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PROBABILISTIC NEURAL NETWORK FOR ANOMALY DETECTION IN MOUNT MERAPI'S SEISMIC ACTIVITY: PERFORMANCE EVALUATION AND INSIGHTS

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ABSTRACT

This research aims to evaluate the performance of the Probabilistic Neural Network (PNN) method for detecting seismic anomalies in the monitoring data of Mount Merapi. The study utilized a dataset comprising 368 records, representing both normal activity and increased seismic activity. The dataset was divided into 70% for training and 30% for testing. During the training phase, the PNN model achieved an accuracy of 87%, indicating its capability to identify patterns in the seismic data effectively. However, the testing phase, conducted to validate the model's generalization ability, yielded an accuracy of 64%. These results suggest that while the PNN method demonstrates promise in detecting seismic anomalies, its performance requires further improvement to enhance reliability in operational volcanic monitoring systems.
Keywords: *probabilistic neural network, seismic, performance*

INTRODUCTION

Volcanic activity monitoring is a critical component of disaster mitigation, particularly for highly active volcanoes that pose significant risks to surrounding communities. Seismic monitoring provides valuable insights into the subsurface dynamics of a volcano, including magma migration, pressure buildup, and structural changes within the volcanic edifice. These activities are often reflected in specific types of seismic events such as deep volcanic earthquakes (VA), shallow volcanic earthquakes (VB), low-frequency earthquakes (LF), and rockfall events. At Mount Merapi, one of Indonesia's most active and hazardous volcanoes, these seismic phenomena serve as key indicators of volcanic unrest. Monitoring these events is essential for identifying patterns of activity that may signal an impending eruption, enabling authorities to implement timely mitigation measures and safeguard affected populations. Advanced monitoring systems are therefore vital for interpreting seismic signals and improving early warning capabilities.

The Probabilistic Neural Network (PNN) is a machine learning technique known for its probabilistic approach to classification tasks. PNN is particularly well-suited for problems involving noisy or non-linear data, as it does not require extensive parameter tuning and operates based on simple mathematical principles. Its applications span a wide range of fields, including medical diagnosis, where it has been used to classify diseases, image recognition, and fault detection in engineering systems. In the context of natural disaster monitoring, PNN offers potential advantages in identifying subtle patterns within complex datasets. Its ability to generalize and accurately classify data makes it a promising candidate for anomaly detection in seismic monitoring, where early detection of critical changes can significantly enhance preparedness and response strategies.

This study aims to adopt the PNN method to evaluate its performance and effectiveness in detecting seismic anomalies associated with increased volcanic activity at Mount Merapi. Specifically, it investigates the model's ability to classify seismic data into normal and anomalous categories based on historical records of volcanic activity. By training the model on real-world data and validating its predictions through testing, this research seeks to assess the feasibility of PNN as a reliable tool for volcanic monitoring. Ultimately, the findings of this study are expected to contribute to the advancement of machine learning applications in geophysical research and the development of more robust early warning systems for volcanic hazards.

METHODS

Research Object

This study focuses on Mount Merapi, one of the most active and hazardous volcanoes in Indonesia. The research utilizes daily seismic monitoring data collected between 2009 and 2013. The dataset encompasses various types of earthquakes, including deep volcanic earthquakes (VA), shallow volcanic earthquakes (VB), multiphase earthquakes, rockfall events, and low-frequency earthquakes (LF). A total of 368 data points were compiled, which were divided into 70% for training the model and 30% for testing. These data provide a comprehensive representation of the seismic activity, enabling the model to identify patterns indicative of increased volcanic activity.

Development of the Anomaly Detection Model

The anomaly detection model for Mount Merapi's seismic data was developed using the Probabilistic Neural Network (PNN) through several stages. The first stage involved data collection and preprocessing. The seismic data were gathered from manual observations and instrumental measurements, focusing on key parameters of volcanic activity, such as the counts of VA, VB, multiphase earthquakes, rockfalls, and LF events. These data were converted into numerical formats that reflect the primary characteristics of volcanic activity.

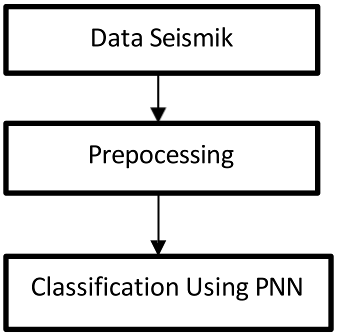

Figure 1. Probabilistic Neural Network Model

The PNN model employed in this study consists of three main layers: the input layer, the hidden layer, and the output layer. The input layer receives the numerical seismic data as input. The hidden layer processes this input using a probabilistic approach with a Gaussian kernel function to calculate the distribution of normal and anomalous data based on the training dataset. The output layer provides a binary decision, where "0" represents normal activity and "1" indicates an anomaly or increased activity.

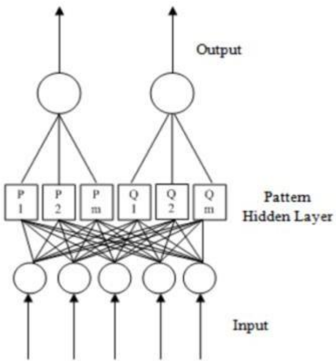

Figure 2. PNN Architecture

This architecture allows the PNN to classify seismic data effectively while distinguishing critical patterns that signal potential volcanic unrest.

During the testing phase, the stored initial weights, spread constants, and final weights were utilized to classify new, unseen data. The classification process's accuracy was evaluated using the following metrics:

- True Positive (TP): Test data of increased activity correctly identified as increased seismic activity.
- True Negative (TN): Test data of normal activity correctly identified as normal active conditions.
- False Positive (FP): Test data of normal activity incorrectly identified as increased seismic activity.
- False Negative (FN): Test data of increased activity incorrectly identified as normal active conditions.

These metrics provide a comprehensive evaluation of the model's performance in distinguishing between normal and anomalous seismic activity, ensuring the reliability of the anomaly detection system.

RESULTS AND DISCUSSION

Result

The training phase aimed to optimize the Probabilistic Neural Network (PNN) model in identifying anomalies in Mount Merapi's seismic activity data. A total of 258 datasets, representing 70% of the total data, were used for training. These datasets included five seismic parameters: deep volcanic earthquakes (VA), shallow volcanic earthquakes (VB), multiphase earthquakes, rockfall events, and low-frequency earthquakes (LF). The objective was to enable the model to recognize patterns that distinguish normal seismic activity from anomalies associated with increased volcanic activity.

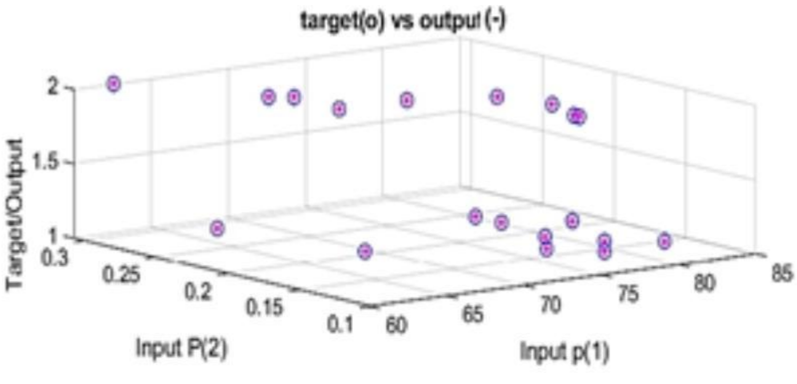

Figure 3. Graph of Dataset Testing Results Using PNN

During the training phase, the PNN model achieved an accuracy of 87%, demonstrating its capability to learn and classify seismic data effectively. This performance indicates that the model was able to generalize the relationships between input features (seismic parameters) and output classes (normal vs. anomalous activity) with a high level of precision. The Gaussian kernel function in the hidden layer facilitated the probabilistic computation, allowing the model to differentiate between normal and anomalous data distributions accurately.

Despite the high accuracy, some classification errors occurred due to overlapping characteristics in the data. For example, low-magnitude seismic fluctuations during normal activity might share similarities with the initial stages of increased activity. These challenges highlight the complexity of seismic data and the need for further refinement of the model to handle edge cases. However, the results from the training phase provide a strong foundation for evaluating the model's effectiveness during the testing phase.

The results from the training phase were employed to evaluate the model's detection capabilities on new, unseen data. During this testing phase, 110 datasets were used, representing both normal seismic activity and increased seismic activity of Mount Merapi. These datasets were selected to validate the Probabilistic Neural Network (PNN) model's ability to classify and detect seismic anomalies accurately.

The testing results revealed that the PNN model achieved an accuracy of 64% in detecting seismic activity anomalies. Although this accuracy is lower than the 87% achieved during the training phase, it still provides a reasonably good indication of the model's capability in identifying abnormal patterns in seismic data. The reduction in accuracy during testing can be attributed to several factors, such as increased complexity in the testing dataset or discrepancies between training and testing data conditions. These challenges underscore the importance of refining the model to handle diverse and complex scenarios more effectively.

The evaluation of the model’s performance on the 110 testing datasets yielded the following classification outcomes:

- True Positive (TP): 40 data points representing increased seismic activity were correctly identified as anomalous.
- True Negative (TN): 30 data points representing normal activity were correctly classified as normal.
- False Positive (FP): 20 data points representing normal activity were incorrectly classified as increased activity.
- False Negative (FN): 20 data points representing increased activity were incorrectly classified as normal.

These results indicate that the model successfully classified 70 out of 110 data points correctly, aligning with the calculated accuracy. Despite the observed limitations, the findings highlight the PNN model's potential for seismic anomaly detection and provide a foundation for further improvements. Enhancements such as incorporating more comprehensive datasets and fine-tuning model parameters could significantly increase the accuracy and reliability of this anomaly detection system for monitoring Mount Merapi's activity.

Discussion

The testing results of the Probabilistic Neural Network (PNN) model in detecting seismic activity anomalies at Mount Merapi demonstrate promising performance, albeit with notable limitations. Historical seismic activity data, including variables such as deep volcanic earthquakes (VA), shallow volcanic earthquakes (VB), multiphase earthquakes, avalanche data, and low-frequency earthquakes (LF), were utilized to validate the model. The model was evaluated against critical pre-eruption conditions in 2006 and 2010, focusing on its ability to detect volcanic activity patterns leading to eruptions. During the 2006 pre-eruption period, the model successfully identified a surge in volcanic activity as anomalies, particularly with increased VB and multiphase earthquakes, aligning with field observations of magmatic pressure accumulation.

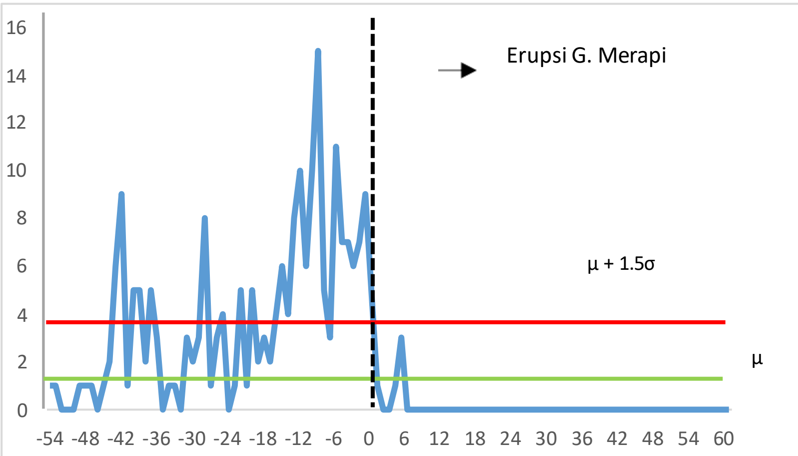

Figure 4. Visualization of PNN Testing Results on Mount Merapi 2010 Eruption Data

However, the 2010 eruption dataset presented more complex results. The model detected anomalies indicating increased activity three weeks before the eruption, showcasing high sensitivity to activity pattern changes. Yet, this early detection highlights a limitation in distinguishing normal fluctuations from truly critical patterns. Classification errors were significant, with normal volcanic activity often misclassified as anomalies, reducing the overall accuracy. These findings suggest that while PNN can identify fundamental volcanic activity patterns, its robustness against dynamic data variations is limited. Further refinement, such as richer datasets and the integration of complementary methods, is necessary to enhance its reliability and accuracy for operational anomaly detection.

CONCLUSION

The study highlights the potential of the Probabilistic Neural Network (PNN) method in detecting seismic anomalies on Mount Merapi, particularly in identifying volcanic activity surges leading to eruptions. The model achieved high accuracy in analyzing shallow volcanic and multiphase earthquakes before the 2006 eruption and demonstrated strong sensitivity by detecting anomalies up to three weeks before the 2010 eruption, proving its capability for early disaster warnings.

However, the model has limitations, such as high false positive rates, where normal volcanic activity is often misclassified as anomalies, and difficulties distinguishing normal fluctuations from critical conditions. Enhancements, including richer datasets and integration with other learning methods, are needed to improve reliability and manage complex data variations. While promising, further development is essential for effective implementation in volcanic early warning systems.

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