Nuclear Activity Detecting Methodology Using Artificial Intelligence

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1. Introduction

Artificial intelligence (AI) technology is undergoing rapid development in the modern world, and these advances offer new possibilities for international politics and security. AI technology enables computer systems to mimic human intelligent behavior, including learning, reasoning, problem-solving, natural language processing, and more. Recent advances have enabled AI to revolutionize various fields, with particular strengths in areas requiring large amounts of data processing.

Advances in AI technology are also opening up new possibilities in the detection field. AI's data processing far exceeds the speed and volume of human data processing, and with suitable models, it can improve the accuracy of data [1] analysis. As a result, it can completely replace existing simple tasks, support more sophisticated analysis that can be compared to human analysis, or expand into previously unexplored areas.

AI technology opens up new possibilities for nuclear activity detection. Analyzing large amounts of data and recognizing patterns can detect nuclear activity more accurately and quickly than traditional detection methods. This enables countries and international organizations to develop more effective response strategies. AI models can be trained using various data sources related to nuclear activity (satellite imagery, sensor data, social media), which allows for more sophisticated detection. To explain this, we will introduce the leading deep learning models that can be used for nuclear activity detection, their advantages and disadvantages, and how they can be used. Then, we will analyze precedents of how AI is used in other industries and research and suggest ways to incorporate AI into existing nuclear activity detection methods.

2. Existing Methodology for Detecting North Korean Nuclear Activities

2.1 Detection with seismic waves

Nuclear weapon testing generates seismic waves [2]. Therefore, it is possible to determine the location and magnitude of nuclear weapon tests by analyzing seismic waves [3]. To this end, the Korea Geological Institute operates observatories nationwide and analyzes the causes of earthquakes. Seismic waves generated by North Korea's third and fourth nuclear weapon tests were observed at the Wonju Seismic Observatory [4]. However, the test in North Korea cannot be conclusively attributed to a North Korean nuclear test because it can be confused with an artificial earthquake caused by a simple construction site explosion or a conventional weapon, as the distance is more than 200 kilometers away. The waveform can be analyzed to determine this to distinguish the nuclear weapon test. Also, even if a nuclear explosion occurs underground, the shock wave is extreme and causes the surface to vibrate. The vibrations caused by the frequency of the shock wave propagate in the form of sound waves, called airborne sound waves. These are low-frequency sound waves of 20 Hz or less and cannot be heard by humans. In the case of a nuclear weapon test, it is often used to complement the analysis of seismic data [5].

2.2 Detection with nuclide analysis

Nuclear weapon tests can be confirmed by capturing inert gases that leak out through cracks in the rock to the outside. Nuclear weapon tests produce a variety of radioactive isotopes, of which inert gases such as xenon and krypton are emitted, which can be evidence of the test because they can travel up to hundreds of kilometers from the test site and are distributed in the air according to their half-life [5,6]. If the amount of capture is sufficient, the ratio of isotopes such as xenon and krypton can also be measured to determine whether the material used in the test is uranium or plutonium [5,6].

2.3 Detection with satellite imagery

It is a standard detection method that can directly capture signs of nuclear weapon test preparation or changes in the situation before and after the test. It is analyzed by using the difference between the before and after images of the presumed nuclear weapon test site using time change analysis of optical images [7]. A blog specializing in North Korea called 38North reported that satellite imagery showed activities near the Punggye-ri nuclear test site even before North Korea conducted its fifth nuclear test [8].

3. Application in Nuclear Activity Detection

Artificial intelligence can play several roles in detecting nuclear activity, maximizing the efficiency of existing detection processes, and supporting or even replacing human resources. First, maximizing efficiency involves processing large amounts of data. AI can detect and collect data such as satellite imagery, sensor data, and communication signals in real-time and analyze and process the data. This exceeds the amount of data humans can process, and the accuracy is similar to that of humans [9].
On the other hand, AI is still subject to error [10], so human experts can supplement the existing accuracy of nuclear activity detection based on AI-analyzed data. This will support the human workforce and produce more precise results.

3.1 A Mixed-Method Proposal for Traffic Hotspots Mapping in African Cities using Raw Satellite Imagery [11]

3.1.1. Research Overview

It leverages raw satellite data and open data sources to provide a low-cost and labor-intensive method for analyzing traffic accident data. The study also extends the research to predict and map road accidents with various geographic variations, such as using New York as a data source to predict African cities.

3.1.2. Research result

This study proposes a novel framework for predicting public safety by treating city-scale satellite maps as a series of images. Official police reports collected from police departments were used to generate high-resolution satellite image data [12] labeled with safety scores calculated based on the number and severity/category of incidents. We evaluated the accuracy of road safety prediction using models trained on four U.S. cities-New York, Chicago, San Francisco, and Denver-and found that the best-performing models were up to 79% accurate on the raw satellite images. We also found that models trained on data collected in one city can be effectively reused in other cities.

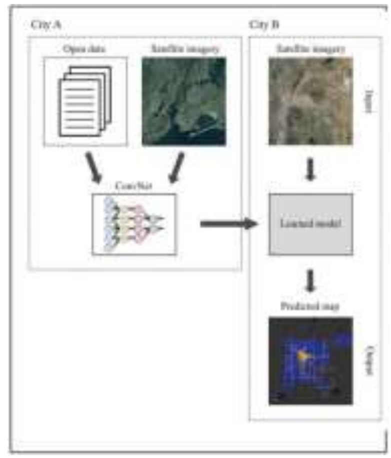

Fig. 2. Convolutional neural network

3.1.3 Applications

It can only sometimes rely on high-resolution satellite data when detecting nuclear activity. In particular, satellite data from North Korea is often of low quality, so mapping specific spots using raw satellite data can be a great advantage. Also, the weighted severity index used in this study is limited to the risk areas of automobile accidents. However, the index is extended to nuclear activity detection. In that case, it is expected to be utilized in various fields, such as identifying logistics concentrations and suspected nuclear activity.

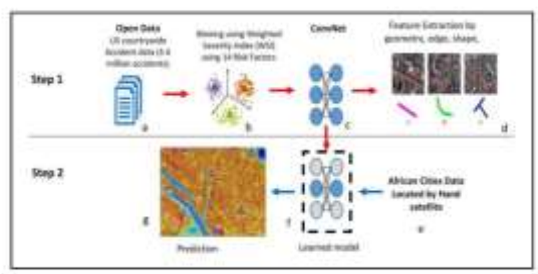

Fig. 3. Methodological order

In addition, the study's machine learning method successfully mapped African areas by learning New York satellite images. The analysis was successful despite the learning base and target being completely different, such as building styles and road conditions. Suppose the research's methodology is used to map areas in Korea and analyze nuclear activities in neighboring countries. In that case, progress is expected in detecting nuclear activities in neighboring countries, which has been difficult.
3.2 Feasibility and accuracy of extracting room temperature information from mid-infrared sensor satellite imagery [13].

3.2.1 Research Overview

Although it was initially argued that the measurement of temperature near room temperature using mid-infrared radiation lacks objectivity, the possibility of measuring temperature near room temperature using mid-infrared sensors has recently been proposed. In this paper, we examine the feasibility and accuracy of extracting room temperature information from satellite images using results from actual operational satellites.

3.2.2 Research result

Infrared imagery from modern operational infrared satellites exhibits characteristics different from those of conventional infrared cameras. Unlike ground-based infrared cameras, which use only a detector to observe objects directly, they are largely unaffected by solar reflections. In the case of atmospheric absorption, the thickness of the atmospheric layer remains almost constant for satellite imaging. The uniform atmospheric layer of less than 10 kilometers is observed vertically from space at about 500 kilometers or more from the surface. Therefore, it is safe to assume that the atmospheric absorption is constant. However, the uncertainty in the radiation coefficient due to material properties cannot be resolved due to the non-contact nature of the thermometer. This problem is unavoidable because it is impossible to determine a material's properties based on image information alone.

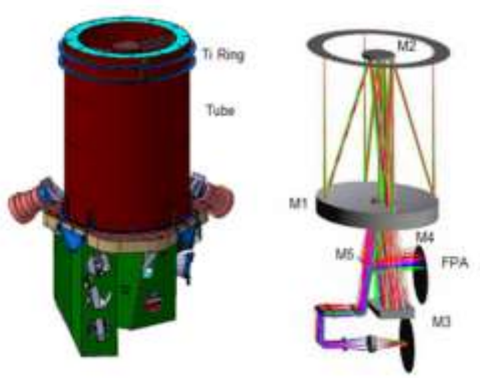

Fig. 4. Mid Wave InfraRed(MWIR) Sensor

3.2.3 Applications

Using artificial intelligence and big data, nuclear activity can be detected through mid-infrared satellite data. Artificial intelligence using satellite data is currently limited to object detection, pre-processing, and time series analysis. However, it is possible to develop algorithms that compare the temperature of active and inactive periods by training a large amount of data from nuclear facilities to compare surface temperatures. Thermal imaging big data can verify daily temperatures and provide meaningful grounds for suspecting nuclear activity when the data is out of the average temperature range. Nevertheless, there are limitations due to various technical limitations that can lead to low accuracy, which are currently identified as follows.

Resolution issues: The images have a pixel resolution of 50 meters, which can confuse a small facility's temperature with the surrounding terrain's temperature. Higher-resolution imagery is necessary to address this problem.

Seasonal and weather variations: Variables result from seasonal and monthly temperature differences and weather changes. For example, snow accumulation and ice formation on the ground in winter can cause problems. Regression and weather patterns have to be learned and augmented with long-term data to address this problem.

Whether the building is air-conditioned: It is difficult to determine whether a nuclear facility is air-conditioned. Air conditioning is a technology that moves heat from the inside of a facility to the outside, so the better the air conditioning, the more heat will escape from the inside. Nonetheless, since we have yet to learn the detailed air conditioning design in North Korean nuclear facilities, this limitation is difficult to overcome without additional information.

Fig. 5. Satellite imagery of the Forsmark nuclear power plant area in Sweden, measured by mid-infrared sensor

3.3 Application of Artificial Intelligence in Predicting Earthquakes: State-of-the-Art and Future Challenges[14]

3.3.1 Research Overview

Earthquake monitoring requires more efficient and powerful tools to handle higher data volumes. The collected data is also conceptually simple, and the large amount of labeled data lends itself to data analysis using artificial intelligence. Based on current

detection methods, analyzing seismic signals and seismic waves is a challenging problem in earthquake monitoring. Noisy data and microseismic monitoring are not easily discriminated against, so higher efficiency and accuracy must be pursued.
To address these issues, this study presents a global deep-learning model that simultaneously performs seismic detection and seismic phase peaking (measuring the arrival time of a specific waveform within a seismic signal).
By introducing an attentional mechanism to combine seismic phase picking and phase information, the model's detection and seismic wave discrimination performance is improved by combining the entire waveform and phase information of the seismic signal, which provides higher accuracy and efficiency. The data and machine learning methods used in the study were as follows.
Data: We recorded five weeks of continuous data during the 2000 Tottori, Japan earthquake [15]. However, this research used only a fraction of the seismic stations (less than a third); twice as many earthquakes could be detected and located.
Network architecture: A very deep encoder and three separate decoders consisting of a 1D convolutional, bidirectional, and undirected Long Short Term Memory, Network-in-Network, residual connectivity, feed-forward layer, transformer, and self-attention layer.
Training: Trained using the ADAM optimization algorithm and data augmentation. The training was completed on the TensorFlow framework using four parallel Tesla-V100 GPUs.

3.3.2 Research result

The deep learning model developed in this study outperformed existing deep learning and traditional phase picking and detection algorithms. In addition to selecting P and S phases with a precision close to manual picking by human analysts, it could detect and characterize more events and smaller events with higher efficiency and sensitivity.

The model accurately identifies seismic signals and phases through two attention mechanisms, one global and one local. These mechanisms allow the network to focus on specific parts of the input time series to provide higher accuracy. The model was applied to continuous waveforms recorded in Japan to localize detected events, demonstrating that it can be generalized to other regions.

The correlation between the noise level and the prediction variation helped reduce the false positives. For instance, longer layers could be used to analyze the probability of detection to eliminate false positives due to cultural noise recorded in West Texas. In conclusion, the new model using deep learning provides high efficiency and accuracy in seismic signal detection and phase picking, representing a significant advance compared to traditional methods. The model is beneficial in microseismic monitoring and has been demonstrated to work effectively in various geographic and structural settings.

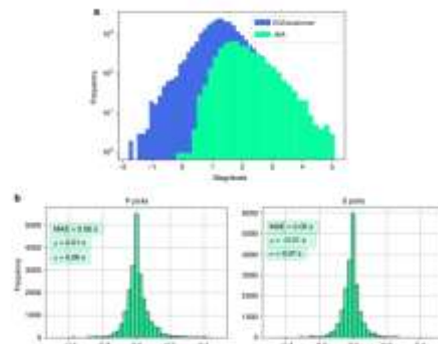

Fig. 6. Distributions of frequency magnitude of earthquakes and picking errors

3.3.3 Applications

Seismic waves from nuclear weapon tests produce different waveforms from general seismic waves [15]. Figure 5 shows the difference in waveforms between seismic waves generated by the tests and naturally occurring seismic waves.

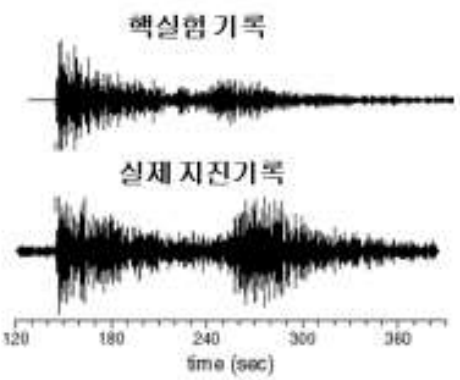

Fig. 7. Comparing seismic waves from nuclear tests and natural earthquakes [16]

Seismic waves can also be generated by microscopic elements such as vehicles and footsteps, which can interfere with the tracking of seismic waves [17].
On the other hand, this study utilizes deep learning models' high sensitivity and accuracy to distinguish between P and S waves and improve detection accuracy. These mechanisms can be applied to nuclear activity detection to highlight and identify specific features of the waveforms caused by nuclear

explosions. Thus, the deep learning model used in this study could analyze the seismic waves and distinguish whether a nuclear weapon test or a natural earthquake caused them. In addition, the global and local attention mechanisms used in the study provided higher accuracy by focusing on specific parts of the seismic waveform. By training a deep learning model on continuous waveforms recorded in Japan and applying it to seismic wave analysis in Texas, the researchers demonstrated that the model can be generalized to different regions.

Hence, it is expected to work effectively in various geographical and structural settings for nuclear activity detection in Korea. Moreover, this research can help reduce false positives by analyzing the noise level and prediction changes. For instance, noise caused by mixing with seismic waves from other regions during the detection process can be removed to improve the accuracy of nuclear activity detection.

3.4 Combining scenario-based and conversation models[18]

3.4.1 Research Overview

Chatbots are used in various fields, including contact centers, psychological counseling, surveys, and more. Chatbots are implemented in two ways: conversational model and scenario-based. A hybrid chatbot was proposed to maximize the advantages of both methods and compensate for their disadvantages (Design of a chatbot to support victims of sexual violence, 2021). The researchers asked survey participants to be all women to develop the hybrid chatbot. To present a sexual assault situation, ask the chatbot questions from the victim's perspective and analyze the data. Through this process, the researchers collected the questions that sexual assault victims would ask the chatbot and analyzed them to derive guidelines for designing a hybrid chatbot.

3.4.2 Research result

This study presents the concept of a hybrid chatbot to help victims of sexual violence and derives guidelines for designing one. To achieve the research objectives, researchers collected questions that sexual assault victims could ask the chatbot and analyzed the content and characteristics of the questions.

The researcher analyzed the characteristics of the questions and found that 30% lacked contextual information, and 10% were asked with keywords rather than complete sentences. This suggests that victims need to improve how they specify context when asking the chatbot questions.

3.4.3 Applications

Building a chatbot that generates scenarios related to denuclearization may require insufficient conditions or data provided by the user. This research believes that after designing a basic scenario, designing the chatbot to provide context that the user misses will help derive the expected scenario related to North Korea.

4. Conclusion

AI is used in various industries and research, such as thermal camera analysis and facial recognition during the coronavirus outbreak, public opinion analysis of voting processes and politics, and seasonal flood prediction. Nuclear activity detection fields should follow suit as various countries and organizations overcome disasters and achieve research results. It will be necessary to actively utilize AI as it can process information analysis that takes a long time for humans in a short period.

This study analyzes how AI can detect nuclear activities through four papers. Each paper describes how AI can be utilized in satellite imagery, mid-infrared, hybrid chatbots, and seismic wave analysis between man-made and naturally occurring earthquakes and derived various approaches. Based on the methodology of each study, we propose a method that can be applied to nuclear activity detection.

Nevertheless, there are some limitations to this study. There is very little publicly available information on AI research in nuclear activity detection, so the study was limited to introducing research results from other fields. Although we have introduced various AI-related papers and their applications in nuclear activity detection, the proposed applications are as simple as possible. Technical problems still need to be solved, and it is doubtful that each research can be valuable for nuclear activity detection as they are in different fields. Also, AI's limitations are clear. For one thing, AI requires vast amounts of data to be reliable, and even then, algorithms can be unreliable and fallible. Errors in AI systems for monitoring and detecting nuclear activities can have serious consequences. Therefore, the results of data analysis using AI should be taken with a grain of salt.

Finally, there are security and privacy concerns. AI systems used to collect and analyze nuclear-related information may have access to sensitive information, and inappropriate external access could lead to worse negative consequences than before the use of AI.

Therefore, further research should include an in-depth analysis of how research results from other fields can be applied to nuclear activity detection and a discussion of how to address each of the shortcomings. In addition, since the components of the AI models in the existing studies are unsuitable for nuclear activity detection, further research is needed on these components. Besides, it should be conducted to evaluate the effectiveness of the developed AI models in the field of nuclear activity detection.

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