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Channel Estimation In MIMO-OFDM Communication Systems

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Abstract-
The wireless communication system modulation technique known as OFDM (Orthogonal Frequency Division Multiplexing) involves breaking up the available bandwidth into a number of narrowband subcarriers, each of which is modulated with data. MIMO (Multiple Input, Multiple Output) systems use numerous transmitting and receiving antennas to increase the wireless communication system performance. The channel estimate is the process of determining the properties of the wireless channel between the transmitter and receiver in a communication system. In OFDM-MIMO systems, it is necessary to approximate the channel response for every subcarrier and antenna in order to decode the sent data properly. In this instance, deep learning techniques were applied. We suggest a Long Short-Term Memory (LSTM)-based method, specifically for channel estimation. It has been demonstrated that deep learning methods are efficient for estimating OFDM-MIMO channels. These techniques require utilizing a trained neural network to estimate the channel in real time after training it on a huge dataset of input data and channel estimations. Our approach is contrasted with the minimum mean square error (MMSE) estimation method and the least squares (LS) method. We evaluate the effectiveness of the suggested technique using the mean-squared error of the estimated channel. (MSE). The simulation findings demonstrate that, in situations when the signal-to-noise ratio (SNR) is small, the proposed CNN-based estimator performs better than the LS and MMSE estimators.

Keywords- *Channel Estimation, MIMO-OFDM system, Least Square (LS), Minimum Mean Square Error (MMSE), Long Short Term Memory (LSTM), Deep Learning*

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I. INTRODUCTION

Telecommunications services require high data rates and dependability, but achieving high data rates requires a wide spectral bandwidth, which can make the system economically unfeasible. Additionally, the channel can become very selective, reducing the reliability of received information. To address these issues, digital signal processing techniques and transceiver design strategies are used, with MIMO receiving special attention. MIMO systems use multiple antennas to transmit and receive signals, allowing for increased diversity or multiplexing. Combining MIMO with OFDM modulation can achieve dependable high data transmission rate over wireless broadband channels.

Recently, deep learning models have been introduced to observe channel state knowledge of MIMO systems based on a arrangement which are pilot-aided. The MIMO-OFDM system performance is often measured by using Bit Error Rate (BER), which is the measure of the number of bit errors occurring in a transmission. By improving channel estimation methods and utilizing deep learning models, the reliability and efficiency of MIMO-OFDM systems can be improved, leading to more dependable and high-speed telecommunications services.

Channel estimation is a critical component in MIMO-OFDM systems as it enables reliable transmission over the wireless channel. In order to achieve accurate channel estimation, the time domain and frequency domain characteristics of OFDM system must be considered. One of the challenges in channel estimation is the need for prior knowledge of the information of state of the channel at the receiver. In estimation of the channel parameters, pilot symbols are transmitted along with the data symbols, and the receiver side uses these pilot symbols to estimate the channel.

In packet transmission, the channel is estimated separately for each packet. This is because the channel transfer function may change between different packets due to the time-varying nature of wireless channels.

There are numerous techniques for channel estimation that are developed for MIMO-OFDM systems, such as Least Squares (LSE), Minimum Mean Square (MMSE), and Maximum Likelihood (ML) estimation.

The conventional LSE channel estimation method assumes that the channel is slowly varying, wherein the channel transfer function remains stable within single OFDM data block. However, in practice, the channel may change rapidly, and the conventional LSE method may not provide accurate channel estimates. To improve the performance of the conventional LSE method, efforts are being made to develop more advanced channel estimation techniques.

Overall, accurate estimation of channel is vital for the reliable operation of MIMO-OFDM systems, and researchers are continuously working on improving the existing channel estimation techniques to achieve higher data rates and greater dependability.

II. RELATED WORK

The authors Yushi Shen and Ed Martinez conducted a study on various techniques of estimation of channel in OFDM systems and highlighted the importance of channel state information for maximizing performance. They compared and evaluated Comb-Type Channel Estimation, Block-Type Pilot Channel Estimation, and Other Pilot Aided Channel Estimation methods but only for single input and single output communication systems.

The authors J.-J. Van de Beek et al. proposed the usage of multiple amplitude signaling techniques in OFDM systems and discussed estimation of channel based on time-domain statistics of the channel. They presented the LS and MMSE estimation techniques, along with a method for modifying them to balance complexity and performance, and showed that up to 4 dB of SNR can be added to the LS estimation technique, depending on estimator complexity.

The authors Subhuh Pramono and Eddy Triyono studied faded channel estimation on OFDM-MIMO and presented the results of using the LS and MMSE methods. They required channel impulse response (CIR) to overcome inter-symbol interference and obtained it through channel estimation. They used the technique called monte-carlo in iterance simulation in determination of the performance of (BER) Bit Error Rate and (MSE) Mean Squared Error and showed that MIMO system outperformed the SISO system in terms of mean squared error.

The authors Akash Doshi, Erin Balevi, and Jeffery G. Andrews proposed a Deep Learning algorithm built on Deep Image Prior Network used to denoise the received signal before using the Least Estimation method. This was found to be more efficient than MMSE as it avoided complex inversion of channel and required Information about the channel covariance matrix. The proposed estimation technique employed a uniquely created (DNN) deep neural network based on the (DIP) deep image prior network and conventional least-squares (LS) estimation for interference-limited multi-cell massive MIMO systems. However, this method was only operational for OFDM systems with 64 antennas and 64 subcarriers.

III. METHODOLOGY

WORKING MODEL

Two antennas are used in 2x2 MIMO, also called 2T2R, to connect up to two data streams to the receiving system. 2x2 gives up to a 100% improvement in throughput over conventional single antenna networks. Hij being the channel coefficient for i th receiver and j th transmitter. x1(t) and x2(t) are the data streams through the 2 transmitters which would undergo modulation before being transmitted and are received as the linear combination of the transmitted signals as shown in the figure. This OFDM signal generation takes place according to the block diagram. In the modern era everything is digital. But for transmission only analog signals are used. Thus, as a first step digital bits are to be converted into analog using various techniques for the transmission of data efficiently. For the OFDM signal transmission, we use QAM (Quadrature Amplitude Modulation) encoding.

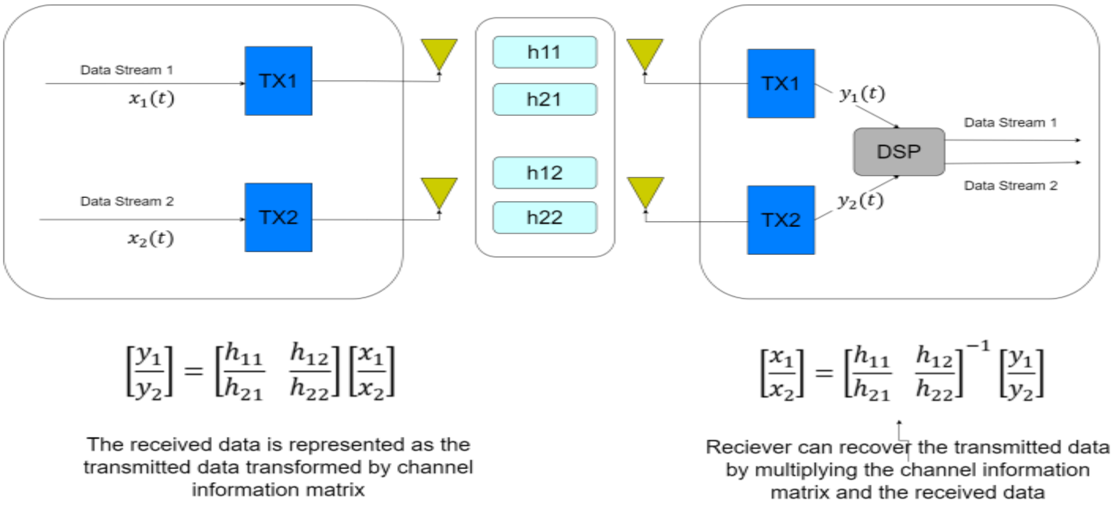

FIG 1: 2x2 MIMO-OFDM system

At transmitter end:

Firstly, the serial bits are converted into parallel data. These parallel groups of bits are then mapped to analoge using 16 bit QAM. Then the analoge pilot data which are used for the channel estimation are inserted in their respective places as per the frequency considered. This data is sampled and converted into digital domain using IDFT. The parallel data is converted back to serial for the easier transmission. For error detection and correction, cyclic prefix is added as per the required frequency and then transmitted in the channel. This channel effect is mathematically considered as the convolution of channel coefficient function and the signal and adding the noise as per the Signal to Noise Ratio taken.

At receiver end:

The signal received is first removed of its cyclic prefixes as they are the extra bits added to the data. Then serial data is converted to parallel and converted back to time domain by DFT. This obtained data is used for the channel estimation and equalized (removing Inter Symbol Interference and noise). The Channel estimation is done here using Least Square, Minimum Mean Square Error methods as a factor of comparison. The equalized bits are de-mapped and converted back into serial data. The received pilot data and the transmitted pilot data are then compared to find the bit error rate (BER) at various SNR and are plotted. The suggested DL model will estimate the error in transmission without comparing the encoded and decoded data. Instead it trains the network to find the error of transmission by comparing the transmitted and received bits of data before decoding them. This eliminates the need of prior knowledge of information on channel state.

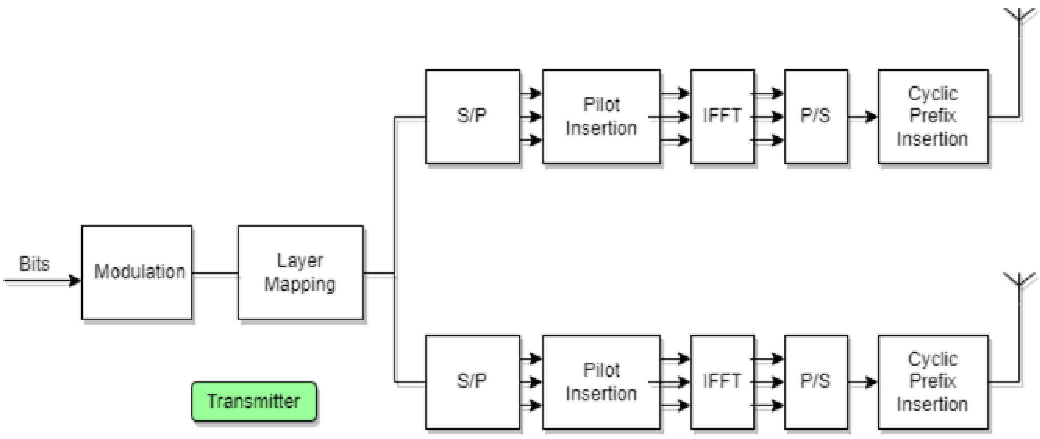

FIG 2: Transmitter side Block diagram of the system

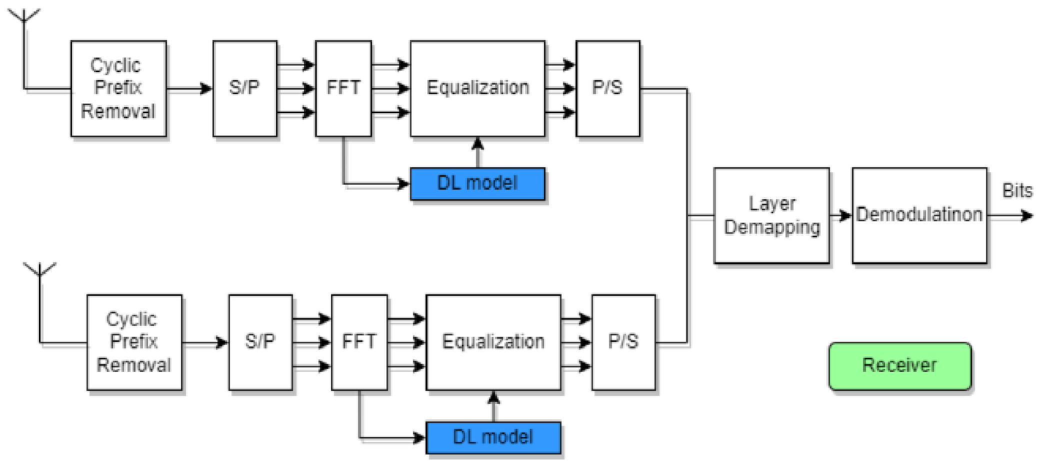

FIG 3: Receiver side Block diagram of the system

IV. IMPLEMENTATION PROCESS

The equation below is for IFFT process (Inverse Fast Fourier Transform). By multiplying the given signal by a succession of sinusoids, the Fourier transform divides a signal into various frequency bins. In essence, the signal is translated from time domain to frequency domain. However, we always think of IFFT as a time domain to frequency domain conversion procedure. IFFT, which may be considered as converting frequency domain samples to time domain samples, is the best option to employ in the transmitter. Separate sinusoidal converters are not required because the IFFT in the transmitter serves that purpose. IFFT and FFT blocks in the transmitter can be substituted for one another as long as the receiver is using the corresponding duals. The obtained time domain parallel data is transformed back to serial data for the easier transmission. Then cyclic prefix of N length is added for the obtained samples for the error correction.

$$x(n) = \left(\sum_{k=0}^{N-1} X(k)\exp(^{-}j2\pi nk/N)\right) / N$$

The reverse process is followed for the received linear combination of signals to obtain the data required. Firstly, the cyclic prefixes added are removed in the first block. Then serial to parallel converter will change the received data to parallel bits. After the DFT step performed by DFT / FFT block, channel estimation is performed by Least Square estimation method. The equation for the DFT is given as below.

$$X(k) = \left(\sum_{k=0}^{N-1} x(n)\exp(j2\pi nk/N)\right) / N$$

Estimation Methods:

These methods are a form of mathematical regression analysis which is utilised to determine the line of most appropriate fit for a set of data, giving a visual demonstration of the connection amid the data points. The data after converted back into time domain are sampled for the pilot data received. This data is compared to transmitted pilots to find the error rate. The ratio of the received and transmitted pilots gives us the estimated channel parameters for which there is efficient data transmission. An LSTM based channel estimation is also proposed here which is an Deep learning based model which further reduces the constraints in training phase of the machine learning model. The transmitted and received data signals are constructed based on the MIMO system considered. In this, a 2x2 MIMO OFDM system is constructed as per the standards.

LEAST SQUARE ESTIMATION:

The least squares technique is utilized to find out the line of best fit because it is a very effective strategy to reduce the amount of error in the data. Error is the variance between some observed data and the data predicted by the line. We can get a very good approximation of the underlying trend in the data by diminishing error. Here, Y represents the received pilot data vector. Whereas P represents the transmitted pilot data. The solution of the above equation would give us the estimated channel parameters.

$H_{LS\text{-}estimate} = YX^T(XX^T)^{-1}$

MINIMUM MEAN SQUARE ESTIMATION:

(MMSE) Minimum mean square error is a evaluation of the quality of an estimation system, which is a function that estimates the value of a parameter based on observed data. The MMSE of an estimator is the minimum mean square error that the estimation system can achieve among all possible estimators for the given problem. The mean square error of an estimation system is defined as the average of squares of the errors between the true value of the parameter and the estimated value. The MSE is a measure of variance of the estimation system and is a way to quantify the accuracy of the estimator.

$H_{MMSE} = R_{YY}\ R_{HY}(Y\text{-}\mu_{\ Y}) + \mu_h$

LSTM (LONG SHORT TERM MEMORY)

For high data transfer rate wireless communication systems OFDM has become popular. However, its performance is affected by the frequency-selective fading channels, which can cause an interference between adjacent subcarriers. This interference can degrade the quality of the received signal and reduce the reliability of the communication system. To mitigate these issues, multiple antennas are used in MIMO systems to increase the robustness and data rate of the system.

Long short-term memory also known as LSTM is a form of recurrent neural network that is able to learn long-term dependencies in data. This network can be used to adcance the accuracy of estimation of channel in MIMO-OFDM system without the need for prior knowledge of Channel State Information. LSTM uses gates to selectively remember or forget past information, which allows it to learn patterns over long periods of time.

In the MIMO-OFDM system, the LSTM network is trained using various standard data labels and their corresponding correlated possible OFDM symbols. This eliminates the need for prior information of the channel state and increases the accuracy of error estimation, reducing processing time. The performance of MIMO-OFDM system can be measured using the Bit Error Rate also known as BER.

By combining MIMO and OFDM with LSTM-based channel estimation, high data rate transmission can be achieved over wireless channels in broadband with improved reliability and decreased processing time. This technique has potential applications in various fields, including wireless communication systems for industrial automation, smart cities, and autonomous vehicles.

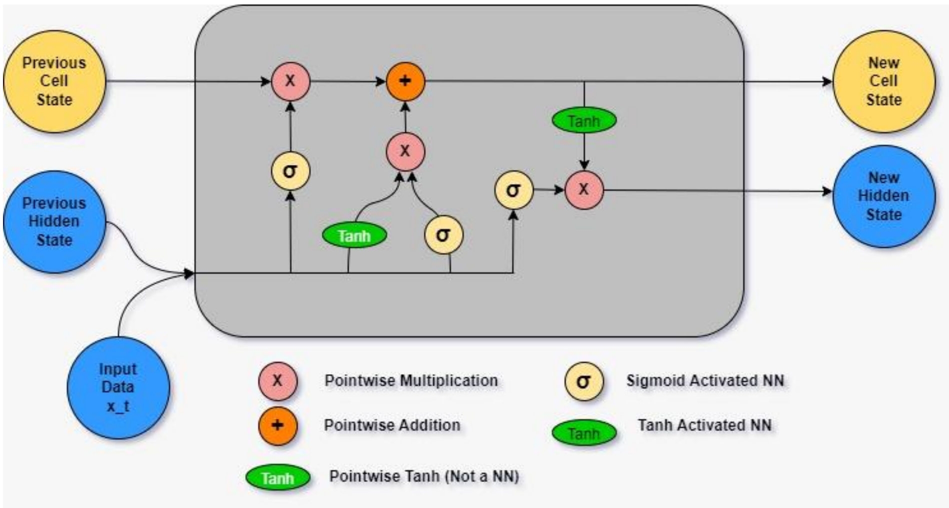

FIG 4: LSTM Block Diagram

Advantages:

- LSTMs are able to learn long-term dependances in data, which in turn makes them suitable for channel estimation processes that require the network to remember past events and utilize them to make predict the future events.
- They are extremely adjustable and can be trained on a widespread variety of different loss functions and optimizers, depending on the specific task at hand. This allows for a high degree of customization and fine-tuning to suit the needs of the particular application.
- They are robust and able to handle noise and interference in the data, which can be common in communication channels.
- They are efficient and can be trained relatively quickly, even on large datasets.

V. RESULTS DISCUSSIONS

Using the MATLAB software, the following observations are captured

The training phase of the LSTM Network:

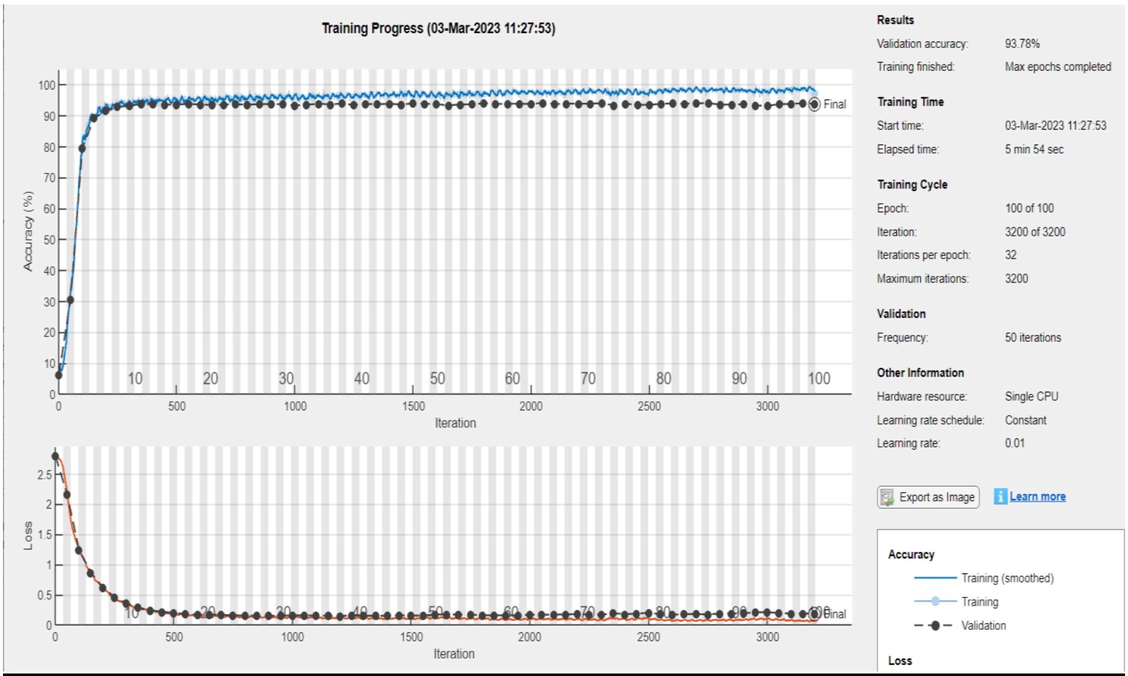

FIG 5: Validation Accuracy of the LSTM network trained with 64000 data symbols

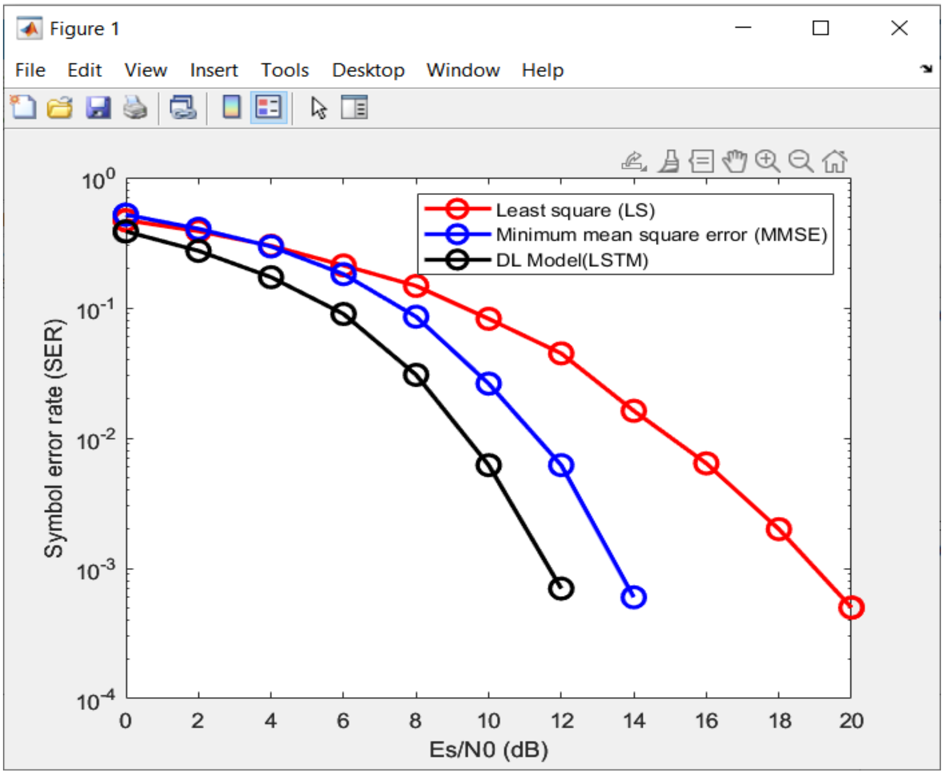

FIG 6: SNR vs BER graphs in comaprision of the three estimation methods

VI. CONCLUSION AND FUTURE SCOPE

Channel estimation using OFDM and deep learning techniques, such as LSTM also known as Long Short-Term Memory networks, can be a powerful method for refining the performance of OFDM-based communication systems. LSTM networks are particularly well-suited for channel estimation in OFDM systems due to their ability to capture long-term dependencies and handle time-varying channels. By training an LSTM network on a dataset of channel responses, it is possible to learn the underlying channel characteristics and make accurate estimates of channel in real-time. The use of deep learning techniques can lead to significant improvements in the accuracy and robustness of channel estimation, as well as increased flexibility in handling different channel scenarios.

However, it is important to carefully design and optimize the LSTM network and training process to achieve good performance. This may involve selecting appropriate network architecture and hyper parameters, and using appropriate pre-processing and normalization techniques on the training data. In addition, it may be necessary to carefully examine the performance of the LSTM-based channel estimation system in several scenarios and environments to ensure that it performs well in practice.

Application of Bi-LSTM will increase the efficiency of the system due to its bidirectional data flow. This will preserve both the future and past information.

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