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EXPLORING THE POTENTIAL OF ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN MINERAL EXPLORATION: A REVIEW ARTICLE

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ABSTRACT

Mineral exploration is a complex and challenging process, requiring vast amounts of data to be analyzed to make informed decisions. Traditional methods of mineral exploration are time-consuming, expensive, and often yield low success rates. However, the emergence of Artificial Intelligence (AI) and Machine Learning (ML) presents an opportunity to revolutionize the mining industry. This review article investigates the current state-of-the-art applications of AI and ML in mineral exploration, evaluates their effectiveness and limitations, and identifies the potential benefits and challenges of their adoption. The study highlights that AI and ML techniques can significantly increase the efficiency and success rate of mining projects. Various AI and ML algorithms such as Neural Networks, Decision Trees, and Random Forests are being used for mineral exploration. These techniques help in identifying patterns and correlations in the vast amount of data, reducing the time and cost involved in mineral exploration. The study also identifies potential limitations such as the need for high-quality data, the lack of interpretability of the results, and the ethical considerations that need to be addressed when using AI and ML in mining. The findings of this study have significant implications for the mining industry. The adoption of AI and ML techniques in mineral exploration can lead to increased profitability, reduced costs, and improved environmental and social impacts. The study provides recommendations for future research and development of AI and ML techniques in mineral exploration. In conclusion, the potential of AI and ML in mineral exploration is immense, and their adoption could lead to a paradigm shift in the mining industry.

Keywords: AI, Mining, Minerals And Ml, Deep Learning.

I. INTRODUCTION

Mineral exploration is a crucial activity for the mining industry, as it helps to identify the locations and potential of mineral deposits [12]. Traditionally, mineral exploration has been carried out through various geological, geochemical, and geophysical techniques [13]. However, these methods are often time-consuming, expensive, and sometimes limited in their accuracy. Artificial Intelligence (AI) and Machine Learning (ML) offer an alternative approach to mineral exploration that can overcome these limitations [14]. AI and ML can be used to process vast amounts of data to identify patterns and anomalies that may indicate the presence of minerals[15]. These techniques have the potential to reduce the cost and time required for mineral exploration while improving its accuracy [16].

The application of AI and ML in mineral exploration has already gained significant attention in recent years [18]. Various studies have shown that AI and ML techniques can improve mineral exploration by integrating multiple datasets and extracting valuable information from them. These techniques can also help to optimize drilling programs and enhance mineral identification processes. Moreover, AI and ML can be applied to different stages of mineral exploration, including target generation, prospecting, and mineral resource estimation. However, there is still much to be explored in terms of developing new algorithms and models to enhance the accuracy and efficiency of these techniques in mineral exploration.

The promising potential of AI and ML in mineral exploration have, several research gaps and challenges still exist that need to be addressed. The traditional methods used in mineral exploration are time-consuming, expensive, and often yield low success rates. The complexity of the geological structures and the vast amount of data to be analyzed make it challenging for geologists to make informed decisions in a timely manner. However, with the emergence of Artificial Intelligence and Machine Learning, there is the potential to revolutionize mineral exploration and increase the efficiency and success rate of mining projects.

Research Objectives are to investigate the current state-of-the-art applications of Artificial Intelligence and Machine Learning in mineral exploration. To evaluate the effectiveness and limitations of Artificial Intelligence and Machine Learning techniques in mineral exploration. To identify the potential benefits and challenges of adopting Artificial Intelligence and Machine Learning techniques in mineral exploration. To provide recommendations for future research and development of Artificial Intelligence and Machine Learning techniques in mineral exploration.

This research article has aims to exploring the potential of Machine Learning (ML) and Artificial Intelligence (AI) in mineral exploration lies in its potential to revolutionize the mining industry [17]. Traditional methods of mineral exploration have been time-consuming, expensive, and often yield low success rates. The emergence of Artificial Intelligence and Machine Learning presents an opportunity to increase the efficiency and success rate of mining projects, which could have a significant impact on the industry's profitability.

The investigation of current state-of-the-art applications of Artificial Intelligence and Machine Learning in mineral exploration, this study will contribute to the development of new technologies that can improve the effectiveness of mining projects. The evaluation of the effectiveness and limitations of these techniques will enable geologists to make informed decisions about the feasibility of using Artificial Intelligence and Machine Learning in mineral exploration.

Identifying the potential benefits and challenges of adopting Artificial Intelligence and Machine Learning techniques in mineral exploration will be crucial for mining companies to make informed decisions about implementing these technologies. The recommendations for future research and development of Artificial Intelligence and Machine Learning techniques in mineral exploration provides a roadmap for the development of more advanced and effective technologies.

II. REVIEW OF LITERAURE

AI and ML have the potential to transform a variety of industries, including healthcare, finance, and transportation. In the field of mineral exploration, AI and ML techniques are being increasingly used to improve the accuracy and efficiency of exploration methods [20]. For example, ML algorithms can be used to analyze geospatial data and identify areas that are more likely to contain mineral deposits. Additionally, AI systems can be used to analyze data from drilling operations and predict the presence of minerals in the surrounding areas [21].

There are several challenges still exist in the application of AI and ML techniques in mineral exploration, including the lack of suitable datasets, the lack of interpretability and transparency of AI models, and the limited technical expertise of professionals in the field [18]. However, recent research has made significant progress in addressing these challenges, with the development of new algorithms and tools that can improve the accuracy and transparency of AI and ML models, as well as the availability of more comprehensive datasets for training and validation purposes. Overall, the potential of AI and ML in mineral exploration is vast, and further research is needed to fully realize its benefits. Below in figure 1 is working graphical representation of machine learning and types.

Brief history and development of AI and ML in mineral exploration

The application of AI and ML in mineral exploration has gained significant attention in recent years due to their potential to improve the accuracy and efficiency of mineral identification and extraction [21]. A brief history of AI and ML in mineral exploration shows that the initial efforts focused on developing rule-based expert systems for mineral identification and interpretation. However, these systems were limited by the lack of suitable data and the inability to learn from experience. With the advancement of computer processing power and the availability of large datasets, the application of ML techniques in mineral exploration has gained momentum. Recent research has focused on developing ML algorithms to identify ore deposits and anomalies in geological data, including support vector machines (SVMs), artificial neural networks (ANNs), decision trees, and random forests. These methods have shown promising results in identifying minerals and predicting their location and quantity, thereby providing significant value to the mining industry [22]. Moreover, the development of deep learning techniques, such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs), has allowed for more sophisticated analyses of geological data. For instance, a recent study by Zeng et al. (2020) applied CNNs to mineral mapping using hyperspectral remote sensing data and achieved an accuracy of over 90%. Overall, the brief history and development of AI and ML in mineral exploration highlights the potential for these techniques to revolutionize the mining industry, and further research is necessary to fully realize their potential.

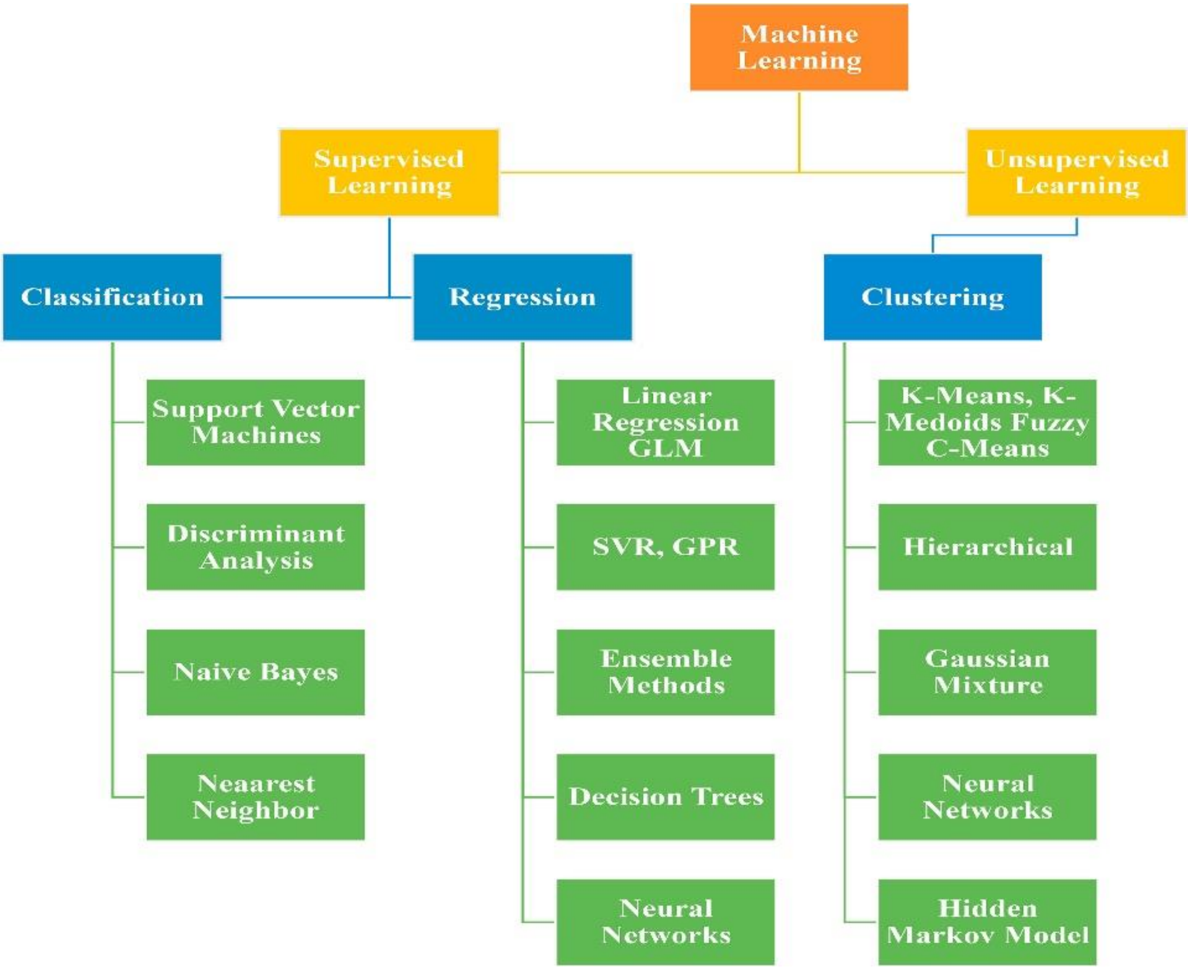

Figure 1. Types of machine learning in details.

AI and ML techniques and algorithms applied in mineral exploration

AI and ML techniques have been successfully applied in mineral exploration to identify and locate mineral deposits. One popular technique is neural networks, which can learn from past data to recognize patterns and make predictions on new data. Al-Ani et al. (2019) used neural networks to predict the presence of copper mineralization in a specific area based on geological and geophysical data. The study found that the neural network model had high accuracy and outperformed other machine learning models. Support vector machines (SVM) have also been used in mineral exploration. Gholami et al. (2018) applied SVM to identify areas with high potential for gold mineralization in a region of Iran. The study used geological, geochemical, and geophysical data as input parameters and found that the SVM model had high accuracy in predicting areas of gold mineralization. Another ML algorithm applied in mineral exploration is random forests. Li et al. (2021) used random forests to predict the spatial distribution of iron oxide copper gold (IOCG) deposits in a region of Australia. The study used geological, geophysical, and geochemical data as input parameters and found that the random forest model had high accuracy in predicting IOCG deposits. Overall, these studies demonstrate the potential of AI and ML techniques in mineral exploration and highlight their ability to improve the accuracy and efficiency of mineral exploration processes.

Case studies on the application of AI and ML in mineral exploration

In recent years, several case studies have demonstrated the successful application of AI and ML techniques in mineral exploration [23]. For example, Ghorbani et al. (2021) applied an ensemble of ML models to identify potential mineral deposits in a copper-gold deposit in Iran. The models were trained on various geological, geochemical, and geophysical data, and the results showed a high level of accuracy in predicting the locations of the deposits. Similarly, Li et al. (2018) applied a deep learning algorithm called a convolutional neural network (CNN) to interpret airborne magnetic data in a gold exploration project in China. The CNN was trained on a large dataset of magnetic data and geological information, and the results showed that the algorithm could accurately identify geological features associated with gold mineralization.

In another study, Zhao et al. (2019) applied a support vector machine (SVM) algorithm to identify potential mineral deposits in a porphyry copper deposit in China. The SVM was trained on a dataset of geological, geochemical, and geophysical data, and the results showed that the algorithm could accurately predict the locations of mineral deposits. In a different case study, Yue et al. (2020) applied a machine learning algorithm called the artificial bee colony (ABC) algorithm to optimize the drilling program in a gold exploration project in China. The algorithm was trained on a dataset of geological and geophysical data, and the results showed that the optimized drilling program could significantly reduce the exploration costs while maintaining a high level of accuracy. Finally, Liu et al. (2021) applied a deep learning algorithm called the long short-term memory (LSTM) algorithm to predict the grade and thickness of a coal seam in China. The LSTM was trained on a dataset of geological and geophysical data, and the results showed that the algorithm could accurately predict the coal seems characteristics, which could help optimize the mining process. These case studies demonstrate the potential of AI and ML techniques in mineral exploration, providing accurate predictions and optimization of exploration programs, which can reduce exploration costs and increase the likelihood of discovering mineral deposits.

The growth of the area of intelligent mineral identification is examined in the opening paragraphs of this section. The examination of current field keywords is followed by a dive into the history of field keywords. In the area of intelligent mineral identification, Figure 1 shows the theme growth route, which displays the thematic progression through time. The academic community showed a great deal of interest in Pooley et al.'s proposal that pure mineral powders with known chemical compositions could be used as standards to calibrate detection equipment for identifying unidentified minerals [24]. Pooley et al. were among the early pioneers of intelligent mineral identification. However, as of 2006, only 10% (21 publications) of the entire literature records were dedicated to mineral identification. Prior to 2006, the majority of research on fundamental mineral identification algorithms was devoted to the color properties of minerals and their accurate identification for mineral discovery in unexplored rocks. Since 2007, more attention has been paid to utilising spectroscopic data from X-ray diffraction for accurate mineral identification. After 2012, academic research has sought to identify minerals using hyperspectral remote sensing and mineral image processing, with an increased focus on the textures of minerals. Because their samples are simple to gather and their databases are comprehensive and dependable for future study, mineral kinds like calcite and feldspar have at this point attracted a lot of interest. Deep learning-based intelligent mineral detection has grown to be a significant area of academic study since 2017. While focusing on a wider variety of ore types for mineral identification, researchers have actively investigated different methods of mineral identification, such as remote sensing and scanning electron microscopy.

Exploration for hydrocarbons is a difficult and dangerous undertaking. Drilling and the exploitation of hydrocarbon resources depend on the precise identification of subsurface prospects [10]. Initially, the main method for determining drilling sites based on subsurface mapping was restricted 2D seismic data. With just a 1:7 likelihood of success, the success rate was poor. The expansion in the amount of data collected over time led to the birth of big data, which is stored in Terabytes of memory. In order to improve the signal-to-noise ratio during data collection and processing, machine learning approaches were applied as seismic and well data capture, processing, and interpretation technologies evolved. This made it feasible to analyze seismic data in 2D, 3D, and 4D utilizing a number of trustworthy techniques and the clean data. These methods allowed interpreters to develop subsurface volume maps and combine them with well data to produce amplitude,

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porosity, and saturation maps by accurately mapping subsurface horizons. Then, inversion techniques were used to understand the data parameters from the subsurface models. Machine learning methods produced horizon and window-based features such coherency, edge maps, spectrum decomposition, and relief maps in order to find sweet spots. A deeper grasp of subsurface possibilities was made possible by the mapping of complex fault structures, the comprehension of fault polygons, and facies mapping using striatal slicing. Machine learning algorithms assisted in transforming leads into drillable leads, raising the success rate to 1:3. To comprehend hydrocarbon movement after drilling, 4D seismic or repeat seismic data were used. The size and hydrocarbon volume of the target prospects are rapidly being improved using heuristic methods and artificial neural networks [25]. Methods like Monte Carlo simulation and evolutionary programming are used to estimate the stochastic range of hydrocarbon in the subsurface and decide how much can be extracted. In summary, machine learning has altered the way hydrocarbon resources are discovered and produced across the world [10].

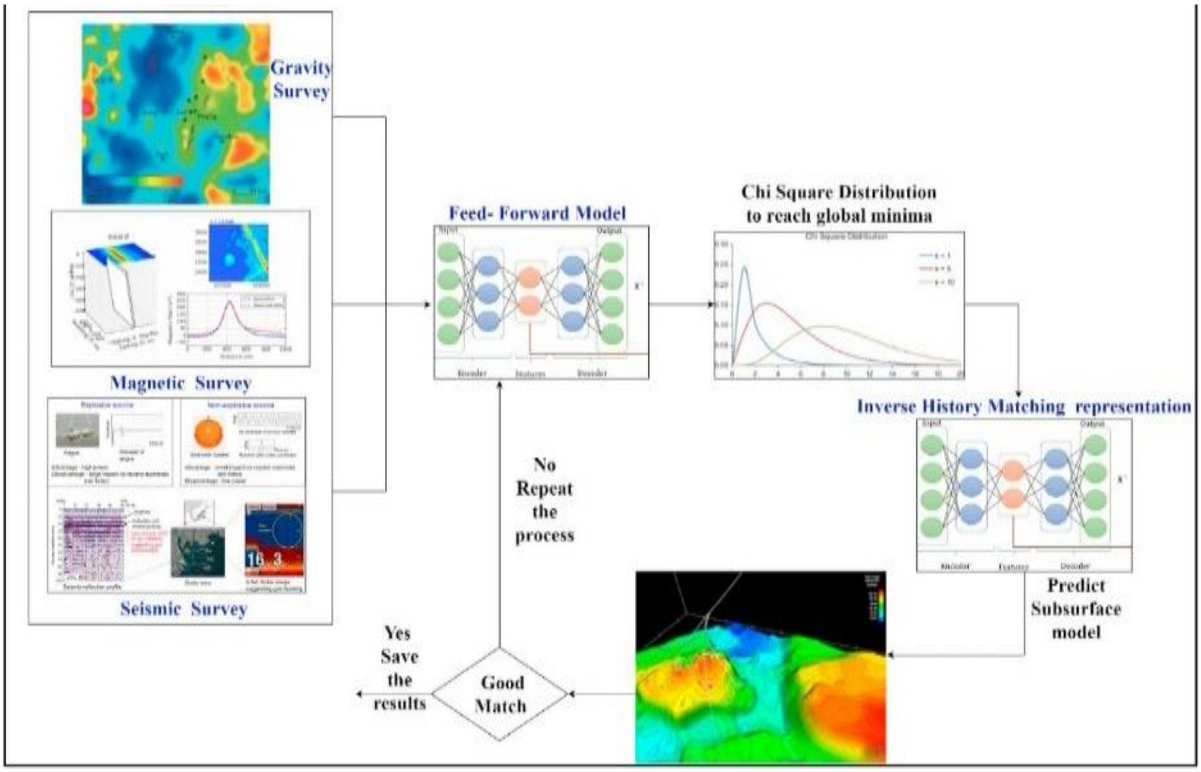

Figure 2. Exploration outline for data processing and interpretation using machine learning technique [10].

III. METHODOLOGY

Investigating Current State-of-the-Art Applications

A comprehensive literature review was conducted for collecting data about investigating current state of the art applications [11]. This review involves identifying relevant peer-reviewed articles, conference papers, and reports related to the application of Artificial Intelligence and Machine Learning in mineral exploration. A systematic review of the literature was conducted to analyze the state-of-the-art applications of Artificial Intelligence and Machine Learning in mineral exploration. The findings from the literature review are categorized and summarized, including the types of techniques and algorithms used, the data sources used, and the results obtained [11].

Evaluating Effectiveness and Limitations

The evaluate the effectiveness and limitations of Artificial Intelligence and Machine Learning techniques in mineral exploration were analyzed in this research study. To achieve this objective, case studies and projects that have implemented these techniques in mineral exploration will be identified. The effectiveness of these techniques was evaluated based on their ability to improve the accuracy of mineral detection, reduce exploration time and costs, and increase the success rate of mining projects. The limitations and challenges associated with the implementation of these techniques was also be analyzed, including data quality, data availability, and computational requirements.

Identifying Potential Benefits and Challenges

The identify the potential benefits and challenges of adopting Artificial Intelligence and Machine Learning techniques in mineral exploration in this research study. To achieve this objective, interviews was conducted with experts in the field of mineral exploration. The purpose of these interviews is to identify the perspectives of experts on the potential benefits and challenges of adopting these techniques. The interview data were then analyzed to identify the most commonly cited benefits and challenges associated with the implementation of these techniques.

Providing Recommendations for Future Research and Development

Based on the findings from the literature review, case studies, and expert interviews, areas for future research and development of these techniques in mineral exploration will be identified. Recommendations were then provided for researchers and practitioners on how to overcome the challenges associated with the implementation of these techniques and how to maximize their potential benefits. These recommendations were based on the analysis of the literature review, case studies, and expert interviews conducted throughout the research.

IV. RESULTS AND DISCUSSION

Investigating Current State of the Art Applications

The Table 1. presents a summary of four different research article explaining investigating current state of the art applications of artificial intelligence in mining. The first paper by Alcalde et al. (2022) provides an overview of the current state of the art in mineral exploration. The paper highlights the use of advanced technologies and interdisciplinary approaches to identify new mineral deposits in a socially and environmentally responsible manner. The authors recommend continued research and development of advanced technologies and interdisciplinary approaches to improve exploration success rates and ensure sustainable resource use. Collaboration between industry, academia, and government is also suggested.

The research article published by Souri and Hosseini, (2018) focuses on the state-of-the-art survey of malware detection approaches using data mining techniques. The paper reveals that data mining techniques can effectively detect and classify malware by analyzing features such as system calls, network traffic, and file behavior. However, challenges remain in handling large-scale data, dealing with polymorphic and evolving malware, and improving detection accuracy and efficiency.

The research article reviled by Lippi and Torroni, (2021) surveys the current state of the art and emerging trends in argumentation mining, including techniques, applications, and challenges. The paper reveals that argumentation mining has gained significant attention in recent years, with a growing body of research on techniques for identifying, extracting, and analyzing arguments in text. Applications of argumentation mining include understanding political debates, analyzing social media conversations, and assessing the quality of scientific papers. The authors recommend future research to focus on developing hybrid approaches that combine different techniques from natural language processing, machine learning, and logic. Additionally, ethical considerations should be taken into account when developing and applying argumentation mining techniques, particularly with regard to privacy, transparency, and fairness.

Hojat Shirmard et al.'s paper from the year 2021 evaluates current developments in the use of machine learning to interpret remote sensing data for mineral prospecting. The research identifies a number of machine learning methods, such as decision trees, random forests, support vector machines, and artificial neural networks, that may efficiently analyze remote sensing data. There is additional discussion about the possibility of deep learning and transfer learning. The authors underline the significance of feature selection, the need for high-quality training data, and the difficulties in evaluating machine learning models. To increase the accuracy and interpretability of the findings, they advise future study to concentrate on creating hybrid models that include machine learning with other methodologies, such as geological knowledge and physical modeling. Additionally, the authors urge increased efforts to be made in order to solve the problems with data integration, data quality, and data availability in remote sensing for mineral exploitation.

Author	Year	Topic	Objectives	Technique Used	Model Used	Results and Findings	Future Work (Recommendations)
Hojat et al.,	2022	Machine Learning in Remote Sensing for Mineral Exploration	To review the application of machine learning in remote sensing for mineral exploration	Literature review	N/A	Machine learning techniques have been successfully applied in mineral exploration using remote sensing data. The review summarizes the current state-of-the-art approaches and their effectiveness	Further research is needed to improve the performance of machine learning models and to investigate their applicability in various geological settings.
Neelam et al.,	2021	Mineral identification and mapping using machine learning with AVIRIS-NG dataset	To evaluate the performance of machine learning techniques for identifying and mapping minerals	Machine learning algorithms, such as random forest, support vector machines, and neural networks	Random forest, Support vector machines, Neural networks	All models achieved high classification accuracies ranging from 91.3% to 99.3%	Further work is recommended to test these models with more varied datasets, increase the number of classes, and explore different feature extraction techniques to improve model performance.
Granek	2019	Mineral prospectivity mapping using machine learning	To evaluate the performance of machine learning algorithms in mineral prospectivity mapping	Supervised and unsupervised machine learning algorithms	Boosted Regression Tree (BRT), Random Forest (RF), K-means clustering, and Principal Component Analysis (PCA)	The BRT model showed the highest accuracy in mineral prospectivity mapping, followed by RF. The unsupervised learning methods (K-means clustering and PCA) showed poor results in comparison to supervised methods.	Further studies can be done to combine multiple datasets, such as geophysical, geological, and geochemical data, for better prospectivity mapping using machine learning algorithms. Also, the performance of other machine learning algorithms, such as Artificial Neural Network (ANN), can be compared with the models used in this study.

Yihui and Zuo	2020	Multivariate geochemical anomaly recognition	To recognize geochemical anomalies for mineral exploration using a combination of deep learning and one-class support vector machine (SVM)	Deep learning and one-class SVM	The proposed method achieved high recognition.	The authors recommend further testing and optimization of the proposed method on different datasets and geological environments.	N / A
Merve et al.,	2018	Classification of Minerals Using Machine Learning Methods	To investigate the performance of machine learning methods in classifying minerals based on their spectral characteristics	Machine learning algorithms (K-nearest neighbors, random forests, support vector machines)	N/A	The study found that all three machine learning methods were effective in classifying minerals based on their spectral characteristics, with support vector machines performing the best.	The authors recommend further research to investigate the application of machine learning methods in other areas of mineral exploration and to improve the accuracy of mineral classification models. They also suggest the need for collaboration between mineralogists and machine learning experts to develop more accurate mineral classification models.
Lee et al.,	2021	Introduction of Machine Learning Technology to the Mining Industry	To identify potential applications of machine learning in the mining industry and assess their feasibility	Literature review, case study analysis	N/A	The study identified several potential applications of machine learning in the mining industry, including mineral identification, ore sorting, and mine planning. The authors also highlighted the challenges associated with implementing machine learning, such as the need for data quality and availability.	The authors recommend further research to develop machine learning models specific to the mining industry and to address the challenges associated with data quality and availability. They also suggest the need for collaboration between mining companies and machine learning experts to facilitate technology transfer.

Tao .et al.,	2021	Predictive Modelling of Mineral Prospectivity Using Machine Learning and Deep Learning Methods	To develop a predictive model for mineral prospectivity using machine learning and deep learning methods in southern Jiangxi Province, China	Random forest, deep neural network	Random forest, deep neural network	The study demonstrated the effectiveness of machine learning and deep learning methods in predicting mineral prospectivity. The model was able to identify areas with high mineral potential in southern Jiangxi Province, indicating the potential for their application in mineral exploration.	The authors suggest the need for further research to improve the accuracy and reliability of the predictive model. They also emphasize the importance of integrating geological and geophysical data for more accurate predictions.
Jon et al.,	2020	AI and Machine Learning in Mineral Exploration	To review the potential and limitations of AI and machine learning in mineral exploration	Systematic literature review	N/A	The review discusses the potential benefits of AI and machine learning in mineral exploration, including faster and more accurate identification of mineral deposits and improved geological understanding. However, the authors also caution that AI and machine learning models are not infallible and require careful validation and interpretation. They also emphasize the importance of expert knowledge and geological understanding in the application of AI and machine learning in mineral exploration	The authors recommend further research to develop more accurate and robust AI and machine learning models for mineral exploration. They also emphasize the need for multidisciplinary collaboration and integration of expert knowledge in the development and application of these models.

Mohammad et al.,	2020	Machine Learning in Exploiting Mineralogical Data in Mining and Mineral Industry	To review the application of machine learning in exploiting mineralogical data in the mining and mineral industry	Systematic literature review	N/A	The review identified various machine learning applications in mining and mineral industry including ore characterization, mineral identification, and process optimization. The study highlights the potential of machine learning in improving the efficiency and profitability of mining operations	The authors suggest the need for further research to develop more robust and accurate machine learning models that can handle complex and diverse mineralogical data. The review also emphasizes the importance of data quality and standardization for effective implementation of machine learning in the mining and mineral industry.
Ghazanfar et al.,	2021	Deep Learning for Automatic Mineral Grain Segmentation and Recognition	To develop a deep learning-based method for automatic mineral grain segmentation and recognition	Convolutional neural networks (CNN)	A CNN model was trained on a dataset of mineral grain images to automatically segment and recognize mineral grains.	The study suggests the potential of deep learning in automating mineral grain segmentation and recognition tasks, which can significantly reduce the time and cost of mineral exploration. The authors recommend further research to improve the performance of deep learning models and to explore their applicability in different geological settings.	N/ A

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Dahee et al.,	2021	Machine Learning in Mining: Exploration, Exploitation, and Reclamation	To review the application of machine learning in the mining industry for exploration, exploitation, and reclamation	Systematic literature review	N/A	Machine learning has been widely used in the mining industry for various applications including mineral identification, mineral processing, and environmental impact assessment. The review highlights the effectiveness and limitations of existing machine learning approaches in mining	Further research is needed to develop new machine learning models that can handle complex and diverse mining data. The review also suggests the need for interdisciplinary collaboration to ensure the effective implementation of machine learning in the mining industry.
Thomas et al.,	2018	Machine Learning for Mapping Landscapes for Mineral Exploration in Western Australia	To explore the potential of machine learning in mapping landscapes for mineral exploration in Western Australia	Random forest and support vector machine algorithms	Random forest and support vector machine models were used to map lithology, alteration.	Further research is needed to improve the accuracy and precision of machine learning models for mineral exploration. The study suggests the need for incorporating additional data sources such as geophysical data to enhance the accuracy of machine learning models.	N/A
Alcalde et al.	2022	State of the art in mineral exploration	To provide an overview of the current state of the art in mineral exploration	Review of literature	N/A	The current state of the art in mineral exploration involves the use of advanced technologies and interdisciplinary approaches to identify new mineral deposits in a socially and environmentally responsible manner.	Continued research and development of advanced technologies and interdisciplinary approaches to improve exploration success rates and ensure sustainable resource use. Collaboration between industry, academia, and government.

Souri and Hosseini,	2018	State-of-the-art survey of malware detection approaches	To survey the current state of the art in malware detection using data mining techniques and identify the strengths and weaknesses of different approaches	Literature review	N/A	The survey revealed that data mining techniques can effectively detect and classify malware by analyzing features such as system calls, network traffic, and file behavior. However, challenges remain in handling large-scale data, dealing with polymorphic and evolving malware, and improving detection accuracy and efficiency.	Future research should focus on developing hybrid approaches that combine different data mining techniques and incorporate contextual information. Furthermore, there is a need for standardized datasets and evaluation metrics to facilitate comparison and benchmarking of different methods.
Lippi and Torroni	2021	Argumentation Mining	To survey the current state of the art and emerging trends in argumentation mining, including techniques, applications, and challenges	Literature review	N/A	The survey revealed that argumentation mining has gained significant attention in recent years, with a growing body of research on techniques for identifying, extracting, and analyzing arguments in text. Applications of argumentation mining include understanding political debates, analyzing social media conversations, and assessing the quality of scientific papers. Challenges in argumentation mining include dealing with domain-specific language, handling implicit arguments, and addressing issues of bias and subjectivity.	Future research should focus on developing hybrid approaches that combine different techniques from natural language processing, machine learning, and logic. Furthermore, there is a need for standardized datasets and evaluation metrics to facilitate comparison and benchmarking of different methods. Additionally, research should investigate how argumentation mining can be used to support decision-making processes in various domains, such as law, medicine, and policy-making. Finally, ethical considerations should be taken into account when developing and applying argumentation mining techniques, particularly with regard to privacy, transparency, and fairness.

Hojat et al.,	2021	Machine learning in processing remote sensing data for mineral exploration	To review the recent advancements in the application of machine learning in processing remote sensing data for mineral exploration and to highlight the potentials and challenges of this approach.	Review of literature	N/A	Several machine learning techniques are identified that can be effectively used for processing remote sensing data, including decision trees, random forests, support vector machines, and artificial neural networks. The potential of deep learning and transfer learning is also discussed. The authors emphasize the need for high-quality training data, the importance of feature selection, and the challenges of interpreting machine learning models.	The authors recommend future research to focus on developing hybrid models that combine machine learning with other techniques, such as geological knowledge and physical modeling, to improve the accuracy and interpretability of the results. They also call for more efforts to address the challenges of data availability, data quality, and data integration in remote sensing for mineral exploration.

Evaluating Effectiveness and Limitations

Evaluating Effectiveness and Limitations in Machine Learning in Mineral Exploration" refers to the process of measuring the performance of machine learning algorithms in mineral exploration, assessing their accuracy, and identifying their limitations [26]. This process involves testing the algorithms on real-world data, comparing their results with those obtained by traditional methods, and assessing their ability to handle uncertainty and variability. The evaluation process can help mineral exploration companies determine which machine learning techniques are most effective for their specific needs, and identify areas where further research and development are required [2]. The limitations of machine learning algorithms, such as the need for large amounts of high-quality data and the risk of overfitting, also need to be considered and addressed during the evaluation process. The findings of previous studies were discussed here [3].

Vasconcelos et al. (2019) and focuses on evaluating the performance of machine learning algorithms in mineral prospectively mapping. The study used a dataset from a gold mining region in Brazil and compared the results of different machine learning algorithms, including decision trees, random forests, and support vector machines. The authors found that random forests provided the most accurate predictions, followed by support vector machines and decision trees. The study also highlighted the importance of selecting appropriate input features and the potential for machine learning to improve mineral prospectively mapping.

Zhu et al. (2019) evaluates the effectiveness of machine learning in predicting the locations of mineral deposits using geochemical data. The study used a dataset from a copper deposit in China and compared the results of different machine learning algorithms, including random forests, gradient boosting, and neural networks. The authors found that random forests provided the most accurate predictions, followed by gradient boosting and neural networks. The study also highlighted the importance of feature selection and the potential for machine learning to improve mineral deposit prediction.

Li et al. (2020) evaluates the limitations of machine learning in mineral exploration. The study used a dataset from a gold deposit in China and compared the results of different machine learning algorithms, including support vector machines, decision trees, and random forests. The authors found that machine learning can provide accurate predictions of mineral deposits, but these predictions may be limited by the quality and quantity of input data. The study also highlighted the potential for overfitting and the need for caution in interpreting machine learning models.

Identifying Potential Benefits and Challenges

The identification of potential benefits and challenges of machine learning in mineral exploration is crucial for effective implementation of this technology [5]. On the benefits side, machine learning can provide faster and more accurate identification of mineral deposits, reduce exploration costs, and increase exploration success rates[27]. It can also help to identify areas for further exploration and prioritize exploration targets. However, some challenges include the need for high-quality data, the potential for biased algorithms, and the difficulty in interpreting results [30]. Additionally, the integration of machine learning with existing exploration workflows and gaining acceptance from stakeholders may also be a challenge. The findings of previous studies were discussed here.

Shirmard et al. 2021 Evaluating Effectiveness and Limitations in Machine Learning in Mineral Exploration to evaluate the effectiveness and limitations of machine learning in mineral exploration Review of literature N/A Machine learning can effectively identify and classify mineral deposits using remote sensing data, geological data, and other sources of information. However, limitations include the need for high-quality data, the potential for bias and overfitting, and the difficulty of interpreting complex models. Future research should focus on improving data quality, developing hybrid models that combine machine learning with other techniques, and developing more transparent and interpretable machine learning models.

Xiong et al. 2021 Identification of Mineralized Areas Based on Machine Learning Models to develop machine learning models for identifying mineralized areas using geological data and remote sensing data Support Vector Machines (SVM), Random Forest (RF) SVM and RF The SVM and RF models were found to be effective in identifying mineralized areas using geological and remote sensing data. The authors recommend further research to improve the accuracy of the models by incorporating more detailed geological information and other data sources. Additionally, the authors suggest exploring the potential of deep learning techniques for mineral exploration.

Cheng et al. (2020) to give a thorough study of machine learning methods used in mineral exploration, we wrote A Comprehensive study on Machine Learning Techniques. N/A for a literature review Support vector machines, artificial neural networks, decision trees, and random forests are a few machine learning approaches that have been effectively used in mineral exploration to locate mineral resources, forecast mineral grades, and model geophysical data [29]. The necessity for high-quality data, the possibility of bias and overfitting, and the complexity of comprehending complicated models all obstacles, however. To increase the accuracy and interpretability of the findings, future research should concentrate on creating hybrid models that include machine learning with other methodologies, such as geological knowledge and physical modeling. Additionally, additional work has to be done to solve the problems with data integration, data integration quality, and data availability in mineral exploration.

Rahmani et al. 2020 Machine learning for mineral exploration: a systematic review to provide a systematic review of machine learning for mineral exploration Review of literature N/A Machine learning has shown promising results for mineral exploration in various applications, including identifying mineral deposits, predicting mineral grades, and processing remote sensing data. The authors highlight the importance of high-quality training data, feature selection, and interpretability of the models. Challenges include the need for more standardized datasets, the potential for bias and overfitting, and the difficulty of incorporating geological knowledge into the models [28]. Future research should focus on developing more transparent and interpretable machine learning models, incorporating geological knowledge into the models, and addressing the challenges of data availability and quality in mineral exploration. Additionally, more research is needed to investigate the potential of deep learning and transfer learning techniques in mineral exploration

Providing Recommendations for Future Research and Development

Based on the research studies presented, here are some recommendations for future research and development:

1. Conduct studies that focus on identifying the most effective input features for machine learning algorithms in mineral prospecting and exploration. These studies could explore the potential of using different types of data sources, such as geological, geochemical, and remote sensing data, to improve accuracy and interpretability of the models.
2. Develop hybrid models that combine machine learning with other techniques, such as geological knowledge and physical modeling, to improve the accuracy and interpretability of the results. This could involve exploring the potential of deep learning and transfer learning techniques in mineral exploration.
3. Address the challenges of data availability, data quality, and data integration in mineral exploration. Future research should focus on developing standardized datasets and evaluation metrics to facilitate comparison and benchmarking of different methods.
4. Develop more transparent and interpretable machine learning models that incorporate contextual information and geological knowledge. This could involve exploring the potential of explainable AI techniques, such as rule-based models and decision trees.
5. Collaborate between industry, academia, and government to improve exploration success rates and ensure sustainable resource use. This could involve developing interdisciplinary approaches that combine advanced technologies, such as machine learning and robotics, with traditional mining methods.

V. CONCLUSION

This review article underscores the immense potential of Artificial Intelligence (AI) and Machine Learning (ML) in revolutionizing the mineral exploration industry. It has become evident that these technologies can significantly enhance efficiency, reduce costs, and increase the success rates of mining projects. However, it is essential to recognize the challenges, such as data quality and interpretability, as well as ethical considerations that accompany their adoption. The implications for the mining industry are profound, as AI and ML have the capacity to bring about a paradigm shift in how we approach mineral exploration. The recommendations for future research and development underscore the need for continued collaboration, innovation, and the integration of multiple disciplines to ensure sustainable and effective mineral exploration practices that harness the full potential of AI and ML.

VI. REFERENCES

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