffic Anomalies in Big Data Environments Using Deep Learning Models. *Emerging Trends in Machine Intelligence and Big Data*, *16*(1), 1-11.
48. Wang, S., Zheng, H., Wen, X., & Fu, S. (2024). Distributed high-performance computing methods for accelerating deep learning training. *Journal of Knowledge Learning and Science Technology ISSN: 2959-6386 (online)*, *3*(3), 108-126.
49. Nam, W., & Jang, B. (2024). A survey on multimodal bidirectional machine learning translation of image and natural language processing. *Expert Systems with Applications*, *235*, 121168.
50. Wu, X., Wu, Y., Li, X., Ye, Z., Gu, X., Wu, Z., & Yang, Y. (2024). Application of adaptive machine learning systems in heterogeneous data environments. *Global Academic Frontiers*, *2*(3), 37-50.
51. Manias, G., Azqueta-Alzúaz, A., Dalianis, A., Griffiths, J., Kalogerini, M., Kostopoulou, K., ... & Kyriazis, D. (2024). Advanced Data Processing of Pancreatic Cancer Data Integrating Ontologies and Machine Learning Techniques to Create Holistic Health Records. *Sensors*, *24*(6), 1739.
52. Becker, A. S., Chaim, J., & Vargas, H. A. (2024). Streamlining Radiology Workflows Through the Development and Deployment of Automated

Microservices. *Journal of Imaging Informatics in Medicine*, 1-7.
53. Mathivanan, S. K., Sonaimuthu, S., Murugesan, S., Rajadurai, H., Shivahare, B. D., & Shah, M. A. (2024). Employing deep learning and transfer learning for accurate brain tumor detection. *Scientific Reports*, *14*(1), 7232.
54. Chen, Y., Huang, W., Zhou, K., Bian, Y., Han, B., & Cheng, J. (2024). Understanding and improving feature learning for out-of-distribution generalization. *Advances in Neural Information Processing Systems*, *36*.
55. Zhao, X., Wang, L., Zhang, Y., Han, X., Deveci, M., & Parmar, M. (2024). A review of convolutional neural networks in computer vision. *Artificial Intelligence Review*, *57*(4), 99.
56. Mienye, I. D., Swart, T. G., & Obaido, G. (2024). Recurrent Neural Networks: A Comprehensive Review of Architectures, Variants, and Applications. *Information*, *15*(9), 517.
57. Rao, S. S., Reddy, E. M., & Tyagi, S. B. (2024). THE EVOLUTION AND IMPACT OF LONG SHORT-TERM MEMORY NETWORKS. *Journal of Nonlinear Analysis and Optimization*, *15*(1).
58. Chakraborty, T., KS, U. R., Naik, S. M., Panja, M., & Manvitha, B. (2024). Ten years of generative adversarial nets (GANs): a survey of the state-of-the-art. *Machine Learning: Science and Technology*, *5*(1), 011001.
59. Berahmand, K., Daneshfar, F., Salehi, E. S., Li, Y., & Xu, Y. (2024). Autoencoders and their applications in machine learning: a survey. *Artificial Intelligence Review*, *57*(2), 28.
60. Abubakr, M., Rady, M., Badran, K., & Mahfouz, S. Y. (2024). Application of deep learning in damage classification of reinforced concrete bridges. *Ain Shams engineering journal*, *15*(1), 102297.
61. Pandey, D., & Gilmour, P. (2024). Accounting meets metaverse: navigating the intersection between the real and virtual worlds. *Journal of Financial Reporting and Accounting*, *22*(2), 211-226.
62. Kaplan-Rakowski, R., Cockerham, D., & Ferdig, R. E. (2024). The impact of sound and immersive experience on learners when using virtual reality and tablet: A mixed-method study. *British Journal of Educational Technology*, *55*(4), 1560-1582.
63. Kasapakis, V., & Dzardanova, E. (2024). Virtual reality learning environments: using high-fidelity avatars to enhance distance learning experience. *Interactive Learning Environments*, *32*(6), 2357-2370.
64. Durneva, P., LeRouge, C., & Lisetti, C. (2024). Designing Virtual Characters in Digital Health Technologies: A Self-presence Perspective. *AIS Transactions on Human-Computer Interaction*, *16*(3), 339-363.
65. Zhu, R., & Yi, C. (2024). Avatar design in Metaverse: the effect of avatar-user similarity in procedural and creative tasks. *Internet Research*, *34*(1), 39-57.
66. Rafique, W., & Qadir, J. (2024). Internet of everything meets the metaverse: Bridging physical and virtual worlds with blockchain. *Computer Science Review*, *54*, 100678.
67. AL-Hawamleh, A., Altarawneh, M., Hikal, H., & Elfedawy, A. (2024). Blockchain technology and virtual asset accounting in the metaverse: A comprehensive review of future directions. *International Journal of Computing and Digital Systems*, *15*(1), 1595-1614.
68. Kuru, K. (2023). Metaomnicity: Toward immersive urban metaverse cyberspaces using smart city digital twins. *IEEE Access*, *11*, 43844-43868.
69. Alam, T. (2024). Metaverse of Things (MoT) Applications for Revolutionizing Urban Living in Smart Cities. *Smart Cities*, *7*(5), 2466-2494.
70. Li, K., Cui, Y., Li, W., Lv, T., Yuan, X., Li, S., ... & Dressler, F. (2022). When internet of things meets metaverse: Convergence of physical and cyber worlds. *IEEE Internet of Things Journal*, *10*(5), 4148-4173.
71. Park, S. M., & Kim, Y. G. (2022). A metaverse: Taxonomy, components, applications, and open challenges. *IEEE access*, *10*, 4209-4251.
72. Paraschos, P. D., & Koulouriotis, D. E. (2023). Game difficulty adaptation and experience personalization: A literature review. *International Journal of Human–Computer Interaction*, *39*(1), 1-22.
73. Hodapp, D., & Hanelt, A. (2022). Interoperability in the era of digital innovation: An information systems research agenda. *Journal of Information Technology*, *37*(4), 407-427.
74. Cheng, F. F., Wu, C. S., & Chen, Y. C. (2020). Creating customer loyalty in online brand communities. *Computers in Human Behavior*, *107*, 105752.
75. Purnomo, A., Susanti, T., Rosyidah, E., Firdausi, N., & Idhom, M. (2022). Digital economy research: Thirty-five years insights of retrospective review. *Procedia Computer Science*, *197*, 68-75.
76. Gadekallu, T. R., Wang, W., Yenduri, G., Ranaweera, P., Pham, Q. V., da Costa, D. B., & Liyanage, M. (2023). Blockchain for the metaverse: A review. *Future Generation Computer Systems*, *143*, 401-419.
77. Kuhail, M. A., ElSayary, A., Farooq, S., & Alghamdi, A. (2022, September). Exploring immersive learning experiences: A survey. In *Informatics* (Vol. 9, No. 4, p. 75). MDPI.
78. Braid, H. R. (2022). The use of simulators for teaching practical clinical skills to veterinary students—A review. *Alternatives to Laboratory Animals*, *50*(3), 184-194.
79. Wang, H., Ning, H., Lin, Y., Wang, W., Dhelim, S., Farha, F., ... & Daneshmand, M. (2023). A survey on the metaverse: The state-of-the-art, technologies, applications, and challenges. *IEEE Internet of Things Journal*, *10*(16), 14671-14688.
80. Chamola, V., Sai, S., Bhargava, A., Sahu, A., Jiang, W., Xiong, Z., ... & Hussain, A. (2024). A Comprehensive Survey on Generative AI for Metaverse: Enabling Immersive Experience. *Cognitive Computation*, 1-30.
81. Alpala, L. O., Quiroga-Parra, D. J., Torres, J. C., & Peluffo-Ordóñez, D. H. (2022). Smart factory using virtual reality and online multi-user: Towards a metaverse for experimental frameworks. *Applied Sciences*, *12*(12), 6258.
82. Zhao, Y., Jiang, J., Chen, Y., Liu, R., Yang, Y., Xue, X., & Chen, S. (2022). Metaverse: Perspectives from graphics, interactions and visualization. *Visual Informatics*, *6*(1), 56-67.
83. [83] Cho, K. H., Park, J. B., & Kang, A. (2023). Metaverse for Exercise Rehabilitation: Possibilities and Limitations. *International Journal of Environmental Research and Public Health*, *20*(8), 5483.

84. Dayoub, B., Yang, P., Omran, S., Zhang, Q., & Dayoub, A. (2024). Digital Silk Roads: Leveraging the Metaverse for Cultural Tourism within the Belt and Road Initiative Framework. *Electronics*, *13*(12), 2306.
85. Mystakidis, S. (2022). Metaverse. *Encyclopedia*, *2*(1), 486-497.
86. Büchel, H., & Spinler, S. (2024). The impact of the metaverse on e-commerce business models–A Delphi-based scenario study. *Technology in Society*, *76*, 102465.
87. Zhai, X., Chu, X., Wang, M., Zhang, Z., & Dong, Y. (2022). Education metaverse: Innovations and challenges of the new generation of Internet education formats. *Metaverse*, *3*(1), 13.
88. George, A. H., Fernando, M., George, A. S., Baskar, T., & Pandey, D. (2021). Metaverse: The next stage of human culture and the internet. *International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)*, *8*(12), 1-10.
89. Chen, J., Zhang, X., Zhang, R., Wang, C., & Liu, L. (2021). De-pois: An attack-agnostic defense against data poisoning attacks. *IEEE Transactions on Information Forensics and Security*, *16*, 3412-3425.
90. Yuan, Y., Apruzzese, G., & Conti, M. (2024). Multi-SpacePhish: Extending the evasion-space of adversarial attacks against phishing website detectors using machine learning. *Digital Threats: Research and Practice*, *5*(2), 1-51.
91. Liu, X., Xie, L., Wang, Y., Zou, J., Xiong, J., Ying, Z., & Vasilakos, A. V. (2020). Privacy and security issues in deep learning: A survey. *IEEE Access*, *9*, 4566-4593.
92. Huang, Y., Li, Y. J., & Cai, Z. (2023). Security and privacy in metaverse: A comprehensive survey. *Big Data Mining and Analytics*, *6*(2), 234-247.
93. Xue, M., Zhang, Y., Wang, J., & Liu, W. (2021). Intellectual property protection for deep learning models: Taxonomy, methods, attacks, and evaluations. *IEEE Transactions on Artificial Intelligence*, *3*(6), 908-923.
94. Ferrara, E. (2023). Fairness and bias in artificial intelligence: A brief survey of sources, impacts, and mitigation strategies. *Sci*, *6*(1), 3.
95. Kornaros, G. (2022). Hardware-assisted machine learning in resource-constrained IoT environments for security: review and future prospective. *IEEE Access*, *10*, 58603-58622.
96. Cinà, A. E., Grosse, K., Demontis, A., Vascon, S., Zellinger, W., Moser, B. A., ... & Roli, F. (2023). Wild patterns reloaded: A survey of machine learning security against training data poisoning. *ACM Computing Surveys*, *55*(13s), 1-39.
97. Jiang, Z., Chen, T., Chen, T., & Wang, Z. (2020). Robust pre-training by adversarial contrastive learning. *Advances in neural information processing systems*, *33*, 16199-16210.
98. Zhu, T., Ye, D., Wang, W., Zhou, W., & Philip, S. Y. (2020). More than privacy: Applying differential privacy in key areas of artificial intelligence. *IEEE Transactions on Knowledge and Data Engineering*, *34*(6), 2824-2843.
99. Lee, S. C. (2022). A black box approach to auditing algorithms. *Issues In Information Systems*, *23*(2).
100. Huang, Z., Wang, Q., Chen, Y., & Jiang, X. (2020). A survey on machine learning against hardware trojan attacks: Recent advances and challenges. *IEEE Access*, *8*, 10796-10826.
101. Habbal, A., Ali, M. K., & Abuzaraida, M. A. (2024). Artificial Intelligence Trust, risk and security management (AI trism): Frameworks, applications, challenges and future research directions. *Expert Systems with Applications*, *240*, 122442.
102. Shafiq, M., & Gu, Z. (2022). Deep residual learning for image recognition: A survey. *Applied Sciences*, *12*(18), 8972.
103. Montejo-Ráez, A., & Jiménez-Zafra, S. M. (2022). Current approaches and applications in natural language processing. *Applied Sciences*, *12*(10), 4859.
104. Fendji, J. L. K. E., Tala, D. C., Yenke, B. O., & Atemkeng, M. (2022). Automatic speech recognition using limited vocabulary: A survey. *Applied Artificial Intelligence*, *36*(1), 2095039.
105. Ko, H., Lee, S., Park, Y., & Choi, A. (2022). A survey of recommendation systems: recommendation models, techniques, and application fields. *Electronics*, *11*(1), 141.
106. Kora, P., Ooi, C. P., Faust, O., Raghavendra, U., Gudigar, A., Chan, W. Y., ... & Acharya, U. R. (2022). Transfer learning techniques for medical image analysis: A review. *Biocybernetics and Biomedical Engineering*, *42*(1), 79-107.
107. Shehab, M., Shambour, M. K. Y., Abu Hashem, M. A., Al Hamad, H. A., Shannaq, F., Mizher, M., ... & Abualigah, L. (2024). A survey and recent advances in black widow optimization: variants and applications. Neural Computing and Applications, 1-21.
108. Mohammad Abualigah, L., Al-diabat, M., Al Shinwan, M., Dhou, K., Alsalibi, B., Said Hanandeh, E., & Shehab, M. (2020). Hybrid harmony search algorithm to solve the feature selection for data mining applications. Recent advances in hybrid metaheuristics for data clustering, 19-37.
109. Almodfer, R., Mudhsh, M., Chelloug, S., Shehab, M., Abualigah, L., & Abd Elaziz, M. (2022). Quantum mutation reptile search algorithm for global optimization and data clustering. Hum-Centr Comput Inf Sci, 12.