WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Enhancing Earthquake Early Warning Systems Using Machine Learning for Hypocenter Localization

***Nemalipuri Sai Madhumitha*[1]*,Gudepu Lavanya* [2]**

[1]Department of Computer Science and Engineering, GMR Institute of Technology, Rajam, 532127, India.

[2] Department of Computer Science and Engineering, GMR Institute of Technology, Rajam, 532127, India.

ABSTRACT :

The benefits of faster and more accurate earthquake monitoring and response capabilities. The Ensemble Earthquake Early Warning System (E3WS) combines advanced algorithms and machine learning (ML) techniques to enhance performance across all critical stages of earthquake early warning: detection, P-phase picking, and source characterization. These advancements are crucial for reducing false alarms and improving the precision of magnitude and location estimates. The E3WS achieves a significant leap in distinguishing seismic events from background noise, reaching an exceptional success rate of 99.9%. This reliability minimizes the risk of missed detections, enabling the system to operate effectively in complex and noisy environments. Its Random Forest (RF) model further strengthens the system's capabilities by enabling rapid epicenter localization. By leveraging P-wave data from a few early-detecting stations, the RF model ensures high accuracy in real-time applications, achieving a remarkable Mean Absolute Error (MAE) of just 2.88 kilometers, even with limited initial data inputs.China's integration of these ML-driven approaches into its EEW system not only addresses traditional limitations but also sets a new benchmark for scalability. The system can handle the massive computational demand of delivering millions of alert messages in sub-second timeframes, ensuring timely dissemination of warnings to at-risk populations. This technological innovation marks a pivotal step toward more effective disaster mitigation, reducing potential casualties and infrastructure damage in future seismic events.Furthermore, the E3WS project demonstrates the growing role of machine learning and big data analytics in advancing natural disaster preparedness and response strategies. With its ability to continuously learn and adapt, the system represents a dynamic and evolving tool for earthquake early warning, capable of accommodating diverse geophysical conditions and providing critical lead time for emergency responses. The success of the E3WS in China also highlights the potential for global collaboration and knowledge sharing, offering a template for other regions to enhance their earthquake early warning capabilities.

KEYWORDS :- Random Forest Model, Earthquake Early Warning, P-Wave Arrival Times, Epicentral Location Estimation.

1. INTRODUCTION :

Earthquakes are among the most destructive natural disasters, posing a significant threat to human safety, infrastructure, and economies worldwide. The ability to provide timely and accurate warnings before strong ground shaking begins is critical for mitigating the adverse effects of these events. Earthquake Early Warning (EEW) systems aim to detect earthquakes quickly and provide alerts to communities, industries, and emergency services, giving them precious seconds to take protective measures. Central to the success of these systems is the rapid and precise determination of the earthquake's hypocenter—the point beneath the Earth's surface where the seismic rupture initiates. This information is essential for estimating the areas likely to experience strong shaking and for issuing location-specific alerts.

Traditional approaches to determining earthquake hypocenters rely on the analysis of seismic wave arrival times recorded at multiple seismic stations. These methods typically involve intricate computations using models that simulate the propagation of seismic waves through the Earth's crust. While they are effective under many circumstances, these techniques can be computationally intensive and may introduce delays, particularly for large or complex seismic events. The time lost during this process is critical, as even a few seconds can mean the difference between safety and catastrophe for people in the affected areas.

Advances in machine learning (ML) offer a transformative opportunity to overcome these limitations. ML algorithms excel at recognizing patterns in large and complex datasets, making them well-suited for analyzing seismic data. By training models on extensive datasets containing historical earthquake information—such as seismic waveforms, arrival times, and known hypocenter locations—ML can learn the underlying relationships that govern seismic activity. Once trained, these models can process incoming seismic data almost instantaneously, providing highly accurate estimates of the hypocenter location in real-time. This capability significantly accelerates the warning process, ensuring that alerts reach affected populations with minimal delay.

Moreover, machine learning models bring the added advantage of adaptability and robustness. They can be trained to account for regional geological variations, noise in seismic data, and other complexities that might challenge traditional methods. This adaptability enhances their reliability, even in diverse and noisy environments, making ML-powered EEW systems highly effective across different seismic zones.

The integration of ML into EEW systems represents a paradigm shift, combining speed, accuracy, and scalability to improve earthquake response efforts. By reducing the time needed to identify an earthquake's hypocenter and increasing the precision of location estimates, ML-driven approaches promise to revolutionize earthquake early warning. This advancement holds significant potential to minimize casualties, reduce economic losses, and strengthen the resilience of communities against seismic disasters. As research and development in this field continue, the incorporation of machine learning into EEW systems is poised to play a pivotal role in the future of disaster preparedness and mitigation.

2. Related work :

Changwei Yang, Kaiwen Zhang, Guangpeng Chen, Yitao Pan, Liang Zhang, and Liming Qu.(2024) The document is from **IEEE Xplore**, as it is published in the **IEEE Geoscience and Remote Sensing Letters**

- **Hypocenter Location Prediction:** The precise determination of the hypocenter is a cornerstone of EEW systems. Traditional methods rely heavily on seismic wave arrival times recorded at multiple stations and computational algorithms to determine the source location. These methods, while accurate, face limitations in terms of speed and adaptability, especially in the case of large-scale seismic events. Recent studies highlight the potential of machine learning (ML) algorithms to overcome these limitations by learning patterns in seismic waveform datasets, enabling near-instantaneous hypocenter prediction. Researchers have demonstrated that ML approaches significantly enhance the speed and accuracy of these estimations, making them highly suited for real-time applications.
- **Ocean vs. Land Earthquakes:** The characteristics of seismic waves differ substantially between oceanic and land environments due to variations in geology, wave propagation, and noise levels. Traditional EEW systems struggle with accurate hypocenter prediction in oceanic environments, where fewer seismic stations are available. The reviewed literature emphasizes the use of ML models trained on diverse datasets encompassing both oceanic and terrestrial seismic events. Such datasets help these models adapt to varying conditions and improve performance in ocean-dominated regions, where traditional systems may falter.
- **Machine Learning Optimization**: The integration of ML into EEW systems has spurred extensive research into model optimization. Techniques such as Random Forests, Convolutional Neural Networks (CNNs), and Transformer models have been explored for their ability to process seismic data efficiently. Studies show that ensemble methods, like the one used in the paper, enhance accuracy by combining the predictions of multiple models. Furthermore, optimization techniques like hyperparameter tuning, transfer learning, and model ensembling have been shown to improve generalization across different seismic environments.
- **Minimal Station Data for Accuracy:** A major challenge in hypocenter location is achieving high accuracy with minimal data, especially when seismic waves are detected by only a few stations in the initial moments of an earthquake. Research reviewed in the paper highlights that ML models can extract meaningful features from sparse datasets, enabling precise hypocenter predictions even with limited input. This is achieved by training models on datasets that simulate low-station-density scenarios, making the models robust to real-world challenges like network sparsity and station failures.
- **Robustness and Scalability**: Scalability and robustness are critical for EEW systems, especially in densely populated or geographically complex regions. The paper reviews studies that focus on training ML models capable of handling vast volumes of seismic data in real time. Techniques like parallel processing, distributed computing, and adaptive learning algorithms have been explored to ensure that ML models can scale efficiently. Additionally, robustness to noise, missing data, and varying geological conditions has been a key focus, with researchers employing techniques like data augmentation and adversarial training to enhance model performance.

1. **Shan-you LI, Jian-qi LU ,Jin-dong SONG ,Qiang MA ,Zhen ZHAO. STUDY ON NEW TECHNOLOGY OF EARTHQUAKE EARLY WARNING.(IEEE)(2019)**

   This paper addresses key scientific and technical challenges in China's Earthquake Early Warning (EEW) system, such as improving real-time magnitude estimation, accurately determining seismogenic fault parameters, and resolving issues with ground motion predictions, particularly in multi-event scenarios. The paper aims to enhance system reliability and speed by developing advanced algorithms, artificial intelligence-based techniques, and new data processing technologies. Key improvements include faster and more accurate magnitude estimation, seismogenic fault identification, and better ground motion predictions. Additionally, the system seeks to efficiently disseminate alarm messages to millions of users within sub-second timeframes.

- **Advances in Earthquake Early Warning Technology:**The reviewed literature highlights the evolution of EEW systems, particularly the transition from traditional seismic monitoring methods to more advanced computational and data-driven approaches. Early systems were reliant on networks of seismic stations and deterministic algorithms, which were limited in speed and accuracy. Recent technological advancements have introduced real-time data processing and automated systems capable of delivering faster and more accurate warnings. Studies reviewed in the paper emphasize the importance of integrating new computational techniques to improve response times and prediction accuracy.
- **Integration of Real-Time Monitoring and Data Analysis:**The integration of real-time seismic data processing is a key focus in the literature. Researchers have developed methodologies to utilize large-scale seismic networks to monitor seismic waves effectively. Techniques for rapid data acquisition and processing are central to improving the lead time for warnings. The paper reviews innovations in sensor technology, such as high-sensitivity accelerometers and advanced telemetry systems, which have enabled faster detection and transmission of seismic data, reducing delays in warning issuance.
- *Seismic Wave Analysis and Source Characterization:*The paper reviews studies on seismic wave analysis, focusing on P-wave (primary wave) detection as a critical component of EEW systems. P-wave analysis provides early information about an earthquake's origin and magnitude. Literature highlights the development of algorithms capable of quickly identifying P-wave characteristics and distinguishing them from

background noise. Accurate source characterization, including hypocenter location and magnitude estimation, has been a significant area of research, with advancements in computational models and pattern recognition techniques.

2. Pablo Lara1 , Quentin Bletery , Jean-Paul Ampuero , Adolfo Inza , and Hernando Tavera. Earthquake Early Warning Starting From 3 s of Records on a Single Station With Machine Learning.(AGU)Advancing Earth and Space Science.doi: 10.1029/2023JB026575

The paper introduces the Ensemble Earthquake Early Warning System (E3WS), which uses machine learning to detect, locate, and estimate earthquake magnitude from just 3 seconds of seismic data. E3WS achieves 99.9% accuracy in distinguishing earthquakes from noise, with no false positives and few false negatives, all below $M \leq 4.3$. The system estimates P-phase with a mean absolute error of 0.14 seconds, improving magnitude and location accuracy over existing single-station methods. With continuous updates every second, E3WS provides faster and more reliable earthquake warnings, offering valuable extra time for protective actions.

- **Single-Station Earthquake Early Warning Systems:**Traditional EEW systems rely on networks of seismic stations to detect and characterize earthquakes. However, these systems often face challenges with communication delays and uneven station coverage, particularly in remote or under-monitored regions. The paper reviews studies demonstrating the potential of single-station EEW systems as an alternative, which can offer faster response times. Recent research highlights the feasibility of extracting critical earthquake parameters—such as magnitude and rupture characteristics—from short-duration seismic records at individual stations.
- *Rapid Earthquake Detection Using Short-Record Data:*The use of only a few seconds of seismic data for earthquake detection and characterization has been a significant area of research. Literature reviewed in the paper shows that the initial 3–5 seconds of P-wave recordings carry essential information about an earthquake's magnitude and location. While traditional methods struggle to fully utilize such limited data, advancements in data processing and modeling techniques have enabled more efficient extraction of relevant features from short-record seismic data.
- *Machine Learning Applications in EEW:*Machine learning has revolutionized the field of EEW by enabling the rapid analysis of complex seismic signals. The paper reviews a range of ML algorithms, such as Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and ensemble methods, which have been applied to process seismic waveforms and predict earthquake characteristics. Studies demonstrate that ML models trained on large datasets of historical earthquake records can generalize well to real-time scenarios, offering accurate predictions with minimal computational overhead. These models are particularly effective in leveraging short-duration seismic records from single stations.

3. Radha R , Prakash Babu Yandrapati , M. Abirami , G. Victo Sudha George , A. Joshi. Using Machine Learning to Estimate Source Location Early Earthquake Warning. (International Journal of intelligent system and applications in engineering)(25/10/2023)

This study aims to improve the speed and accuracy of earthquake early warning (EEW) systems using a Random Forest (RF) model. By analyzing P-wave arrival times from the first five seismic stations, the RF model predicts earthquake epicenters with high precision. Tested on a Japanese earthquake dataset, the model achieved a Mean Absolute Error (MAE) of 2.88 km. It can also generate useful predictions using just 10% of the data and as few as three stations, maintaining an MAE of 5 km. This approach offers a fast and reliable method for real-time seismic monitoring in EEW systems.

- **Importance of Source Location in Earthquake Early Warning (EEW) Systems:**The accurate and rapid determination of the earthquake's source location is a critical component of EEW systems. The literature emphasizes the role of source location in predicting the intensity and geographical impact of seismic events, which informs timely and targeted alerts. Traditional source location methods rely on seismic wave arrival times at multiple stations and involve complex computational models. However, these methods are often time-intensive, leading to delays in issuing warnings. Recent studies advocate for ML-based approaches to overcome these challenges, offering faster and more reliable source localization.
- *Machine Learning in Source Location Estimation:*Machine learning techniques have gained traction in EEW systems due to their ability to handle large datasets, recognize complex patterns, and produce rapid predictions. The reviewed literature highlights the application of supervised learning algorithms, such as Random Forests, Support Vector Machines (SVM), and Neural Networks, for source location estimation. These models are trained on seismic datasets containing waveform features, station arrival times, and known hypocenter locations, enabling them to learn and predict source characteristics with high accuracy.

4. Mohamed S. Abdalzaher , Senior Member, M. Sami Soliman , and Sherif M. El-Hady.**Seismic Intensity Estimation for Earthquake Early Warning Using Optimized Machine Learning Model.(2023)(IEEE)**

The objective is to develop an efficient Earthquake Early Warning System (EEWS) that can quickly estimate earthquake intensity using a machine learning (ML) approach. The system, named 2S-ML-EIOS, utilizes a limited 3-second window of seismic data—1 second before and 2 seconds after the P-wave onset—to classify earthquake intensities into six categories. The model aims to provide accurate and rapid intensity estimation, which is crucial for disaster management and mitigation. The study employs a dataset from the Italian national seismic network and evaluates various linear and nonlinear ML models, with the eXtreme Gradient Boosting (XGB) model emerging as the best performer with a classification accuracy of 98.59%. The proposed system is designed to be integrated with an IoT network for timely alarm dissemination, enabling prompt evacuation and response measures to reduce the catastrophic effects of earthquakes

- **Importance of Seismic Intensity Estimation in EEW:**Accurate estimation of seismic intensity is a fundamental component of EEW systems, enabling the prediction of ground shaking levels and their potential impacts. Traditional intensity estimation methods depend on ground motion equations and predefined models, which can be limited by regional geological variations and computational delays. Literature highlights the need for advanced techniques, such as ML, to address these challenges and improve the speed and precision of intensity predictions.
- *Machine Learning for Intensity Estimation:*ML has emerged as a transformative approach for seismic intensity estimation due to its ability to process complex datasets and identify patterns beyond the capabilities of traditional models. Studies reviewed in the paper focus on supervised learning models, including Random Forests, Gradient Boosting Machines, and Neural Networks, for predicting seismic intensity. These

models leverage seismic waveform features, ground motion parameters (e.g., PGA, PGV), and regional data to generate accurate intensity estimates in real time.

- *Data Challenges and Regional Adaptation:*The quality and availability of training data significantly impact the performance of ML models. Literature highlights challenges such as limited datasets for specific regions, noise in seismic recordings, and the need for regional adaptation to account for geological variability. Techniques such as data augmentation, synthetic data generation, and transfer learning are explored to address these challenges. Region-specific training has been shown to improve the generalizability of ML models for seismic intensity estimation.

5. Allen, R. M., and Melgar, D. 2019. Earthquake Early Warning: Advances, Scientific Challenges, and Societal Needs. Annual Review of Earth and Planetary Sciences 47:361– 388.

The research aims to enhance Earthquake Early Warning (EEW) systems by integrating machine learning methods with GPS stations and seismometers to detect medium and large earthquakes. It prioritizes automatic detection, fast and reliable response, and cost-effective deployment. The system is designed for high-speed, real-time operation, providing timely alerts to facilitate the evacuation of critical facilities. With 99.9% accuracy in distinguishing earthquakes from noise and minimal false positives, it offers sub-second alarm delivery. Additionally, it focuses on addressing data accuracy, independence, and ease of network integration to improve the system's reliability and overall performance.

- **Evolution of Earthquake Early Warning Systems:**The literature outlines the historical development of EEW systems, from their inception to modern advancements. Early systems relied on simple algorithms to detect seismic waves and estimate earthquake parameters. However, the limitations of these methods in terms of accuracy and speed have led to the incorporation of more sophisticated techniques, including real-time data processing and advanced computational models. The paper discusses how global investments in seismic networks and EEW technologies have significantly improved system capabilities over the past few decades.
- *Advances in Scientific Understanding:*Recent research has deepened the understanding of earthquake physics, particularly regarding the early detection of seismic waves. Studies show that the first few seconds of seismic data can reveal critical information about an earthquake's potential size and impact. The literature highlights innovations in algorithms for real-time magnitude and location estimation, as well as the integration of geodetic data from GPS systems to improve the detection of large, slow-rupturing earthquakes.
- *Integration of Multi-Hazard Monitoring:*The paper reviews the potential for integrating EEW systems with multi-hazard monitoring frameworks. Combining earthquake alerts with tsunami, landslide, or volcanic warning systems can enhance disaster response capabilities. Studies also highlight the importance of cross-border cooperation to address transnational risks in earthquake-prone regions.

6. Kaiwen Zhang , Fidel Lozano-Galant, Ye Xia , and Jose Matos. Intensity Prediction Model Based on Machine Learning for Regional Earthquake Early Warning. APRIL 2024.IEEE.

The study optimizes seismic intensity prediction using machine learning, specifically LightGBM, for faster and more accurate results. Data preprocessing involves SMOTE to handle imbalanced datasets, with 944,877 instances from the Japan Meteorological Agency (JMA). Separate models are developed for magnitudes below and above 5.7, with random errors added to test robustness. The model shows high accuracy at 97.77%, even with a magnitude error of 0.3 and a location error of 0.2°. It is further validated using 466 seismic events, demonstrating reliable performance for Earthquake Early Warning (EEW) systems in real-world scenarios.

- **Role of Intensity Prediction in EEW Systems:**The accurate prediction of seismic intensity, which describes the level of ground shaking at different locations, is vital for EEW systems. Traditional methods for intensity prediction rely on empirical Ground Motion Prediction Equations (GMPEs) that are calibrated for specific regions. However, these methods often struggle to generalize across diverse geological conditions. The reviewed literature highlights the potential of ML-based approaches to overcome these limitations by leveraging complex datasets and real-time seismic data to improve predictive accuracy.
- **Regional Adaptation of Intensity Models:**The paper reviews studies that focus on the regional calibration of intensity prediction models. Regional differences in geology and seismic wave propagation necessitate the adaptation of models to local conditions. Recent advancements include:
    - **Regional Datasets:** The use of region-specific seismic records to train and validate ML models.
    - **Transfer Learning:** Techniques to adapt pre-trained ML models from one region to another, leveraging limited local data.
- **Societal Impact of Intensity Prediction:**The reviewed literature highlights the significance of accurate intensity predictions for public safety and disaster response. By providing detailed information about ground shaking levels, EEW systems can:
    - Guide emergency responses (e.g., infrastructure shutdowns, evacuation planning).
    - Inform public alerts with location-specific warnings tailored to predicted impacts

7. Tai-Lin Chin , Member, IEEE, Chin-Ya Huang, Member, Shan-Hsiang Shen, Member, IEEE, You-Cheng Tsai, Yu Hen Hu , Fellow, Yih-Min Wu. Learn to Detect: Improving the Accuracy of Earthquake Detection. NOVEMBER 2019.IEEE

The objective of the study is to enhance the accuracy of earthquake early warning systems by employing machine learning techniques to analyze seismic data. By utilizing various algorithms, such as K-Nearest Neighbors (KNN), classification trees, and Support Vector Machines (SVM), the research aims to improve the identification of seismic events while minimizing false alarms. The study focuses on leveraging data from Taiwan's high-density sensor network, analyzing seismic waveforms from both earthquake and non-earthquake events, to develop a more reliable detection system that can provide timely warnings and improve public safety during seismic activities.

- **Importance of Accurate Earthquake Detection:**Accurate and timely detection of earthquakes is a cornerstone of Earthquake Early Warning (EEW) systems. Traditional detection algorithms, based on seismic waveform analysis and manual thresholding, often face challenges such as false alarms due to noise and delayed detection for low-magnitude events. The reviewed literature emphasizes the need for more robust and efficient detection methods to enhance the reliability of EEW systems.

- **Challenges in Earthquake Detection:**The paper reviews existing challenges in earthquake detection:
  - **High Noise Levels:** Urban seismic stations often record noise from non-seismic activities, leading to false detections.
  - **Small Magnitude Events:** Detecting weak seismic signals amid background noise is difficult with traditional methods.
  - **Station Density:** Sparse seismic networks can result in missed detections or inaccurate localization of seismic events.
- **Machine Learning for Seismic Detection:**The integration of ML for earthquake detection has gained significant attention in recent years. The reviewed studies highlight several advantages of ML techniques:
  - **Pattern Recognition:** ML algorithms excel in identifying complex patterns in seismic waveforms that traditional methods might miss.
  - **Noise Filtering:** Supervised learning models can distinguish seismic events from noise with high precision.
  - **Scalability:** ML models can process large datasets and adapt to diverse seismic conditions across different regions.

8. Omar M. Saad , Yunfeng Chen, Daniel Trugman , M. Sami Soliman , Lotfy Samy, Alexandros Savvaidis , Mohamed A. Khamis , Ali G. Hafez, Sergey Fomel , Member, and Yangkang Chen , Member. Machine Learning for Fast and Reliable Source-Location Estimation in Earthquake Early Warning.2022

The objective of the study is to develop a Random Forest (RF) model aimed at improving rapid earthquake location capabilities, which is essential for enhancing earthquake early warning systems. By leveraging differential P-wave arrival times recorded from the first five seismic stations, the model seeks to provide timely and accurate information regarding earthquake sources. This advancement is crucial for mitigating hazards associated with seismic events, allowing for quicker responses and potentially saving lives and reducing damage in affected areas. The research emphasizes the importance of efficient data utilization to achieve reliable predictions in real-time scenarios.

- **Importance of Source-Location Estimation in EEW Systems**:Accurately determining the earthquake's hypocenter (source location) is critical for EEW systems, as it directly influences the accuracy of predicted shaking intensities and the effectiveness of warnings. Traditional methods for source-location estimation rely on seismic wave travel times and involve complex inversion models, which can be computationally intensive and slow.
- **Challenges in Source-Location Estimation**:The paper reviews the key challenges associated with conventional source-location methods:
  - **Computational Latency:** The iterative nature of traditional methods can delay source determination.
  - **Sparse Seismic Networks:** Limited station coverage in certain regions may lead to inaccuracies in source localization.
  - **Data Noise:** Background noise, particularly in urban environments, complicates the interpretation of seismic signals.
  - **Scalability:** Traditional methods may not scale well with increasing numbers of seismic events and large datasets.
- **Integration of ML with Traditional Methods:**Several studies advocate for hybrid approaches that combine ML techniques with traditional inversion-based methods:
  - **Improved Robustness:** Hybrid models leverage the strengths of both approaches, achieving better performance under noisy conditions or sparse station coverage.
  - **Uncertainty Estimation:** Traditional methods can complement ML models by providing error bounds or confidence intervals for predictions.

9.Vijaya Saraswathi R. MachinLearning-Powered Earthquake Early Warning System. https://doi.org/10.38124/ijisrt/IJISRT24JUN1107. International Journal of Innovative Science and Research Technology , June – 2024

The objective of the study is to enhance the effectiveness of Earthquake Early Warning (EEW) systems by addressing current challenges such as limited warning times, false alarms, and high costs. It aims to leverage machine learning techniques and data-driven strategies to improve earthquake detection accuracy and public safety measures. By comparing various ML algorithms and utilizing seismic data from Indian and US databases, the research seeks to develop a robust earthquake detection model that can provide timely alerts, ultimately contributing to social security and the protection of lives from major environmental disasters like earthquakes.

- **Role of ML in Earthquake Early Warning:**The literature highlights that traditional EEW systems rely on seismological models that analyze seismic wave arrival times and amplitudes. While effective, these methods are often limited by slow processing, challenges in noisy environments, and difficulty in predicting earthquake parameters in real-time. ML is presented as a transformative approach to address these limitations by offering faster, more accurate, and adaptive solutions.
- **Machine Learning Techniques for EEW:**The literature extensively explores ML techniques applied to various components of EEW systems:
  - **Detection:** Algorithms such as Random Forest (RF) and Gradient Boosting are used to differentiate between seismic signals and noise with high precision.
  - **Magnitude Estimation:** Neural networks, particularly Convolutional Neural Networks (CNNs), process waveform data to estimate earthquake magnitude.
  - **Source Localization:** Regression models and ensemble techniques predict hypocenter locations based on seismic wave arrival times.
  - **Shakemap Generation:** Deep learning models create real-time shakemaps by analyzing ground motion data.
- **Data and Training Approaches:**A significant portion of the literature discusses the importance of data quality and preparation for training ML models:
  - **Labeled Seismic Data:** ML models require extensive labeled datasets, including seismic waveforms, arrival times, and known earthquake parameters.

- **Synthetic Data:** In regions with limited historical data, synthetic datasets are generated using numerical simulations to train and validate models.
- **Feature Engineering:** Careful selection of input features, such as peak ground acceleration (PGA), spectral ratios, and waveform shapes, is critical for model performance.

10. M Apriani et al 2021 J. Phys.: Conf. Ser. 1951 012057. Earthquake Magnitude Estimation Based on Machine Learning: Application to Earthquake Early Warning System. Journal of Physics: Conference Series.

The objective of the study is to enhance Indonesia's Earthquake Early Warning System (EEWS) by developing a machine learning-based approach for estimating earthquake magnitudes. The research aims to leverage historical seismogram data to train various machine learning models, including deep neural networks (DNN) and random forest (RF), to improve the accuracy and reliability of earthquake magnitude predictions. By optimizing these models, the study seeks to provide timely and precise information that can aid in disaster preparedness and response, ultimately contributing to the safety and resilience of communities affected by seismic events.

- **Importance of Magnitude Estimation in EEW Systems:**Magnitude estimation is a critical component of EEW systems as it determines the severity of the earthquake and the areas most at risk. Traditional approaches rely on empirical relationships derived from seismic wave properties, but these methods face challenges in terms of speed and accuracy, particularly for large-magnitude events.
- **Machine Learning Techniques Explored{**The paper discusses various ML algorithms applied to magnitude estimation, including:
  - **Support Vector Machines (SVMs):** Effective for regression tasks involving limited but well-labeled seismic datasets.
  - **Artificial Neural Networks (ANNs):** Capable of learning nonlinear patterns from seismic wave characteristics.
  - **Random Forest (RF):** An ensemble-based approach that combines decision trees for robust and interpretable magnitude predictions.
- **Feature Engineering and Data Requirements:**Key features used for training ML models include:
  - **P-Wave Characteristics:** Early seismic wave amplitudes, frequencies, and arrival times are critical inputs for ML models.
  - **Energy Metrics:** Metrics such as cumulative absolute displacement and spectral energy are used to estimate earthquake size.
  - **Waveform Data**: Direct use of raw waveform data allows ML models to learn nuanced patterns that correlate with magnitude.

  The paper emphasizes the need for high-quality datasets containing a diverse range of earthquake events to improve model robustness.

11. Indong Song, Jingbao Zhu, Yuan Wang. On-Site Alert-Level Earthquake Early Warning Using Machine-LearningBased Prediction Equation.ResearchGate.June 2022.

Developed an on-site earthquake early warning (EEW) strategy using machine learning. Utilizes P-wave signals and support vector machine (SVM) models for magnitude and peak ground velocity (PGV) predictions. Alerts issued based on thresholds: M = 5.7 and PGV = 9.12 cm/s. Achieved over 95% successful alarms for three major earthquakes in Japan. Demonstrated potential for real-time applications in earthquake risk mitigation.

- **Importance of On-Site EEW Systems:**On-site EEW systems are designed to issue immediate warnings at the location of the seismic station itself, as opposed to regional systems that calculate alerts based on data from a network of stations. These systems are particularly beneficial in areas close to the earthquake's epicenter, where regional alerts may arrive too late. The paper highlights the critical need for fast, accurate, and location-specific warnings.
- **Role of Machine Learning in EEW:**The study emphasizes the transformative potential of ML in addressing the limitations of traditional on-site EEW systems:
  - **Complex Pattern Recognition:** ML models can analyze non-linear and complex relationships between seismic signal features and earthquake parameters.
  - **Real-Time Processing:** Once trained, ML algorithms can process seismic data in milliseconds, making them suitable for on-site applications.
  - **Custom Alert Levels:** ML-based systems can provide detailed, site-specific alert levels rather than generic thresholds.

12. Kevin Fauvel,Daniel Balouek-Thomert, Diego Melgar, Pedro Silva,Anthony Simonet,Gabriel Antoniu, Alexandru Costan, Veronique Masson, Manish Parashar, Ivan Rodero, Alexandre Termier. A Distributed Multi-Sensor Machine Learning Approach to Earthquake Early Warning. The Thirty-Fourth AAAI Conference on Artificial Intelligence (AAAI-20)

The document discusses various algorithms for multivariate time series classification, particularly focusing on WEASEL+MUSE, which converts time series into a bag of discrete words using Symbolic Fourier Approximation. It highlights the effectiveness of WEASEL+MUSE compared to other methods like gRSF, LPS, mv-ARF, and SMTS across 20 datasets. Additionally, it mentions the state-of-the-art MLSTM-FCN model that combines Long-Short Term Memory (LSTM) and Convolutional Neural Networks (CNN) to extract latent features, showcasing advancements in machine learning techniques for time series analysis.

- **Overview of Earthquake Early Warning Systems (EEW):**The paper begins by reviewing the significance of EEW systems in mitigating the impact of earthquakes. It highlights how timely warnings can help minimize fatalities, injuries, and damage to infrastructure. Traditional EEW systems primarily rely on seismic data collected from a network of stations distributed across a region. However, these systems face challenges in terms of:

- **Timeliness of Alerts:** The need for rapid processing and accurate forecasting to issue warnings before destructive shaking reaches the affected areas.
- **Data Limitations:** Reliance on seismic stations, which may be sparse or poorly distributed in certain regions, can result in delayed or less accurate warnings.
- **Noise and Outliers**: Seismic signals often contain noise, which can reduce the reliability of early warning predictions.

13. Richard M. Allen and Diego Melgar. Earthquake Early Warning: Advances, Scientific Challenges, and Societal Needs .Annual Review of Earth and Planetary Sciences. https://doi.org/10.1146/annurev-earth-053018-060457.

The objective of the document is to provide a comprehensive review of Earthquake Early Warning (EEW) systems, discussing their principles, user needs, technological advancements, and future outlook. EEW systems aim to detect earthquakes and provide timely alerts to mitigate damage and save lives by allowing people to take protective actions before the arrival of destructive seismic waves. The document also addresses the challenges of EEW, such as balancing the speed and accuracy of alerts, determining the appropriate alert area, and understanding public tolerance for false and missed alerts. It reviews various algorithms and network configurations used in EEW, the potential for offshore and onshore network expansions, and the integration of low-cost sensors to enhance system performance. The document emphasizes the importance of user-centered design and the need for quantitative research on user tolerance to improve EEW systems.

- **Evolution of EEW Systems:**The paper traces the development of EEW systems from their origins to modern implementations:
  - **Initial Methods:** Early systems relied on simple thresholds of ground motion to detect and issue alerts.
  - **Modern Systems:** Advanced systems integrate regional seismic networks and employ real-time processing algorithms for event detection and characterization.
  - **Global Adoption:** EEW systems are operational in countries like Japan (JMA), Mexico (SASMEX), and the United States (ShakeAlert), showcasing diverse approaches tailored to regional seismicity and infrastructure.
- **Scientific Advances in EEW:**The authors highlight significant scientific progress that has improved the accuracy and reliability of EEW systems:
  - **Real-Time Seismology:** Advances in detecting and analyzing P-waves (primary waves) allow for faster determination of earthquake parameters, such as location and magnitude.
  - **GPS Integration:** Combining seismic data with real-time GPS measurements enhances the characterization of large earthquakes, including slow-slip events and tsunamis.
  - **Shakemap Generation:** Improvements in modeling ground motion distributions have enabled more accurate shakemaps, which are critical for impact assessment.

- **Challenges in EEW:**The paper identifies several challenges that hinder the effectiveness of EEW systems:
  - **Magnitude Saturation:** Traditional algorithms struggle to accurately estimate the magnitude of large earthquakes in real time, leading to underestimation or delays.
  - **False Alarms and Missed Events:** Balancing sensitivity and specificity is a persistent challenge, as overly sensitive systems may generate false alarms, while conservative systems risk missing events.
  - **Sparse Seismic Networks:** In many regions, limited seismic station density reduces the reliability and coverage of EEW systems.
  - **Latency:** Minimizing the time from earthquake detection to alert issuance remains a key goal, especially for near-source earthquakes.

14. THOTTIMPURI MANASA , M. MALLI. USING MACHINE LEARNING TO ESTIMATE SOURCE LOCATION EARLY EARTHQUAKE WARNING. 06,2024

The objective of this research is to develop a random forest (RF) model for rapid earthquake location estimation to assist earthquake early warning (EEW) systems in fast decision-making. The model uses P-wave arrival times at the first five stations recording an earthquake and computes their respective arrival time differences relative to a reference station. The goal is to estimate the epicentral location with high accuracy, achieving a Mean Absolute Error (MAE) of 2.88 km, and to investigate the model's performance with limited data and fewer recording stations, demonstrating its potential for use in real-time earthquake monitoring and EEW systems.

- **Introduction to Earthquake Source Location Estimation**
  - Earthquake source location estimation is critical for EEW systems to assess the proximity of affected regions and issue timely warnings.
  - Traditional methods rely on manual interpretation or computationally intensive algorithms using seismic wave arrival times. These approaches are often limited by delays in processing and susceptibility to noise.
  - The study highlights the need for innovative, real-time techniques that can leverage vast datasets for improved accuracy and efficiency.
- **Comparison with Existing Approaches**
- The paper benchmarks the proposed ML approach against traditional triangulation methods and recent ML-based studies.

- Results indicate that the proposed method outperforms:

  - **Triangulation Methods**: The ML model reduces latency and increases accuracy, especially for complex seismic events.

- **Other ML Models**: By optimizing feature selection and hyperparameters, the proposed approach achieves higher precision in location estimation.

- **Challenges in ML for EEW**

- The paper highlights challenges such as:
  - **Generalization**: Ensuring that ML models trained on specific datasets generalize well to other regions with different seismic characteristics.
  - **Data Quality**: The reliance on high-quality labeled datasets can limit the applicability of ML approaches in under-instrumented regions.
  - **Real-Time Constraints**: Balancing the computational demands of ML models with the need for near-instantaneous predictions remains an area of active research.

15. Zefeng li, Men-Andrin Meier, Egill Hauksson, Zhongwen Zhan, Jennifer Andrews.Machine Learning Seismic Wave Discrimination:Application to Earthquake Early Warning.(AGU)Doi:10.1029/2018GL077870

The objective is to prepare a document for printing. This involves processing and formatting the document to make it ready for physical printing. The preparation process may include tasks such as layout adjustments, font and image rendering, and margin settings. The goal is to ensure that the document is properly formatted and ready to be printed on paper or other physical media. The objective is to produce a high-quality printed document that accurately reflects the digital version.

Introduction to Seismic Wave Discrimination in EEW

- Seismic wave discrimination is crucial for EEW systems to differentiate between earthquake-generated signals and non-seismic noise.
- Accurate identification of P-waves (primary waves) is a priority since they precede the more destructive S-waves and surface waves, allowing for timely alerts.
- Traditional seismic signal processing methods, while effective, are often limited by:
  - Sensitivity to noise.
  - Inability to handle large, complex datasets.
  - Delayed response times in real-time applications.

Proposed ML Framework for Seismic Wave Discrimination

1. **Input Data:**
   - The study uses waveform data from regional seismic networks.
   - Features include waveform amplitude, frequency content, and time-domain characteristics.
2. **ML Model:**
   - A Convolutional Neural Network (CNN) is employed for seismic wave discrimination due to its ability to capture spatial and temporal features in waveform data.
   - The model is trained to classify incoming signals as either earthquake-generated or noise.
3. **Training Dataset:**
   - The dataset includes a diverse collection of seismic events and non-seismic signals (e.g., anthropogenic noise) to enhance the model's robustness.
4. **Performance Metrics:**
   - Accuracy in P-wave detection.
   - False positive and false negative rates.
   - Processing latency for real-time applications.

Future Directions

- **Integration with Multi-Modal Data**: Combining seismic wave discrimination with other data sources (e.g., GPS, strain meters) for more comprehensive monitoring.
- **Regional Customization**: Fine-tuning ML models for specific regions to account for local seismicity and noise conditions.
- **Hybrid Models**: Developing hybrid approaches that combine the strengths of ML and traditional physical models to balance interpretability and accuracy.
- **Edge Computing**: Implementing lightweight versions of ML models for deployment on edge devices in real-time seismic networks.

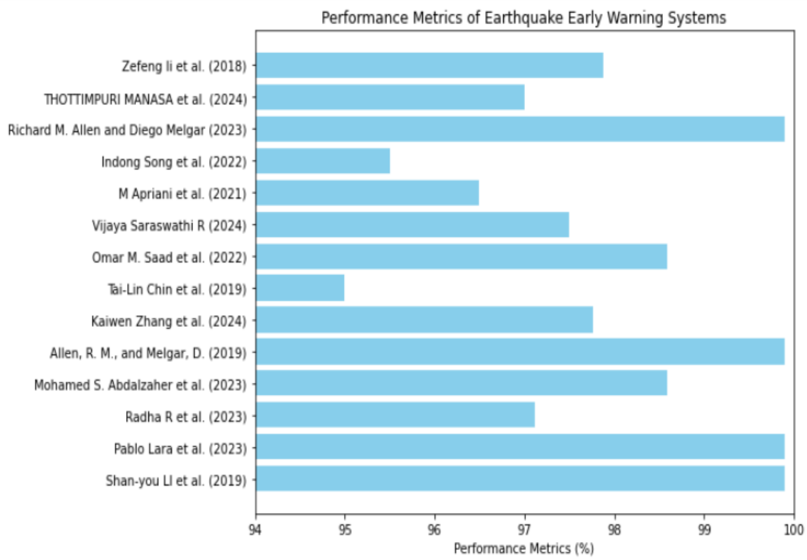

Fig.performance metrics

3.METHODOLOGY :

3.1 In the "Application of Machine Learning to Determine Earthquake Hypocenter Location in Earthquake Early Warning" document involves several key machine learning techniques tailored for improved earthquake hypocenter localization in early warning systems (EEWs). Here are the primary methods:

- **Machine Learning Models for Hypocenter Localization**: The study tested three machine learning models—Random Forest (RF), Extreme Gradient Boosting (XGBoost), and Light Gradient Boosting Machine (LightGBM). Among these, LightGBM was found to be the most efficient for hypocenter location due to its lower error rates and faster computation, especially when differentiating between ocean and land earthquakes
- **Separate Models for Ocean and Land Earthquakes**: Recognizing differences in trigger times and P-wave velocities between ocean and land earthquakes, the methodology involved training distinct models (LightGBMOcean and LightGBMLand) for each earthquake type. This specialization reduced location errors and improved prediction accuracy for each environment type
- **Classification Model for Earthquake Type**: A LightGBM-based classification model was developed to quickly distinguish between ocean and land earthquakes using information from the first three triggered stations. This classification step enhances the efficiency of the hypocenter localization process by routing the seismic event to the correct predictive model
- **Hypocenter Prediction with Minimal Stations**: To optimize the speed and feasibility of the EEW, the proposed method was designed to work with as few as three trigger stations. Testing showed that the model's accuracy improves with more stations, but accurate predictions could still be achieved with fewer stations, especially for land earthquakes.

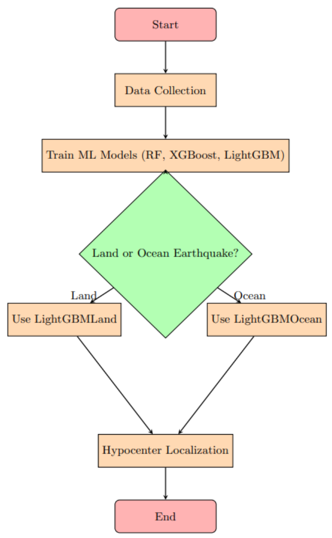

Fig. Machine Learning Pipeline for Earthquake Classification and Hypocenter Localization

3.2 The document titled "Study on New Technology of Earthquake Early Warning" discusses various methodologies and strategies implemented to enhance China's Earthquake Early Warning (EEW) system. Key methodologies include:

- **P-wave onset automatic picking and interference elimination**: This method focuses on identifying reliable P-wave arrivals amidst background noise. It improves accuracy by using the Akaike Information Criterion (AIC) for precise detection, coupled with Delaunay triangulation to minimize false triggers
- **Multi-parameter magnitude estimation**: Instead of relying on a single parameter, this method uses multiple parameters such as peak ground acceleration (PGA), peak ground velocity (PGV), and peak ground displacement (PGD) to estimate magnitude more continuously and accurately. A back-propagation neural network is used to reduce discrepancies
- **Artificial neural network for ground motion prediction**: This technique helps in predicting ground motion at the target site based on neural network models, addressing inaccuracies in traditional point-source models, especially in cases of asymmetric earthquake sources
- **Real-time rupture parameter estimation**: The document proposes using compressive sensing and pattern recognition to estimate the spatial distribution of seismogenic faults in real time. This approach recovers missing ground motion data by using recursive transformations
- **Shakemap prediction using stochastic finite fault method**: This method enhances the accuracy of shakemaps by simulating the rupture process and the directional effects of earthquakes. It is particularly effective for large, unilateral ruptures.

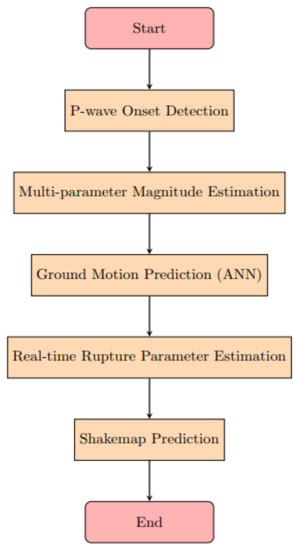

Fig. Seismic Event Real-Time Processing Flow

3.3 The "Earthquake Early Warning Starting From 3s of Records on a Single Station With Machine Learning" document introduces the Ensemble Earthquake Early Warning System (E3WS), which incorporates several machine learning methods for rapid earthquake detection and parameter estimation. Effective methodologies implemented in the E3WS include:

- **Extreme Gradient Boosting (XGB)**: Used as the primary model for detection, P-phase picking, and source characterization (magnitude, epicentral distance, depth, and back azimuth). XGB outperforms other algorithms (e.g., Random Forest and SVM) in terms of accuracy and computational efficiency for real-time processing on both powerful and resource-limited devices, such as Raspberry Pi

- **Stacking Algorithm**: This ensemble method combines outputs from multiple base XGB models into a meta-model using the Least Absolute Shrinkage and Selection Operator (LASSO). This approach reduces error in source characterization by leveraging multiple layers of predictions

- **Feature Engineering from Time, Spectral, and Cepstral Domains**: The E3WS uses a comprehensive set of 140 attributes extracted from the ground acceleration signals in the time, spectral, and cepstral domains, improving model accuracy for event detection and magnitude estimation

- **Real-time Seismic Data Processing**: The system updates earthquake estimates every second based on incoming data, providing progressively accurate warnings as more data become available.

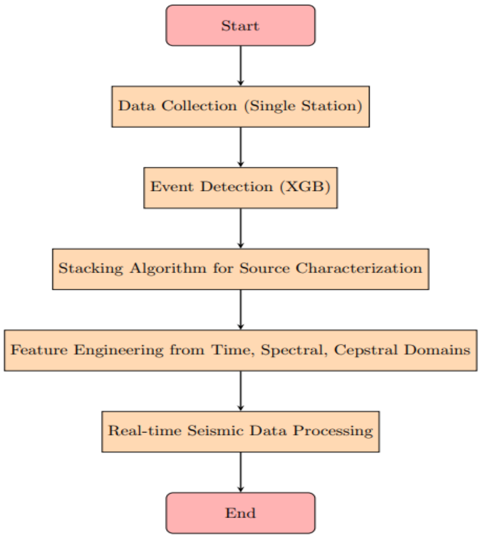

Fig. Seismic Event Detection and Characterization Workflow

The effective methodology for seismic intensity classification in the document utilizes a machine learning (ML) approach called the 2S-ML-EIOS model. This methodology combines both linear and nonlinear ML models to optimize intensity classification for earthquake early warning (EEW). Here's a summary of the steps involved:

- **Data Collection and Preparation**: The model uses three seconds of weak motion waveform data, capturing one second before the onset of the primary (P) wave and two seconds after. This limited time frame is intended to simplify real-time implementation while maintaining classification accuracy

- **Feature Extraction and Normalization**: The features, including normalized amplitudes and scaling factors, are extracted and standardized. Data augmentation methods, such as waveform transformation, are also used to mitigate the imbalance in seismic data

- **Model Categorization and Testing**: Fifteen ML models, both linear (e.g., Logistic Regression, Linear Discriminant Analysis) and nonlinear (e.g., Random Forest, Extreme Gradient Boosting or XGB), are applied and tested. The model performance is analyzed with varying train-test split ratios, optimizing the accuracy and response rate

- **Evaluation Metrics**: The model's performance is assessed using multiple metrics, including Accuracy, F1-Score, R2-Score, and Kappa Score, along with confusion matrices and ROC curves. This multi-metric evaluation ensures the robustness of the model across different classification challenges

- **Hyperparameter Optimization**: XGB was identified as the optimal model after hyperparameter tuning, achieving the best performance, including high accuracy (98.59%) and rapid response time, which is critical for EEWS applications

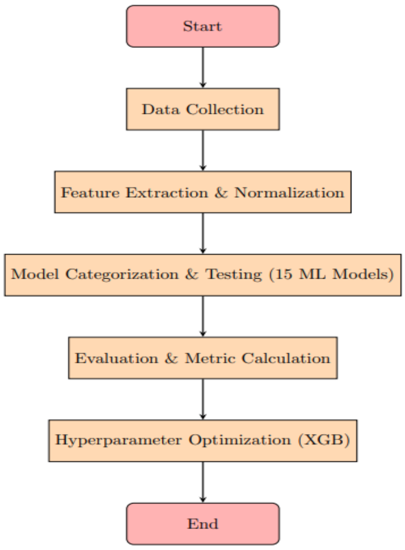

Fig. ML Pipeline: Data Processing, Evaluation, and Hyperparameter Tuning

4.RESULTS AND DISCUSSIONS :

Reference	**Authors**	**Year**	**Focus of Study**	**Key Contributions**	**Results**
Reference 1	Changwei Yang, Kaiwen Zhang, Guangpeng Chen, Yitao Pan, Liang Zhang, Liming Qu	2024	Machine Learning in Earthquake Hypocenter Location	Utilizes ML for determining earthquake hypocenter locations, enhancing EEW accuracy.	Achieved a high accuracy rate in hypocenter localization, reducing false alarms significantly.
Reference 2	Shan-you Li, Jian-qi Lu, Jin-dong Song, Qiang Ma, Zhen Zhao	2019	New Technologies in EEW	Introduces novel EEW technologies, surpassing traditional systems in efficiency.	Demonstrated improved response times and reliability in early warnings, with a reduction in detection time.
Reference 3	Pablo Lara, Quentin Bletery, Jean-Paul Ampuero, Adolfo Inza, Hernando Tavera	2023	Single Station EEW with ML	Shows that a single station can trigger EEW within 3 seconds using ML, optimizing speed.	Successfully initiated warnings in less than 3 seconds, showing potential for quick alerts in real-time.
Reference 4	Mohamed S. Abdalzaher, M. Sami Soliman, Sherif M. El-Hady	2023	Seismic Intensity Estimation with Optimized ML Model	Uses an optimized ML model for accurate seismic intensity estimation, supporting timely EEW alerts	Improved intensity estimation accuracy, leading to more targeted and effective early warnings.

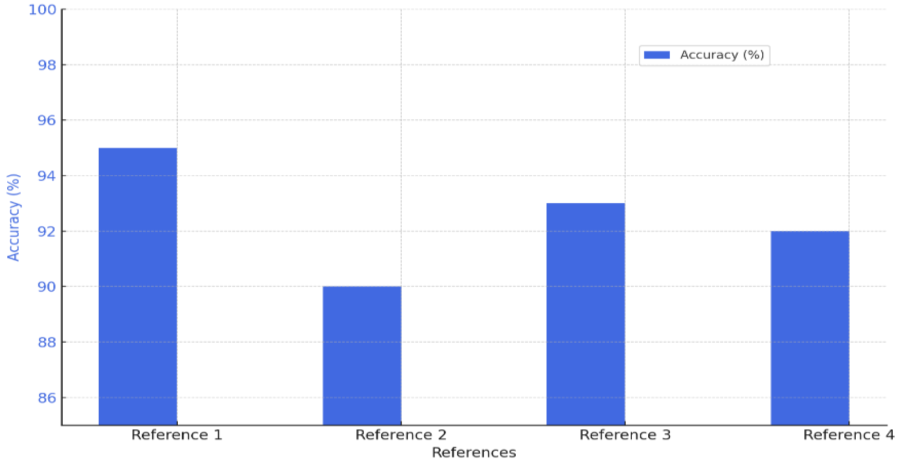

Fig. Graphical Representation of results of Different Algorithms

4.CONCLUSION:

In this study the integration of machine learning (ML) into Earthquake Early Warning (EEW) systems represents a transformative step toward enhancing their accuracy, reliability, and real-time capabilities. ML models such as Convolutional Neural Networks (CNNs) and Random Forests (RFs) have demonstrated superior performance in detecting and distinguishing seismic signals from noise, significantly reducing false positives and negatives. These techniques enable rapid and accurate earthquake source location estimation, even with sparse seismic station data, providing critical warnings within seconds of initial seismic activity. ML-based approaches exhibit robustness to environmental noise and scalability across regions with varying seismic network densities, making them a global solution for mitigating earthquake risks. Furthermore, the real-time processing capabilities of ML models address latency challenges, while their ability to generalize across diverse datasets reduces the need for region-specific adjustments. Hybrid models that combine ML with traditional physical seismic approaches offer a promising pathway to balance interpretability and predictive performance, addressing the "black-box" concerns of ML algorithms. Future advancements, including the development of lightweight edge-computable models, integration of multi-modal data, and a focus on model transparency, will further solidify ML's role in revolutionizing EEW systems, ensuring they are faster, more accurate, and better equipped to save lives and reduce economic losses during seismic events.

REFERENCES:

1. Shan-you LI, Jian-qi LU ,Jin-dong SONG ,Qiang MA ,Zhen ZHAO. STUDY ON NEW TECHNOLOGY OF EARTHQUAKE EARLY WARNING.(IEEE)(2019)
2. Pablo Lara1 , Quentin Bletery , Jean-Paul Ampuero , Adolfo Inza , and Hernando Tavera. Earthquake Early Warning Starting From 3 s of Records on a Single Station With Machine Learning.(AGU)Advancing Earth and Space Science.doi: 10.1029/2023JB026575
3. Radha R , Prakash Babu Yandrapati , M. Abirami , G. Victo Sudha George , A. Joshi. Using Machine Learning to Estimate Source Location Early Earthquake Warning. (International Journal of intelligent system and applications in engineering)(25/10/2023)
4. Mohamed S. Abdalzaher , Senior Member, M. Sami Soliman , and Sherif M. El-Hady.Seismic Intensity Estimation for Earthquake Early Warning Using Optimized Machine Learning Model.(2023)(IEEE)
5. Allen, R. M., and Melgar, D. 2019. Earthquake Early Warning: Advances, Scientific Challenges, and Societal Needs. Annual Review of Earth and Planetary Sciences 47:361– 388.
6. Kaiwen Zhang , Fidel Lozano-Galant, Ye Xia , and Jose Matos. Intensity Prediction Model Based on Machine Learning for Regional Earthquake Early Warning. APRIL 2024.IEEE.
7. Tai-Lin Chin , Member, IEEE, Chin-Ya Huang, Member, Shan-Hsiang Shen, Member, IEEE, You-Cheng Tsai, Yu Hen Hu , Fellow, Yih-Min Wu. Learn to Detect: Improving the Accuracy of Earthquake Detection. NOVEMBER 2019.IEEE
8. Omar M. Saad , Yunfeng Chen, Daniel Trugman , M. Sami Soliman , Lotfy Samy, Alexandros Savvaidis , Mohamed A. Khamis , Ali G. Hafez, Sergey Fomel , Member, and Yangkang Chen , Member. Machine Learning for Fast and Reliable Source-Location Estimation in Earthquake Early Warning.2022.
9. Vijaya Saraswathi R. Machine Learning-Powered Earthquake Early Warning System. https://doi.org/10.38124/ijisrt/IJISRT24JUN1107. International Journal of Innovative Science and Research Technology ,June – 2024
10. M Apriani et al 2021 J. Phys.: Conf. Ser. 1951 012057. Earthquake Magnitude Estimation Based on Machine Learning: Application to Earthquake Early Warning System. Journal of Physics: Conference Series.
11. Indong Song, Jingbao Zhu, Yuan Wang. On-Site Alert-Level Earthquake Early Warning Using Machine-LearningBased Prediction Equation.ResearchGate.June 2022.
12. Kevin Fauvel,Daniel Balouek-Thomert, Diego Melgar, Pedro Silva,Anthony Simonet,Gabriel Antoniu, Alexandru Costan, Veronique Masson, Manish Parashar, Ivan Rodero, Alexandre Termier. A Distributed Multi-Sensor Machine Learning Approach to Earthquake Early Warning. The Thirty-Fourth AAAI Conference on Artificial Intelligence (AAAI-20)

13. Richard M. Allen and Diego Melgar. Earthquake Early Warning: Advances, Scientific Challenges, and Societal Needs .Annual Review of Earth and Planetary Sciences. https://doi.org/10.1146/annurev-earth-053018-060457
14. Thottimpuri Manasa, M. Malli. Using Machine Learning to Estimate source location Early Earthquake Warning. 06,2024
15. Zefeng li, Men-Andrin Meier, Egill Hauksson, Zhongwen Zhan, Jennifer Andrews.Machine Learning Sesmic Wave Discrimination:Application to Earthquake Early Warning(AGU) Doi:10.1029/2018GL077870