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### Application of MIMO Neural Networks in Wireless Signal Monitoring

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#### Abstract

The integration of IoT technology in wireless signal monitoring holds substantial potential for both military and civilian applications, including signal reconnaissance, anti-jamming, and device identification. Traditional modulation recognition methods, based on likelihood and feature extraction, face limitations in computational complexity and reliance on expert knowledge. In contrast, ML and DL models like Support Vector Machines (SVM) and Convolutional Neural Networks (CNN) offer superior performance without manual feature extraction. We propose

a MIMO neural network model for automatic modulation classification and direction of arrival (DOA) estimation. The system, detailed through functional block diagrams, includes components such as antenna arrays, analog preprocessing units, radio signal receivers, digital signal processors, MIMO neural networks, data processors, and display units. This model simultaneously performs modulation classification and DOA estimation, providing an efficient and cost-effective solution for real-time signal monitoring.

**Keywords:** IoT, Sensors, Wireless Monitoring

#### 1. Introduction

In the context of the rapid development of information and communication technology, the monitoring and identification of wireless signals play an essential role in both the military and civilian sectors. Applications such as signal reconnaissance, anti-jamming, and signal identification require modern systems to ensure high efficiency and accuracy. The development of modern communication systems and military electronic warfare systems has made signal identification increasingly complex, especially when dealing with multiple signals coexisting in the same space and time<sup>[2]</sup>.

Therefore, digital transformation in radio monitoring is a critical step in building automated systems for identifying radio signal sources. IoT technology, with its ability to connect and collect data from sensors, provides a powerful platform for continuously and accurately monitoring wireless signals.

Recent research has demonstrated that ML and DL models have significant potential in signal recognition. Traditional methods based on hypothesis testing and feature extraction, while effective, face limitations due to computational complexity and reliance on expert knowledge. In contrast, ML and DL algorithms, such as CNNs, have shown superior performance in many fields without requiring manual feature extraction<sup>[3]</sup>.

In this paper, we propose a MIMO neural network model to address two main issues: Automatic modulation classification and DOA estimation of radio emissions. This model promises high efficiency in monitoring and identifying wireless signals while minimizing costs and hardware resources. The paper also discusses the challenges of implementing IoT technology, including investment costs, cybersecurity, and the skill requirements of operators<sup>[1, 4]</sup>.

Through this, the authors aim to contribute to the development of advanced solutions in wireless signal monitoring, opening up new opportunities for both military and civilian applications.

#### 2. Two Main Problems in Wireless Signal Monitoring Systems

Wireless signal monitoring systems focus on two main problems: Analyzing and classifying signal modulation and estimating the DOA of the radio emissions.

The first problem is the analysis and classification of signal modulation. This is a crucial task. In the context of wireless technology, signal modulation can involve various techniques such as amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), and more complex modulation schemes like QAM or PSK. The goal here is to accurately identify the modulation type of the signal to understand the information it carries. However, the biggest challenge in

modulation classification is the often complex transmission environment with the presence of noise and signal fading, making analysis and classification more difficult<sup>[5]</sup>. The second problem is the estimation of the DOA of the radio emissions. This is the process of determining the direction from which the wireless signal arrives at the monitoring system. DOA estimation has diverse applications, from locating the source of the signal in tracking systems to improving target detection capabilities in military applications. The challenge in DOA estimation is that the system needs to analyze data from multiple antennas to accurately calculate the angle of arrival of the signal while also addressing issues such as noise and reflections that can distort the results.

### 3. Application of AI Algorithms in Wireless Signal Monitoring

To address the two main problems in wireless signal monitoring, the application of AI algorithms, particularly ML and DL, is becoming a significant research trend. Modern AI algorithms can provide effective solutions to complex issues in wireless signal monitoring. In the field of machine learning, models such as SVM have been used to classify different modulation types based on features extracted from the signal. SVM can achieve high accuracy in classification tasks but still faces challenges related to computational complexity and the need for expert intervention to extract features<sup>[6]</sup>. In contrast, deep learning, a subset of machine learning with models like CNN, has demonstrated superior performance

across various fields, including signal modulation classification. CNNs can automatically learn features from raw data without the need for manual feature extraction, reducing dependence on expert knowledge and enhancing classification efficiency.

However, modern AI algorithms also face several challenges. First is computational complexity, as deep learning models require powerful and efficient hardware to process large and complex datasets. The second is the flexibility of AI models, as algorithms must be adaptable to diverse conditions in the real-world environment of wireless signals. Third, the hardware resources required for AI algorithms are often very costly, which can increase the deployment costs of monitoring systems. Finally, computation time is a critical factor, as signal monitoring systems need to operate in real-time to analyze and classify signals as soon as they are received.

### 4. Wireless Signal Monitoring System Using MIMO Neural Networks

To address the difficulties and challenges in wireless signal monitoring, we propose the use of a MIMO neural network model. This model aims to focus on two main issues: The analysis and classification of signal modulation and the estimation of the DOA of radio emissions<sup>[7]</sup>.

The proposed wireless signal monitoring system using MIMO neural networks is described through a functional block diagram, as shown in Fig 1. It includes the following main components:

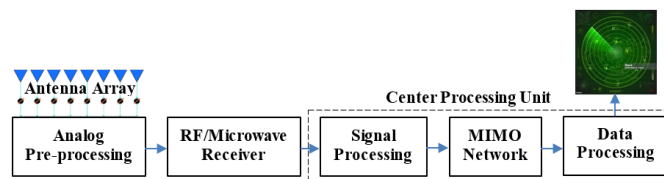


Fig 1: Wireless Signal Monitoring System Using MIMO Neural Networks

#### 4.1 Antenna Array

The antenna array is a crucial electromagnetic sensing module in the wireless signal monitoring system. The primary function of the antenna array is to convert electromagnetic waves in free space into electrical signals within the transmission system. By using an antenna array, we can perform tasks such as spatial filtering and frequency filtering, thereby determining the direction of the signal, also known as DOA estimation.

There are various antenna array configurations, each with its own characteristics and applications. Below are the main antenna array configurations, along with their advantages and disadvantages:

- **Linear Array:** This is one of the simplest configurations, where antennas are arranged in a straight line. This configuration reduces the number of antenna elements and can create a large aperture in two-dimensional space. However, it can only estimate the DOA angle horizontally or vertically from  $-90^\circ$  to  $+90^\circ$ , so it cannot determine both directions simultaneously.
- **Circular Array:** In this configuration, antennas are arranged in a circle. This allows for DOA estimation both horizontally and vertically, with the capability to cover  $360^\circ$  azimuth and  $180^\circ$  elevation. However, due

to its small aperture, the angle estimation accuracy and resolution of this array type are limited. Additionally, circular arrays often have higher production costs due to the need for more antenna elements.

- **Rectangular Array:** This configuration combines linear and circular arrays, with antennas arranged in a rectangular grid. This configuration can estimate DOA in both spatial dimensions, improving angle estimation accuracy compared to circular arrays. However, rectangular arrays also have limitations, including a restricted aperture and high production costs due to the large number of elements.

Besides these three main configurations, other antenna array configurations, such as spherical arrays or dome arrays, also exist. These configurations will be studied to find the optimal solution for the wireless signal monitoring system, ensuring high accuracy in DOA estimation while minimizing production costs.

Researching and selecting a suitable antenna array configuration is a critical part of the task, aiming to find the most optimal configuration for accurately determining the direction of wireless signals while considering cost and production efficiency.

#### 4.2 Analog Signal Processor

The analog signal processor is a crucial component in the wireless signal monitoring system, responsible for preparing signals from the antenna array before they are converted to digital form for further processing. This block mainly includes high-frequency elements and related controllers.

Specifically, each antenna element in the array is connected to a quadrature channel, also known as an I/Q (in-phase/quadrature) channel. This channel includes the following key components: Filters, amplifiers, mixers, and phase shifters.

- **Filters:** The function of the filter is to remove unwanted frequencies from the received signal, ensuring that only the necessary frequency components are retained.
- **Amplifiers:** The amplifier's task is to increase the signal strength to a suitable level for subsequent processing steps.
- **Mixers:** The mixer combines the received signal with a local oscillator signal to convert the signal frequency to an intermediate level, preparing it for the next processing stages.
- **Phase Shifters:** The phase shifter adjusts the phase of the signal to ensure that all signal channels are time-synchronized, which is crucial for maintaining synchronization among signals from different antenna elements.
- **Local Oscillator:** The local oscillator is a common component for all channels, generating the necessary oscillation frequency for the signal mixing process.

To ensure effective processing, the signal channels must meet several key requirements. Specifically, these channels need to be uniform in terms of time delay and designed to minimize signal distortion. Maintaining time synchronization among the channels and reducing signal distortion are vital to ensuring the quality and accuracy of the signal before it is converted to digital form.

#### 4.3 Radio Signal Receiver

The radio signal receiver plays a crucial role in the wireless signal monitoring system, being responsible for receiving and converting signals from analog to digital form for subsequent processing steps in the system.

The main functions of the radio signal receiver include:

- **Receiving Signals from the Antenna Array:** The receiver collects signals from the elements of the antenna array, where the signals have been amplified and phase-adjusted but remain in analog form.
- **Preliminary Signal Processing:** The received signal undergoes further preliminary processing. At this stage, the signal can be filtered, amplified, and noise-reduced to ensure the highest quality signal.
- **Converting Signals from Analog to Digital Form:** After preliminary processing, the analog signal is converted into digital form.
- **Providing Digital Data:** The output of the signal receiver is digital data that is transmitted to the digital signal processor. This data will be used in subsequent processing steps, including signal analysis, modulation classification, and DOA estimation.

#### 4.4 Digital Signal Processor

The digital signal processor is a crucial component in the wireless signal monitoring system, responsible for

efficiently and rapidly processing digital signals. This component is designed using FPGA chips, which provide high-speed processing capabilities and flexibility.

The processing steps in the digital signal processor are as follows:

- **Temporary Storage:** The digital signal, after being converted from analog form, is temporarily stored in the processor. This step ensures that the signal is ready for immediate processing.
- **Signal Formatting:** The digital signal is formatted according to a predefined structure. This includes reformatting the data to meet the requirements for subsequent processing stages.
- **Algorithm Execution:** The digital signal processor performs a series of algorithms for real-time signal processing. These algorithms may include filtering, Fourier transforms, and other signal processing techniques to optimize signal quality and effectiveness.
- **Transmitting Signal to the MIMO Neural Network:** After processing, the digital signal is transmitted to the MIMO neural network. This step is crucial for the modulation classification and DOA estimation processes.

The digital signal processor is essential for ensuring that signals are processed efficiently and quickly, which supports the subsequent steps of signal analysis and classification in the wireless signal monitoring system. Using high-speed FPGA chips enhances the system's performance and flexibility, ensuring that all signals are processed in a timely manner.

#### 4.5 MIMO Neural Network

The MIMO neural network is the core software module in the wireless signal monitoring system, responsible for executing two main functions:

- **Modulation Classification:** The MIMO neural network utilizes deep learning algorithms to analyze and classify the modulation schemes of wireless signals. This process helps to identify specific signal characteristics and determine the type of modulation used, such as AM, FM, PSK, QAM, and others.
- **Direction of Arrival Estimation:** In addition to modulation classification, the MIMO neural network performs DOA estimation for the source of the radio emissions. This involves determining the direction from which the signal is coming and providing important information about the location of the signal source.

Benefits of the MIMO Neural Network:

- **High Accuracy:** By leveraging deep learning algorithms, the MIMO neural network achieves high accuracy in both modulation classification and DOA estimation tasks.
- **Real-Time Processing:** The MIMO neural network is designed to process data quickly and efficiently, meeting the real-time processing requirements of the wireless signal monitoring system.
- **Versatility:** The network is capable of handling diverse types of signals and environmental conditions, enhancing the system's flexibility and broadening its range of applications.
- **Enhanced Performance:** As a critical component of the wireless signal monitoring system, the MIMO

neural network plays a significant role in precise and effective signal classification and DOA estimation. Its deep learning capabilities and advanced data analysis techniques improve the system's performance and reliability.

**4.6 Data Processor**

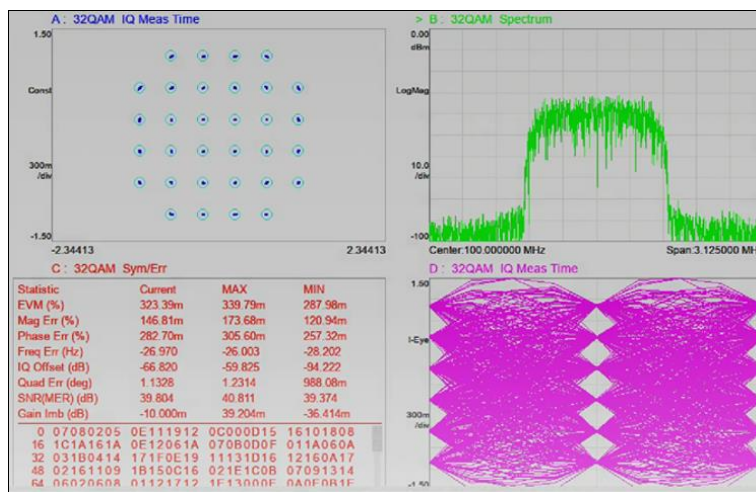
After collecting and processing key parameters of the wireless signal, such as the frequency spectrum, signal parameters, modulation type, and DOA, this information is forwarded to the data processor. The data processor performs the following steps to analyze and utilize this information:

- **Data Collection:** Assuming the antenna array consists of M elements, there will be M signal channels collected. When the presence of a wireless signal is detected by a trigger pulse, the signal processor synchronizes and collects signal samples from M channels.
- **Data Storage:** The collected signal samples are stored in RAM with a pre-designed signal window size, such as a window length of N. This results in a matrix of size  $M \times N$ .
- **Digital Processing:** In the digital processor, the time-domain signal can be converted into the frequency domain using the Fourier transform or into a time-frequency spectrum using the Short-Time Fourier transform.
- **Input to CNN:** The CNN can accept input from various domains, such as the time domain, frequency domain,

time-frequency spectrum, constellation diagram, or a combination of these forms of data.

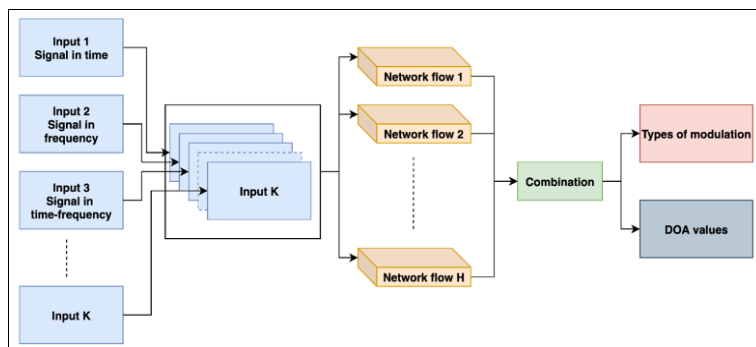
- **CNN Classification:** The CNN classifies the current signal, determines its modulation type, and provides a classification decision. The CNN is trained with a labeled dataset and applies the learned weights for real-time signal classification.
- **MIMO Neural Network Optimization:** To optimize resources and reduce hardware costs, the MIMO neural network is proposed to perform both modulation classification and DOA estimation concurrently. The MIMO neural network will be integrated into a single hardware platform to economize resources and cut costs.
- **Versatility of the MIMO Neural Network:** The MIMO neural network processes various types of input data in different formats and provides results for different tasks and formats. In this setup, the inputs are signals from different domains, and the outputs include signal modulation types and the DOA of the wireless signal source.

The data processor is essential for synthesizing and analyzing wireless signal parameters. Supported by the MIMO neural network, the signal monitoring system can accurately and efficiently perform modulation classification and DOA estimation while optimizing resources and minimizing hardware costs. This approach is expected to improve the performance and reliability of future wireless signal monitoring systems.



**Fig 4:** Analysis Results of the 16QAM Modulated Signal

The proposed design of the MIMO neural network model is illustrated in Fig 5.



**Fig 5:** MIMO Neural Network Model for Modulation Classification and DOA Estimation

## 5. Conclusion

The research and development of wireless signal monitoring systems are becoming increasingly important in the context of modern communication and electronic warfare systems, which are becoming more complex and diverse. Digital transformation in wireless monitoring, particularly through the application of artificial intelligence, has brought significant advancements in signal classification and recognition.

This paper presents an advanced MIMO neural network model designed to address two critical tasks: Modulation classification and DOA estimation of radio emissions. The proposed wireless signal monitoring system includes several functional components, ranging from antenna arrays, analog and digital signal processors, to MIMO neural networks and data processors.

The MIMO neural network model not only enhances the accuracy and efficiency of the monitoring system but also saves resources and reduces hardware costs by performing both essential tasks simultaneously. The integration of advanced hardware and software components has created a robust system capable of operating in complex and diverse environments.

Research results demonstrate that this model has the potential for broad applications in both military and civilian domains, particularly for signal reconnaissance, anti-jamming, and device identification tasks. The development of artificial intelligence, especially through machine learning and deep learning techniques, has opened up new opportunities to improve the performance and reliability of wireless signal monitoring systems.

In the future, continued research and improvement of AI algorithms, along with advancements in hardware, will lead to further breakthroughs in this field. Future studies will continue to build upon and expand upon the achieved results, contributing to the advancement of wireless signal monitoring technology.

## 6. References

1. Le Ngoc Giang, Vrung Thuy Linh, Phuong Nhat Minh. Research and application of IoT technology for food warehouse monitoring. *International Journal of Multidisciplinary Research and Growth Evaluation*. 2022; 03(06):662-668. Doi: 10.54660/anfo.2022.3.6.20.
2. Hong X, Wang J, Wang C-X, Shi J. Cognitive radio in 5G: A perspective on energy-spectral efficiency trade-off. *IEEE Communications Magazine*. 2014; 52(7):46-53.
3. Khan AA, Rehmani MH, Rachedi A. Cognitive-radio-based internet of things: Applications, architectures, spectrum related functionalities, and future research directions. *IEEE Wireless Communications Magazine*. 2017; 24(3):17-25.
4. Nekovee M. Dynamic spectrum access — concepts and future architectures. *BT Technol J*. 2006; 24:111-116. Doi: <https://doi.org/10.1007/s10550-006-0047-4>.
5. Pandit S, Singh G. An overview of spectrum sharing techniques in cognitive radio communication system. *Wireless Netw*. 2017; 23:497-518. Doi: <https://doi.org/10.1007/s11276-015-1171-1>.
6. Hazza A, Shoaib M, Alshebeili SA, Fahad A. An overview of feature-based methods for digital modulation classification. In 2013 1st International Conference on Communications, Signal Processing, and

their Applications (ICCSPA), 2013. Doi: 10.1109/iccspa.2013.6487244.

7. Dobre OA, Abdi A, Bar-Ness Y, Su W. Survey of automatic modulation classification techniques: Classical approaches and new trends. *IET Communications*. 2007; 1(2):137. Doi: 10.1049/iet-com:20050176