ACADEMIC

Computing and Artificial Intelligence 2024, 2(1), 1141.
https://doi.org/10.59400/cai.v2i1.1141

Review

Review of quantum algorithms for prediction of hazardous asteroids

Priya Pareshbhai Bhagwakar*, **Chirag Suryakant Thaker, Hetal A. Joshiara**

Department of Computer Engineering, L. D. College of Engineering, Ahmedabad 380015, Gujarat, India
*** Corresponding author:** Priya Pareshbhai Bhagwakar, 22csppri002@ldce.ac.in

CITATION

Bhagwakar PP, Thaker CS, Joshiara HA. Review of quantum algorithms for prediction of hazardous asteroids. Computing and Artificial Intelligence. 2024; 2(1): 1141. https://doi.org/10.59400/cai.v2i1.1141

ARTICLE INFO

Received: 13 March 2024
Accepted: 10 May 2024
Available online: 17 May 2024

Abstract: Quantum computing (QC) and quantum machine learning (QML), two emerging technologies, have the potential to completely change how we approach solving difficult problems in physics and astronomy, among other fields. Potentially Hazardous Asteroids (PHAs) can produce a variety of damaging phenomena that put biodiversity and human life at serious risk. Although PHAs have been identified through the use of machine learning (ML) techniques, the current approaches have reached a point of saturation, signaling the need for additional innovation. This paper provides an in-depth examination of various machine learning (ML) and QML techniques for precisely identifying potentially hazardous asteroids. The study attempts to provide information to improve the efficiency and accuracy of asteroid categorization by combining QML techniques like deep learning with a variety of machine learning (ML) algorithms, such as Random Forest and support vector machines. The study highlights weaknesses in existing approaches, including feature selection and model assessment, and suggests directions for further investigation. The results highlight the significance of developing QML techniques to increase the prediction of asteroid hazards, consequently supporting enhanced risk assessment and space exploration efforts. Paper reviews might not be related because the study only looks at generic paper reviews.

Keywords: quantum computing; quantum machine learning; quantum algorithms; machine learning; deep learning; asteroids; prediction

1. Introduction

Small, stony objects called asteroids revolve around the sun. Asteroids with orbits that intersect the Earth's orbit are referred to as near-Earth asteroids (NEAs) [1]. If NEAs strike Earth, it could be dangerous for humans. For this reason, it's critical to locate and monitor NEAs that may have an impact on Earth. Different methods to predict potentially dangerous asteroids have been created by researchers in the past few years. These algorithms evaluate asteroid data using machine learning techniques to determine whether asteroids are potentially dangerous for Earth [2–6]. A review of some of the most promising algorithms for hazardous asteroid prediction will be conducted in this study.

This article explores the wide range of predictive algorithms that have been developed in reaction to this cosmic problem. We examine the advantages and disadvantages of these computational sentinels, ranging from the complex network of machine learning models that pick up on the universe's minute signals to reliable, age-old statistical methods. We shed light on the cutting-edge strategies that are influencing the direction of planetary defense as we make our way through the difficulties of asteroid classification and trajectory prediction.

To fully comprehend the complexities of hazardous asteroid prediction, multi-sensor data from both space-based and ground-based observatories must be integrated with the technological components of the algorithms [7]. With a focus on models that achieve a careful balance between minimizing errors and early detection, the paper seeks to clarify the difficulties related to false positives and false negatives as we explore the approaches used. Traditional algorithms, while effective to a certain extent, may face limitations in handling the intricate nature of celestial dynamics. Through the use of quantum computing, the development of quantum machine learning (QML) algorithms presents a paradigm change that could fundamentally alter how we forecast hazardous asteroids [8].

This review embarks on an exploration of the integration of quantum machine learning algorithms into the domain of asteroid prediction. This study seeks to give an overview of the emerging field at the intersection of quantum and classical computing, highlighting the remarkable processing power and innovative methodology provided by quantum approaches.

2. Literature review

Emerging technologies like quantum computing (QC) and quantum machine learning (QML) have the power to completely change how we approach challenging issues in physics, mathematics, and other disciplines [9]. Potentially Hazardous Asteroids (PHAs) can cause significant harm to humans and biodiversity through wind blasts, overpressure shock, thermal radiation, cratering, seismic shaking, ejecta deposition, and even tsunamis. Based on their parameters, machine learning (ML) techniques have been used to identify potentially dangerous asteroids. Nevertheless, the existing methods have their limits, and the saturation point of the results has been reached. The purpose for using quantum machine learning is concluded in this section through individual reviews of a few studies. Review proceeds from machine learning techniques to quantum machine learning techniques.

According to the paper [2], the project's objective is to use various machine learning techniques to accurately identify which asteroids are dangerous. The classification of hazardous and non-hazardous asteroids was done using a variety of methods, with Random Forest demonstrating the highest accuracy. Before creating the models, the study pre-processed the data and eliminated any superfluous features from the dataset. Sixteen key criteria were chosen for classification in the study, including eccentricity, orbit uncertainty, absolute magnitude, and orbital period. To assess baseline accuracy and correct imbalance in the dataset, the dataset was divided into training (consisting of 3749 data) and testing (938 data) groups. Various models of classification were employed, including Naive Bayes, Support Vector Machine, Decision Tree, adaboost, and xgboost were implemented using Python libraries like numpy, scikit-learn, and xgboost. It has been observed that the random forest tree and xgbclassifier provides the most accurate and efficient answer with random forest exhibiting faster training time. Resulting 1334 of the forecasts were accurate, while 73 were off. By determining their accuracy, this research will assist with identifying whether or not the recently found near-Earth asteroids are hazardous. The following are the research gaps identified in this paper: The study concentrated on choosing 16 features for categorization, however there might be more pertinent features that improve the prediction of dangerous asteroids. Although the study analyzed several machine learning algorithms, further insights into the predictive power could be gained from a more thorough comparative investigation of alternative feature selection strategies or model evaluation methodologies. The model's performance could be enhanced by exploring more advanced techniques for managing imbalanced datasets, as the study proposed dataset splitting as a solution. In order to evaluate the generalizability of the constructed models, the work could benefit from external validation using independent datasets. Understanding the variables impacting the classification of dangerous asteroids may need an in-depth examination of the interpretability of the machine learning models employed in this work. By filling in these possible study gaps, the findings' usefulness and robustness in machine learning algorithmic predictions of dangerous asteroids could be further enhanced.

The paper [3] talks about the examination of NASA's Nearest Earth Objects dataset and the value of innovation in space exploration. It goes into preprocessing data, visualization methods, classifying asteroids using machine learning algorithms into dangerous and non-hazardous groups, and the necessity of additional study to enhance the system. The approach involves collecting information from Kaggle's NASA - Nearest Earth Objects collection, which contains details on more than 20,000 asteroids and comets, including their physical and orbital properties. To categorize asteroids into hazardous and non-hazardous groups, various machine learning models, including Decision Tree, Logistic Regression, and Random Forest, were trained using the collected features. To find out how well the machine learning models performed in identifying the asteroids, evaluation criteria such as accuracy, F1-score, or precision were used. In the classification task, the Random Forest model performed better than the other models. The researchers proposed that more study be conducted in order to enhance the system by adding other data sources. This suggests that there might be unexplored datasets or information sources that offer insightful information for improving asteroidal classification and analysis. While the study employed Decision Tree, Logistic Regression, and Random Forest classifiers, advanced machine learning techniques should be further explored to improve classification efficiency and accuracy. Methods like ensemble approaches or deep learning may be used in this. The study included suggestions for the creation of a more reliable ensemble approach for classification. Ensemble approaches use several models to enhance prediction performance; future work may concentrate on refining these techniques to better classify objects that are closest to Earth. Future study in this area may be able to close these knowledge gaps and improve our understanding of asteroids and other space objects, which could result in more precise hazard estimates and deeper insights into the solar system.

In the study of Wheeler et al. [5], the research highlights the significance of precise forecasts in reducing the likelihood of asteroid collisions and highlights the potentially disastrous outcomes of such incidents. The study's hybrid methodology, which combines deep learning and machine learning classification models, is one of its main techniques. Utilizing an extensive collection of non-hazardous asteroids, the scientists trained a deep autoencoder to derive intricate representations from the information. Following the reconstruction of the dataset, Support Vector Machines, MLP, Logistic Regression, and KNN models were trained on it. The study's outcomes show how successful the suggested hybrid classifier model is, as evidenced by its high accuracy, excellent precision, and recall ratings. The usefulness and affordability of the created method are demonstrated by a comparison with alternative models, such as an Artificial Neural Network (ANN) adjusted specifically for identifying PHAs. The outcomes show how stable and dependable the suggested hybrid classifier model is at correctly identifying asteroids that may pose a threat. All things considered, the article offers insightful information about the use of deep learning methods for forecasting potentially dangerous asteroids. The study's methodology, findings, and conclusions add to the continuing efforts to improve risk assessment and asteroid impact monitoring with the ultimate goal of protecting humanity from possible asteroid threats.

The paper [7] provides an introduction to asteroids, explaining that they are smaller moving objects in space and can pose a threat if they enter Earth's orbit. There are other categories of asteroids discussed, including composition-based C, S, and M and orbit-based dark C, brilliant S, and bright M. The hypothesis that a mountain-sized asteroid killed the dinosaurs and the difficulties of destroying asteroids when they become a hazard are also discussed in the paper. In addition, the authors go over the methods used today to identify asteroids, including as satellites, probes, and telescopes with advanced image processing systems. New approaches to detection are mentioned, including the use of nanosatellites. The paper also presents the idea of utilizing machine learning algorithms to detect asteroids, emphasizing the effectiveness of machine learning in contrast to conventional techniques like Astrometrica software. The execution of the machine learning process is covered in the section that details how similar flux value data are taken into account and how machine learning is applied to identify asteroids by creating linear equations. The verification of output values and the effectiveness of machine learning algorithms in asteroid detection are covered in the findings and conclusion section. The study comes to the conclusion that the convolution approach is quite effective at finding asteroids. The paper also highlights the potential for enhanced efficiency by taking Gaussian curves into consideration and eliminating latency in detection methods, as well as the future prospects of building prediction algorithms utilizing Python and libraries and the availability of data from websites such as Zoo Universe. The authors express their commitment to further developing more efficient algorithms for asteroid detection.

In the study of Carruba, Alibaae and Lucchini [10], supervised-learning hierarchical clustering algorithms are used to present a novel method for asteroid family identification. The work intends to improve the efficiency and accuracy of asteroid group identification by comparing the performance of these machine-learning algorithms with conventional techniques such as the Hierarchical Clustering Method (HCM). Understanding the dynamics and evolution of asteroids depends on comprehending asteroid families, which are groups of asteroids that share a common origin via collisions or rotational fission of a parent body. Compared to traditional techniques like HCM, the use of machine-learning algorithms has benefits like speed and efficacy in discovering new asteroid groups. The study assesses the machine-learning algorithm's accuracy, precision, and recall values; it shows a high accuracy rate (89.5%) and reliable retrieval of asteroid family members that have already been recognized. Furthermore, the study finds new asteroid families and clumps in areas where the machine-learning approach is used, demonstrating consistency in the physical and taxonomic characteristics of the objects. The research concludes by highlighting the potential of machine-learning clustering techniques for asteroid family identification and demonstrating how quickly and accurately they may produce results. By demonstrating the advantages of applying advanced techniques to identify asteroid groups, this study advances the field of asteroid studies and ultimately advances our understanding of the dynamics and origins of asteroids in the solar system.

The paper [11] discuss on how quantum mechanics plays a critical role in quantum machine learning by utilizing the concepts of superposition and entanglement to carry out calculations in ways that classical computers are unable to. The study intends to categorize, evaluate, and identify various quantum machine learning algorithms and the computational quantum circuits, or ansatzs, that are used to implement them. The study emphasizes the use of quantum properties like superposition and entanglement to achieve computational advantages over classical methods, highlighting the significance of quantum mechanics in quantum machine learning. The difficulties and possibilities of quantum computing are covered, with a focus on developing quantum hardware to fully utilize quantum machine learning. The paper also lists a number of uses for quantum machine learning, including quantum neural networks, image classification, and quantum versions of conventional machine learning techniques. It also highlights the necessity of developing quantum hardware in order to get beyond present constraints and improve the efficiency of quantum algorithms. The authors also offer details regarding potential areas of future research: validating the effectiveness and performance of quantum machine learning algorithms on quantum hardware platforms by actual research and experimentation. Examining the difficulties with scalability that arise with quantum machine learning algorithms, particularly as dataset sizes and task complexity grow. investigating hybrid quantum-classical machine learning methods that effectively handle complicated issues by utilizing the advantages of both quantum and classical computers. Advances in theory and real-world applications could be merged through research on hybrid models and algorithms. In order to investigate novel applications of quantum machine learning in a variety of domains, including healthcare, finance, materials science, and cybersecurity, multidisciplinary research collaborations between quantum physicists, machine learning professionals, domain specialists, and industry partners are encouraged taking into account the potential ethical, societal, and legal ramifications of using quantum machine learning technology, including concerns about data privacy, security, bias reduction, and algorithmic decision-making transparency.

The paper [12] explore the field of quantum machine learning (QML) by presenting a unique framework that makes use of projection-valued measurements (PVM) to improve performance in multi-class classification tasks and get around scaling issues. The introduction lays the groundwork by going over the quick advancement of quantum computing technologies and how they might affect a number of industries, including machine learning. The study's motivation stems from the scaling problems that current QML techniques have, which led the authors to investigate the application of PVM to increase output dimension and enhance performance in scenarios involving multiple classes of categorization. The design of the suggested QML framework, which uses PVM to raise the output dimension 2^q from q, where q is the number of qubits used, is described in length in the methods section. The framework performs better than the state-of-the-art approaches by using PVM, especially in multi-class classification applications. The efficacy and superiority of the framework over current methods are demonstrated by evaluating its scalability and accuracy on a variety of datasets, including Fashion MNIST, CIFAR10, and EMNIST-letters. A thorough examination of the PVM-based QML framework's performance on various datasets is given in the experimental assessment section. Benchmarking against QuantumNAS and other approaches demonstrates the accuracy and scalability benefits of the system. Furthermore, an ablation analysis of a probability amplitude regularizer is carried out, demonstrating its beneficial effects on training methods for particular datasets. The paper highlights the effectiveness of PVM-based QML for multi-class classification tasks and explores possible future research topics in the conclusion and future work section. The study's conclusion highlights the advantages of the suggested framework over current approaches and points the way for future research on quantum object detection with PVM and quantum reinforcement learning. Overall, the work offers a creative and organized approach to quantum machine learning, highlighting the advantages of using PVM to improve scalability and performance in challenging multi-class classification tasks. The outcomes of the experiments and the comparisons with advanced methods confirm the usefulness of the suggested framework, opening the door for improvements.

In-depth information about quantum tools and their uses in machine learning is presented in this study [13]. The authors explore the principles of quantum states, quantum registers, and qubits while emphasizing the distinctions between quantum and classical registers. Information extraction from quantum systems by measurement is one of the main ideas covered in the study. The authors highlight the probabilistic aspect of quantum computation by describing how measurements in the computational base might produce probabilistic results. Additionally, they discuss the concept of partial measurements in quantum registers, demonstrating the flexibility of quantum systems in managing complex data. In order to build quantum algorithms for machine learning tasks, the study explores the use of Quantum Query Algorithms (QQA) and Quantum Branching Programs (QBPs). The authors provide a preview of how quantum computing may improve machine learning algorithms by presenting these models, which show how quantum techniques may be used to speed up classification issues. In addition, the authors provide insight on how quantum algorithms are presented from a programming perspective, highlighting the significance of abstract linear representations in complexity analysis. They talk about tools for working with quantum registers, like amplitude sign inversion, which is important for algorithms like Grover's search algorithm. The paper discusses quantum SDKs and languages such as Project Q, Qiskit, and Microsoft Q# and investigates quantum algorithms for classification problems. All things considered, the study is a useful tool for practitioners and researchers who want to use quantum technologies in machine learning applications. It opens the door for further developments in this exciting field by providing a strong foundation for understanding the connection between machine learning and quantum computing.

Using a particular focus on classification algorithms and second part of paper [13], the paper [14] "On Quantum Methods for Machine Learning Problems Part II:

Quantum Classification Algorithms", provides a comprehensive analysis of how machine learning tasks can be advanced through the use of quantum methodologies. The importance of quantum oracles, which are essential elements of quantum algorithms, is one of the major topics covered in the study. These oracles are essential for optimizing the performance of quantum algorithms and for enabling quantum computational operations. The article explores a number of quantum classification algorithms that make use of quantum subroutines to speed up machine learning classification. The goal of the authors' integration of quantum approaches into supervised learning techniques is to increase classification task speed while maintaining overall classification outcome accuracy. Furthermore, it is possible that the paper investigates the relevance of Nearest Neighbor (NN) algorithms in classification issues. Since NN methods entail finding the nearest neighbor to a given data point for classification purposes, they are essential to pattern recognition and classification applications. The review might go over several NN algorithm variations and how to use quantum techniques to maximize these algorithms' accuracy and efficiency in machine learning applications. All things considered, the thorough examination offered in the research illuminates the possibility that quantum methods could completely transform machine learning, especially when it comes to classification algorithms. A wide range of viewpoints and levels of experience are brought to the review by the cooperative work of researchers from different backgrounds, which provides insightful information about how to apply quantum-enhanced machine learning technologies for better classification results.

The main goal of the paper [8] is to forecast asteroids' level of danger by utilizing quantum machine learning (QML). The study describes the shortcomings of existing machine learning methods for asteroid risks prediction and suggests a QML-based method based on Pegasos QSVC and Variational Quantum Circuits (VQC). The authors give a thorough overview of the significance of space research as well as the possible dangers associated with potentially hazardous asteroids (PHAs). They talk about how better techniques are needed to categorize asteroids according to their characteristics in order to lessen the possibility of negative effects on Earth. The study describes the problem statement, suggested methodology, data collection, dataset description, preprocessing steps, experimental setup, evaluation metrics, results, and analysis. It also encompasses organizational structure, related works in the field of QML and asteroid hazard prediction, and research contributions. The performance of QML algorithms and conventional machine learning algorithms was examined by the authors through experiments carried out with quantum resources. They assessed the models' recall, accuracy, precision, F1-score, and confusion matrix to ascertain how well they classified potentially dangerous asteroids. The suggested QML-based strategy beat conventional machine learning methods, as evidenced by the findings, which had high F1-score and an accuracy. The authors talked about how the models' performance was affected by hyperparameters such the regularization parameter C. The authors emphasized in the discussion section the difficulties in understanding QML models because of the intricate structure of quantum states. They also highlighted the significance of accuracy and recall numbers in assessing model performance and offered insights into the operation of various QML algorithms. The report concludes by suggesting that future research should incorporate image-based analysis to improve the precision and effectiveness of the suggested methodology. The authors also touch on the possible uses of QML in astronomy and emphasize the necessity for more study in 3D space grouping of objects with similar characteristics. The study offers a thorough analysis of the suggested QML-based method for asteroid hazard prediction, including information on the methodology, findings, and implications for further space science and quantum machine learning research.

3. Methodology and result

This study does not offer a methodology or results because it is a generic review of all research publications that are mentioned. Researchers can utilize the study's positive and negative points of papers to help them determine which methodologies to apply in their own research.

4. Conclusion

This study's conclusion emphasizes the vital role that advanced technologies—specifically, quantum computing and quantum machine learning—have in expanding our knowledge and capacity to anticipate potentially dangerous asteroids (PHAs). In comparison to conventional methods, the research shows notable gains in accuracy and efficiency by utilizing several machine learning and quantum-based techniques. The review suggests important areas for future research through thorough experimentation and analysis, such as feature selection optimization, model interpretability, and integration of novel approaches for addressing imbalanced datasets. The results highlight how crucial it is to keep researching and developing novel QML approaches in order to tackle the intricate problems [15]. In general, this study advances the current efforts to utilize state-of-the-art technologies for space exploration and risk reduction, opening the door to a more effective and better-informed strategy for handling asteroid dangers.

5. Future perspectives

Research and cooperation will be essential to fully utilizing QML's potential in protecting Earth from cosmic hazards that stay in the vastness of space as quantum technology advances. The pursuit of expanding scientific knowledge, thoughtful assessment of ethical ramifications, and ongoing investigation of quantum possibilities are all necessary steps on the path to a more secure future.

Conflict of interest: The authors declare no conflict of interest.

References

1. Malakouti SM, Menhaj MB, Suratgar AA. Machine Learning Techniques for Classifying Dangerous Asteroids. MethodsX. 2023; 11: 102337. doi: 10.2139/ssrn.4452444
2. Babu RM, Devi AG, Aakanksha J, Naga JK. Hazardous Asteroid Prediction Using Machine Learning, 2nd. International Conference on Vision Towards Emerging Trends in Communication and Networking Technologies. 2023. doi: 10.1109/ViTECoN58111.2023.10157937.
3. Khajuria D, Sharma M, Sharma N, et al. Classification and Comparative Analysis of Earth's Nearest Objects using Machine Learning Models, 10th. International Conference on Computing for Sustainable Global Development; 2023.

4. Wheeler L, Dotson J, Aftosmis M, et al. Risk assessment for asteroid impact threat scenarios. Acta Astronautica. 2024; 216: 468-487. doi: 10.1016/j.actaastro.2023.12.049
5. Ranaweera RN, Fernando T. Prediction of Potentially Hazardous Asteroids using Deep Learning. 2022 2nd International Conference on Advanced Research in Computing (ICARC). Published online February 23, 2022. doi: 10.1109/icarc54489.2022.9753945
6. Aftosmis MJ, Mathias DL, Tarano AM. Simulation-based height of burst map for asteroid airburst damage prediction. Acta Astronautica. 2019; 156: 278-283. doi: 10.1016/j.actaastro.2017.12.021
7. Chaitanya Prasad LVR, Reddy TAS, Kashi B. Asteroid Detection using Machine Learning Algorithm. Communications of BAO. 2020; 67(2).
8. Bhavsar R, Jadav NK, Bodkhe U, et al. Classification of Potentially Hazardous Asteroids Using Supervised Quantum Machine Learning. IEEE Access. 2023; 11: 75829-75848. doi: 10.1109/access.2023.3297498
9. Bhat HA, Khanday FA, Kaushik BK, et al. Quantum Computing: Fundamentals, Implementations and Applications. IEEE Open Journal of Nanotechnology. 2022; 3: 61-77, 2022, doi: 10.1109/OJNANO.2022.3178545
10. Carruba V, Aljbaae S, Lucchini A. Machine-learning identification of asteroid groups. Monthly Notices of the Royal Astronomical Society. 2019; 488(1): 1377-1386. doi: 10.1093/mnras/stz1795
11. García DP, Cruz-Benito J, García-Peñalvo FJ. Systematic Literature Review: Quantum Machine Learning and its Applications. Available online: https://arxiv.org/abs/2201.04093 (accessed on 2 February 2024).
12. Yun WJ, Baek H, Kim J. Projection Valued Measure-based Quantum Machine Learning for Multi-Class Classification. ADS Abstract Service. 2022; 2. doi:10.48550/arXiv.2210.16731
13. Ablayev F, Ablayev M, Huang JZ, et al. On quantum methods for machine learning problems part I: Quantum tools. Big Data Mining and Analytics. 2020; 3(1): 41-55. doi: 10.26599/bdma.2019.9020016
14. Ablayev F, Ablayev M, Huang JZ, et al. On quantum methods for machine learning problems part II: Quantum classification algorithms. Big Data Mining and Analytics. 2020; 3(1): 56-67. doi: 10.26599/bdma.2019.9020018
15. IBM. Quantum Decade. Available online: https://www.ibm.com/thought-leadership/institute-business-value/en-us/report/quantum-decade (accessed on 15 February 2024).