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4 Enhanced Power Line Communication with Adaptive Neuro-Fuzzy Inference System

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ABSTRACT

This chapter deals with the use of Adaptive Neuro-Fuzzy Inference System (ANFIS) in treating signals for effective communication, especially in Power Line Communications (PLC) which has become an emerging trend for smart grid and IoT nowadays. A communication channel established through existing power line has been used to measure the level of noise and interference that affect PLC in narrow and wideband frequency ranges. At the completion of the experiment, results showed an extensive amount of noise that deteriorate the state of the received signal, especially for the narrow band and therefore prompted the need to redesign robust filters to cancel noise. An ANFIS based communication model was further developed in MATLAB to mimic the PLC transmission problem considering two different scenarios of interferences. Results showed that the signals that passed through the ANFIS system were recovered with considerable accuracy for which the two minimal estimated RMSE were respectively 0.717 and 0.847 for the two scenarios tested. This further re-emphasizes the importance and reliability of the ANFIS system.

Keywords: AI, Neuro-Fuzzy, Fuzzy Logic, Neurocomputing Power-Line-Communication (PLC), Smart grid.

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1. INTRODUCTION

Artificial Intelligence is globally gaining widespread use as more intelligence are being put in machines that have actually demonstrated efficiency and efficacy in handling industry related tasks [1, 2]. AI is also referred to as machine intelligence and consists of the demonstration of cognitive abilities by machines, often similar to that of humans and animals.

The popularity of AI can be attributed to the increasing capability of machines in handling tasks and the success story in some specific areas. For instance, AI has been successfully used to decrypt human speech leading to numerous applications for voice recognition, translation from one language to another; AI is also recognized for its numerous advances in gaming and robotics [3]. Today, owing to AI, there are autonomous vehicles including thousands of microcontrollers and sensors that allow a number of automations. The rise and success of unmanned vehicle including the utilization of drone for delivery of medical devices, for spying, for war and others related applications which have become a revolution on their own, derived from AI.

AI can be indexed as one of the major factors, responsible for the new revolution known as 4th Industrial Revolution which succeeded to yet another powerful revolution, the 3rd industrial revolution which was marked by the emergence of digital technologies. The 4IR brings a lot of transformation and technologies for which AI has become very indispensable such as: robotics, and 3-D printing, genome editing, augmented reality, and many more [4].

In Engineering, AI applications combine hardware and software application in building innovative solutions. A number of new algorithms and tools are available with increase programming complexity to handle more intelligence-based tasks. Artificial intelligence combined with artificial neural network has led to the development of many engineering tools and algorithm, especially those related to fuzzy logic [3], [5 - 7].

Fuzzy logic is derived from the fact that humans make decisions related to imprecise and non-numerical information. Subsequently, fuzzy models are mathematical approaches of modelling vagueness and imprecise information in a manner that the models can recognize, represent, interpret and utilize data and information effectively. Fuzzy logic deals with relative importance of precision [8, 9].

Recently, a growing trend in fuzzy logic has to do with its combination with neurocomputing and genetic algorithm leading to the concept of soft computing. Soft computing is more tolerant to imprecision, and uncertainty. The combination of fuzzy logic and neurocomputing is also known as neuro-fuzzy systems [10, 11]. In this perspective, Dr. Roger Jang developed a new method known as Adaptive Neuro-Fuzzy Inference System (ANFIS).

ANFIS refers to a kind of artificial neural network that is derived from fuzzy inference system [12, 13]. The technique has the potential to capture the benefit of fuzzy logic and neural network together since it is a combination of both techniques. In this line, ANFIS is generally considered as a universal estimator and has a lot of application in energy management and related areas.

ANFIS stands for adaptive neuro-fuzzy inference system. It consists of building a fuzzy inference system whose membership function parameters are tuned using well known method like back propagation algorithm or least square method. The fuzzy system learns from the data that are being modelled while the inference system which derives some similarities from neural network, maps inputs to output using their respective membership functions.

According to [14], ANFIS has been used to predict with accuracy, glomerular filtration rate (GFR) variations in long periods, having been trained with 10 years data from patients suffering chronic kidney disease. This model has proved reliable irrespective of the great variations of human body parameters owing to the robustness of the ANFIS method. ANFIS has been used as a strong methodology in medical research especially in predicting parameters relating to early disease detection and cure. Some of this works include [15, 16]. [15] used similar methods to predict building energy consumption while [16] used for classification of EEG signals using wavelet coefficient.

Similarly, [17], also conducted a comparative study on ANFIS for machine learning in order to highlight the strength of the method when predicting skin temperature in lower limb prostheses. Results confirm that the usage of ANFIS is reliable and efficient in producing non-invasive temperature monitoring.

In Engineering equally, ANFIS has been used in many application including the prediction of drilling hole [18]. The prediction of drilling hole size has implications on many manufacturing processes and their qualities and subsequently impact the economy. ANFIS is also used in mobile learning and increases effectiveness in hybrid learning models as well as adaptation to learners' need [19].

In this study, ANFIS has been used to demonstrate an efficient and reliable cancellation of noise and reception of signal which has a significant impact on power line communications (PLC). PLC is an emerging technology aiming at transmission data through power line which is naturally subject to severe interferences. PLC communication could considerably transform internet of things and improve reliability and accuracy in signal reception and in real time. Interference and noise effects are almost unavoidable in PLC communication but the solution is to devise accurate and powerful filters to decrypt signals effectively. We believe that applying ANFIS to the PLC received signal will considerably improve communication efficiency.

The rest of the chapter is presented as follow. Section two deal with the architecture and background of ANFIS, section three presents the methodology and section four deals with the result and their interpretations. Section five covers the discussion, followed by the conclusion.

2. BACKGROUND OF ANFIS

ANFIS basically combines neural networks to with fuzzy logics models such as the Sugeno fuzzy model for various applications. ANFIS basically takes some input and output data set and then construct a Fuzzy Inference System (FIS) [19,20]. The generated intelligence contains membership functions that are tuned with some optimization algorithms such as back propagation and then learns from a given dataset. ANFIS incorporates neural networks because of its ability to recognize pattern.

Fuzzy Inference System is a computing framework that is based on fuzzy set theory, “fuzzy if-then rules” and fuzzy reasoning. Fuzzy Inference Systems perform inferencing decision making by imitating how humans use knowledge they have in decision making. These are illustrated in the IF-then rules.

Adaptive network is a framework that covers a greater number of neural networks with supervised learning capacity [6]. This implies that an adaptive network is a framework that consists of a number of nodes connected by directional links and those nodes are the processing units of the framework. They perform the computations on the input parameter to produce the output ones. However, for adaptive networks the output of the nodes depends on some modifiable parameters. Rules or learning rules are what are used to determine the method to modify the parameters of the node.

ANFIS is therefore a class of adaptive networks that employs the workings of Fuzzy Inference Systems. It basically employs one of the types of the Fuzzy Inference System like Mandani, Sugeno or Tsukamoto Fuzzy models [16], [21-25], and constructs an adaptive network. This implies, the nodes of the adaptive networks employ the functionality of the Fuzzy Model selected to serve as the rules which specifies how the modifiable parameter are updated to produce an output. To better understand the ANFIS architecture, let’s consider a first order Sugeno fuzzy model with two rules. This will give the following fuzzy if-then rules:

- R1: if x is A1 and y is B1 then f1=f (A1, B1)
- R2: If x is A2 and y is B2 then f2=f (A2, B2)

The equivalent ANFIS structure is shown below

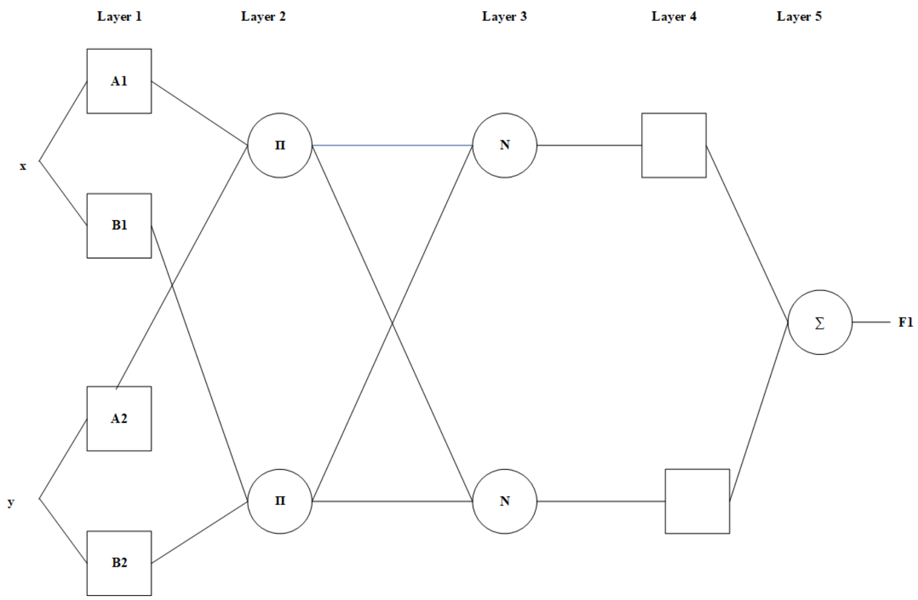

Fig. 1. Architecture of a first order Sugeno ANFIS

- Layer 1: Each node calculates the membership values for the premise parameters
- Layer 2: Each node here calculates the fuzzy strength of the rule or the firing strength of the rules
- Layer 3: Each node here normalizes the firing strength of the rules.
- Layer 4: Perform some computations on the consequent parameters.
- Layer 5: calculate overall output which is the sum of all the incoming signals.

3. METHODOLOGY

The first part of this section presents a scenario of noise affecting a signal transmitted through PLC for which a spectrum analyzer was used at the receiving end to analyze the received signal. This section is followed by a demonstration of how noise can be cancelled from the received signal using the ANFIS system under MATLAB software.

3.1 Signal Transmission over PLC

In this section, the study was concerned with technical assessment of power line channel characteristics such as noise properties on Low Voltage Power lines for frequencies between 1 – 500KHz in the Narrowband and 2- 12 MHz in the Broadband. The experimental setup is shown in Figure 2 and comprises a network diagnostic instrument connected to a laptop computer equipped with Hi-Studio software and a coupler enabling the interfacing of the instruments with a 220 V, 50 Hz power line. The network diagnostic is connected to the mains power line and a laptop.

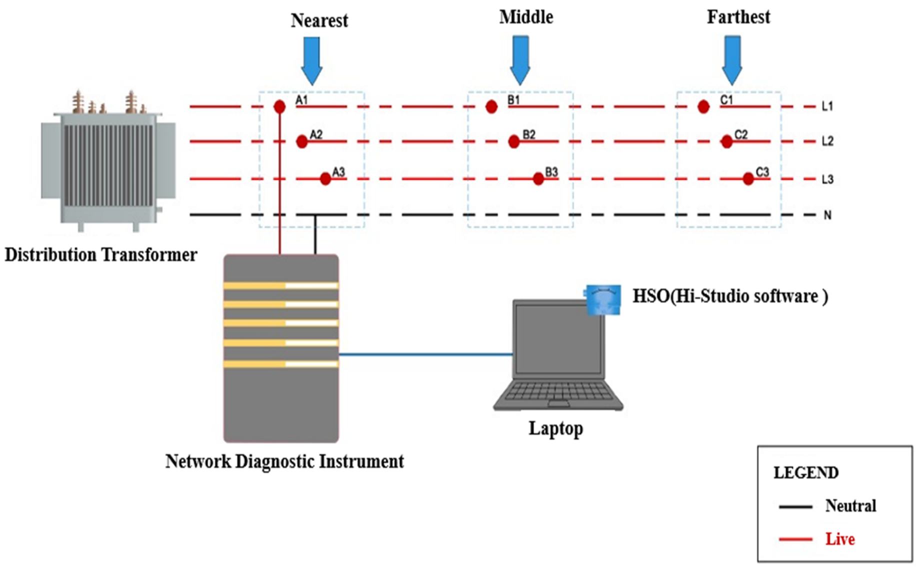

Fig. 2. Noise Test Setup

The received signal is captured by the Hi-Studio software which also provides the noise, attenuation and impedance profile. The experiment has been repeated under the same conditions for the two frequency bands and the obtained graphs have been recorded for analysis. For each scenario, the experiment was done close to a distribution transformer that supplies a considerable number of users to ensure constant power delivery.

Figure 3 shows the results obtained after conducting the test. There is prevalence of noise on the transmitted signal both in the narrow and broadband frequencies that may arise from variety of sources. Man-made noise and harmonics, switch mode power supplies, thyristor circuits and many others may account for the level of noise observed. Flicker noises or low frequency noise are also produced by active devices, integrated circuit, diode, transistors etc. The existence of these unwanted signals cannot be practically avoided in a PLC communication system. The broadband frequency band exhibit lower noise level as compared to the narrowband. A good transmission medium is characterized by a low level of noise. The measurements showed that the noise level decays with frequency and is especially high in the narrowband frequency spectrum.

In reference to the results, the high noise level on the narrowband will limit or make data transmission unreliable. This therefore establish the need to design sophisticate filters to extract with higher efficiency and accuracy, the received signals.

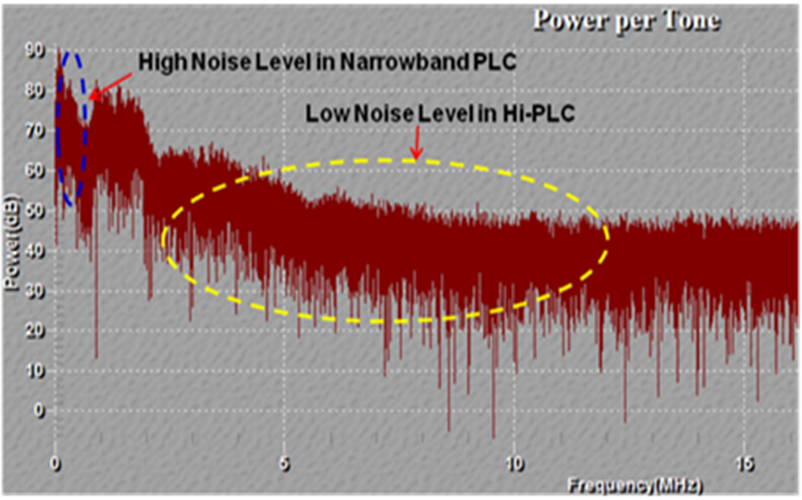

Fig. 3. Noise Distribution on a Low Voltage Power Line in Residential Area

3.2 Adaptive Noise Cancellation Using ANFIS

The following two scenarios were considered:

- Scenario 1:
  - Assuming an information signal with the expression sin(40/(time+0.01)) and varying the noise signal to create an interference to be added to the information signal and then
  - using the adaptive noise cancellation method to reconstruct the signal.
  - Random values between the ranges of -2 and 4 were generated for the noise sources;
  - The interference signal was generated using the formula below which was borrowed from [25]

$$n_2(k) = \frac{4sin\big(n_1(k)\big) \cdot n_1(k-1)}{1 + n_1(k-1)^2}$$

Where,

n_2 : the interference signal and n1 the noise source,

k: parameter that takes integer values.

- Scenario 2:
  - Changing the desired signal x, to x = sin(40./(time+0.01))+ cos(time+0.01) and
  - noise signal to n1 = cos(time)+ sin(time+0.01).*exp(time),
  - and keeping all other parameters same

4. RESULTS AND INTERPRETATION

First of all, the information signal plotted in MATLAB is shown in Figure 4.

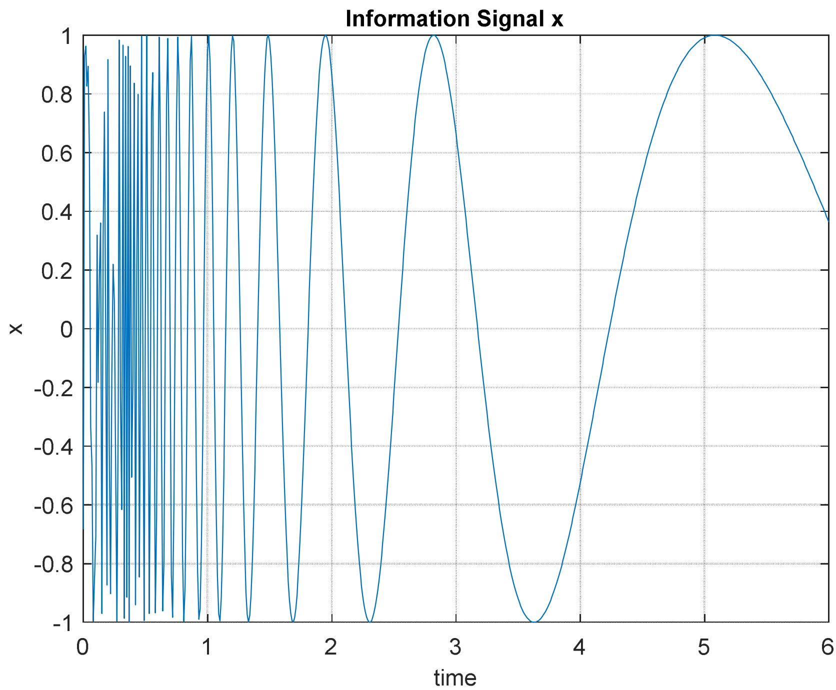

Fig. 4. Information Signal

The noise generated was used to create a nonlinear interference which is assumed to act on the signal information to corrupt it. Therefore, the noise affects the interference channel characteristics to be generated.

Scenario 1

With regard to scenario 1, Figure 5 shows the noise source generated for this scenario and the interference signal. Figure 6 also shows the interference signal generated in 3 dimensions.

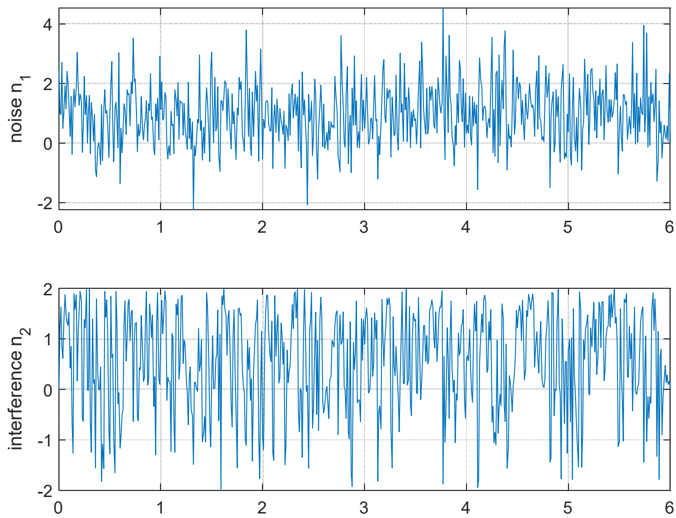

Fig. 5. Noise and Interference Signals

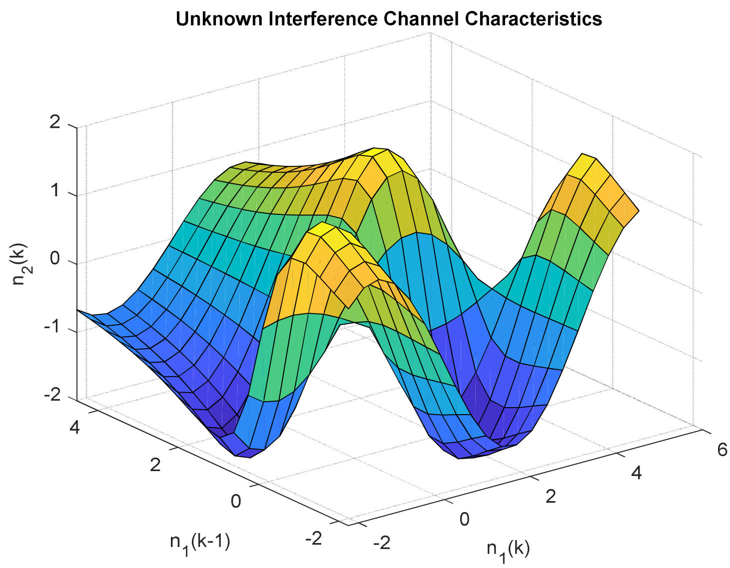

Fig. 6. Interference channel in 3D

Putting together the interference and the noise produces the measured signal which is assumed to be the noise signal added to the interference signal and the original information signal. Therefore, the measured signal is somewhat referred to as the corrupted signal which need to be reconstructed to obtain our signal information. Figure 7 shows the measured signal for this example.

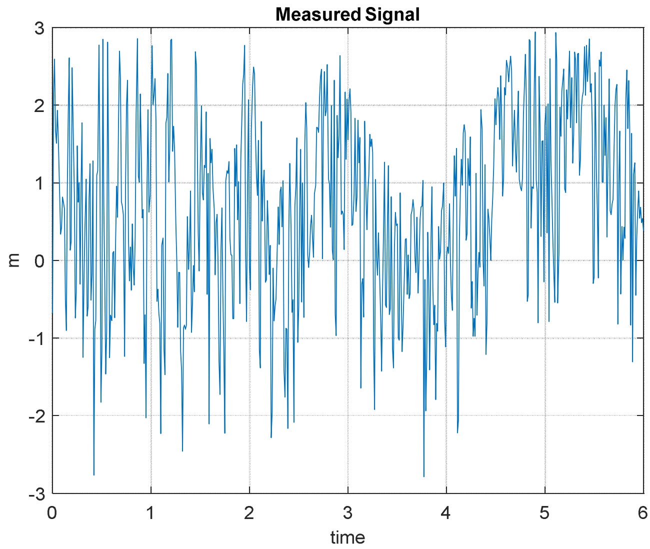

Fig. 7. Measured Signals

The application of the ANFIS algorithm on the data, will lead to the estimation of the interference and subsequently subtracting this estimated interference from the measured signal will lead to the original information signal. Figure 8 shows the estimated signal information and the actually measured signal information. The implementation code is available in Appendix A.

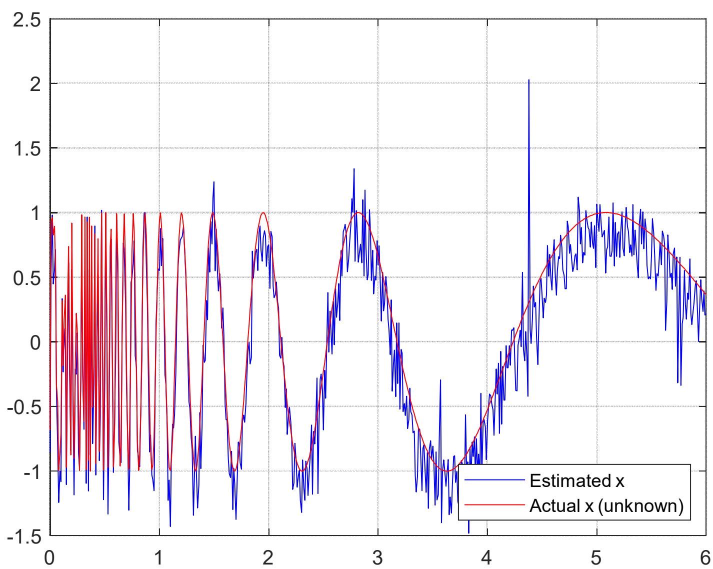

Fig. 8. Recovered Signals

Scenario 2

Changing the desired signal x, to x = sin(40./(time+0.01))+ cos(time+0.01) and noise signal to n1 = cos(time)+ sin(time+0.01).*exp(time), the following results illustrated in Figure 9 to 12 were obtained.

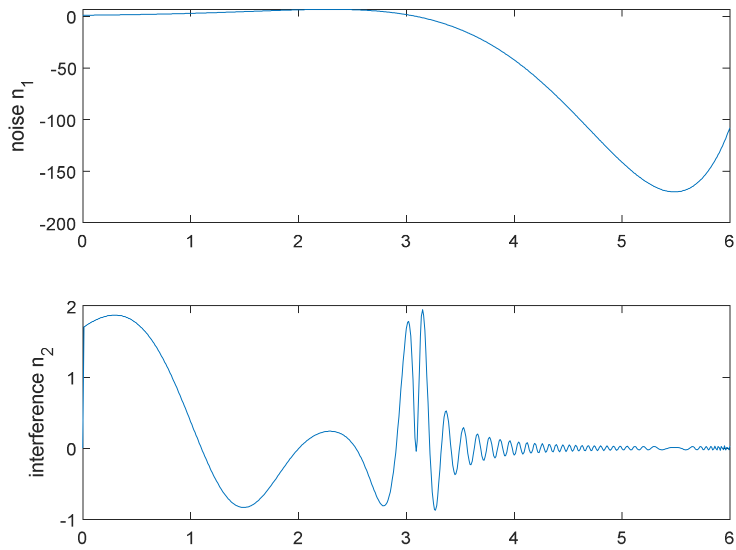

Fig. 9. Noise and Interference Signals (scenario 2)

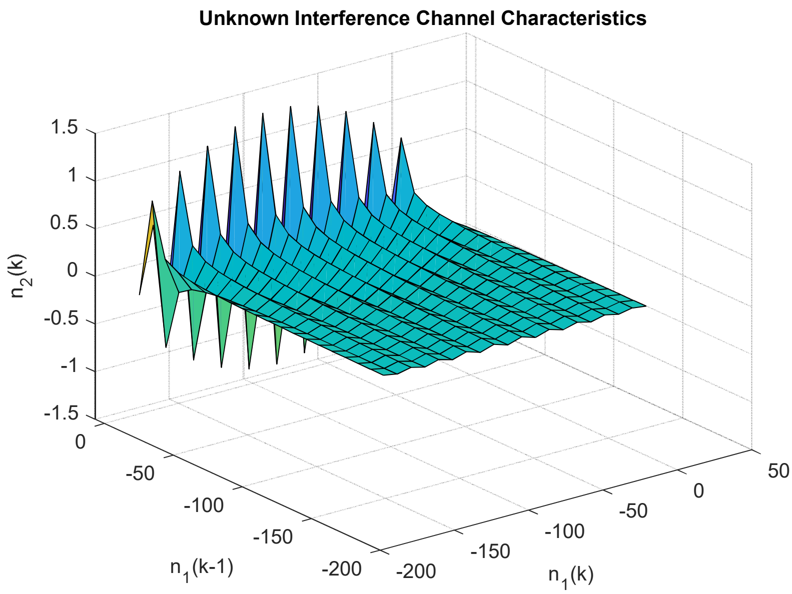

Fig. 10. Interference channel in 3D (Scenario 2)

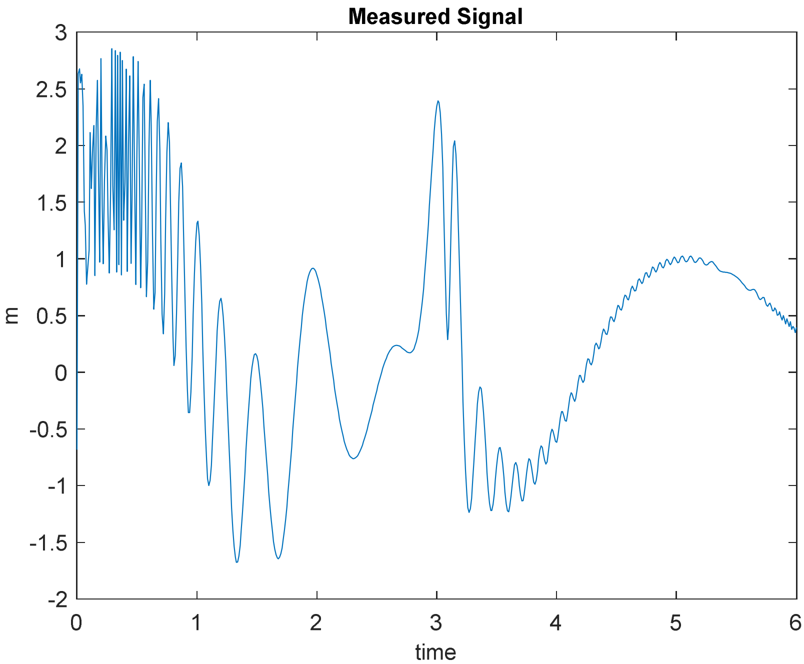

Fig. 11.. Measured Signals (scenario 2)

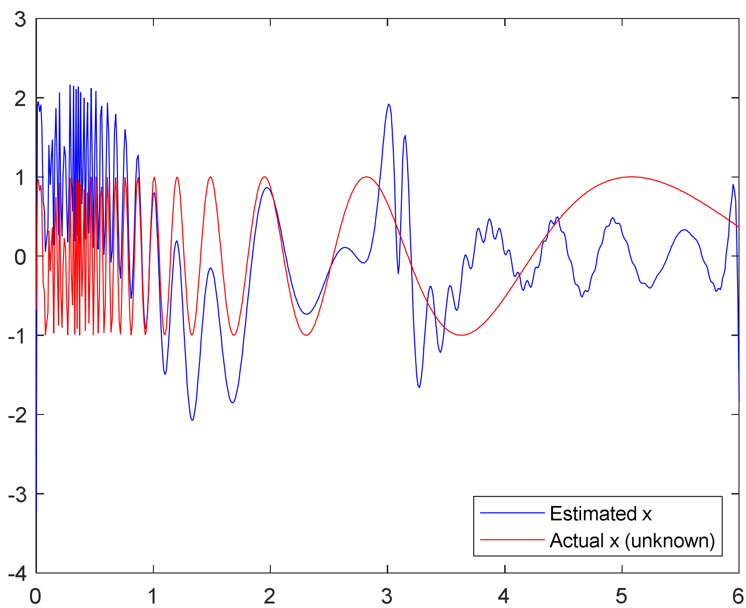

Fig. 12. Recovered Signal (scenario 2)

5. DISCUSSION

Figures 8 and 12 above show the plot of the estimated signal and the actual signal on one plot respectively for the two scenarios. The estimated signal is the signal that was generated by the ANFIS algorithm in its attempt to reconstruct the actual signal, x, that was subject to the interference and noise signal that corrupted the original information signal. The ANFIS algorithm after learning from the training data that was fed into it, obtained a minimal root mean square error of 0.717 for scenario 1 and 0.847 for scenario 2. A small RMSE value, means the algorithm was able to fit the training data, very well. After each epoch, the RMSE value kept reducing as can be observed in Table 1, which means, the algorithm keeps improving the detection. Therefore, the estimated signals are the signals generated after the cancellation of the noises that the information signal was subject to. The ANFIS was successfully able to produce a good estimate of the actual signal; however, the estimated signal can be smoothened or enhanced by a more extensive training.

Table 1. Root mean square values for each epoch (Scenario 1&2)

Epoch Number	Step Size	RMSE Value (Scenario 1)	Step Size	RMSE Value (Scenario 2)
1	0.20	0.819851	0.20	1.05206
2	0.20	0.810236	0.20	1.0323
3	0.20	0.800805	0.20	0.987517
4	0.20	0.791347	0.20	0.847019
5	0.20	0.781561	0.20	0.906449
6	0.22	0.77105	0.20	0.941524
7	0.22	0.758206	0.20	0.902289
8	0.22	0.743936	0.20	0.942638
9	0.22	0.729286	0.20	0.900965
10	0.24	0.717368	0.18	0.943483

It can be observed from the results obtained from scenario 1 and scenario 2 that the estimated signal or recovered signal that was obtained by the ANFIS algorithm, scenario 1's estimate appears to be closer to the actual signal for scenario 1 than that of scenario 2's estimated signal which is a little bit far from scenario 2's actual signal.

Also, the RMSE value for scenario 1 is less than that of scenario 2. This is to confirm that, the smaller the RMSE value the better the results. The difference in the interference generated for the two scenarios which is obvious in Figure 6 and 10, justify the fact that ANFIS predicted the output better in the first scenario than the second one.

6. CONCLUSION

In summary, this chapter presents the strength of the adaptive neuro-fuzzy inference system, to perform effective filtering in noisy and highly polluted environment. A power line communication channel was subjected to a noisy environment and tested with real instrument including a network analyser. Results showed a highly polluted signal from the receiving end with a more pronounced effect in the narrow band as compared to the wide band. Subsequently, a similar transmission system has been considered and modelled with two scenarios under MATLAB to evaluate the strength of the ANFIS algorithm. The application of the ANFIS contributed to reducing the noise level and decrypting the transmitted signal with considerable accuracy. It was found that the ANFIS help predict the received signal with very negligible RMSE, proving its effectiveness. However, there were room to improve the training algorithm which depends on the complexity of the interference system and the nature of the information signal itself. The object of the ANFIS system which is strongly recommended for similar signal treatment is to improve on signal transmission for Power Line Communications that is foreseen as an enabling technology for IoT, smart grid and many other emerging technologies.

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