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Recurrent Neural Network based electricity theft detection

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ABSTRACT Electricity is an essential part of modern life, powering everything from homes and businesses to hospitals and schools and its theft is a widespread problem that affects many countries around the world. It is estimated that electricity theft costs utility companies billions of dollars each year, while also endangering the safety of both consumers and utility workers. Electricity theft can take many forms, from tampering with meters to bypassing them altogether. Some individuals may also connect directly to power lines, which can be incredibly dangerous and potentially deadly. The reasons for electricity theft vary, but often involve a desire to avoid paying for electricity or to generate income through the sale of stolen electricity. Theft also poses a significant safety risk to both consumers and utility workers. Tampering with electrical systems can lead to fires and electrocution, which can cause serious injury or death. Preventing electricity theft requires a multi-faceted approach. One key strategy is to improve metering systems, which can detect and prevent unauthorized access to electricity. Additionally, governments can increase penalties for those caught stealing electricity, which can act as a deterrent to potential thieves, etc. This paper aims a different method for theft detection which uses comprehensive features in time and frequency domains in a recurrent neural network-based classification approach usig LSTM.

INDEX TERMS Recurrent neural network, machine learning, electricity theft, lstm

I. INTRODUCTION

ELECTRICITY is a crucial necessity in today's modern society. It fuels industries, transportation, residences, and workplaces. However, despite its significance, many regions of the world continue to have problems with a lack of electricity, high costs, and theft. Particularly in many nations worldwide, electricity theft is a serious issue. Electricity theft happens when people or organizations improperly access the electrical system, evading the meter and failing to pay for the electricity they consume. This practice contributes significantly to the insufficient supply of power and costs governments and electricity suppliers billions of dollars annually.

There are several causes of electricity theft. In some circumstances, it is because people are too poor to purchase the electricity they require. In other instances, it is the result of corruption, where some people or companies engage in criminal activity to profit. Sometimes it's because there isn't enough enforcement by the authorities, which makes it simpler for people to steal electricity without worrying about getting caught. Governments and electrical companies must adopt a multifaceted strategy to address electricity theft. This entails enhancing access to electricity for people who cannot afford it, toughening up on electricity theft, and putting detection and prevention mechanisms in place. Innovative grid technologies, which employ digital monitoring systems to quickly identify and pinpoint electricity theft, have been adopted in several nations.

In developing nations, the problem of insufficient electrical supply is particularly pronounced. Many people in these areas don't have access to power, and those who do frequently experience blackouts because of inadequate infrastructure and supply. Access to vital services like healthcare, education, and communication is impacted by energy availability, which inhibits economic growth and development. There are many causes of insufficient electrical supply. In certain circumstances, especially in rural areas, it results from a lack of infrastructure investment. Other times, it's because of inefficient resource use, which causes power shortages during demand times. In certain instances, it's because of political unrest, which disrupts the supply chain.

Governments and electrical suppliers must invest in infrastructure, especially in rural regions, to address the problem of a lack of electricity supply. Additionally, they must develop renewable energy sources like wind and solar, which are more resilient and sustainable to supply chain shocks. They also need to promote energy efficiency and decrease waste because doing so will assist to balance supply and demand. A further big issue that many individuals deal with is the price of electricity. Electricity costs are excessive in several nations, making them unaffordable for many people and enterprises. Electricity subsidies in other nations result in underinvestment in infrastructure and wasteful resource utilization.

In conclusion, electricity is an essential resource for contemporary society, yet it is still a problem in many regions of the world due to low availability, excessive prices, and theft. Governments and electrical suppliers must adopt a multifaceted strategy to tackle these issues, one that includes spending money on infrastructure, creating renewable energy sources, increasing energy efficiency, and putting in place tools to stop and detect theft. Then and only then can we guarantee that everyone has access to safe, dependable electricity.

In this paper, we provide an efficient electricity theft detection method based on carefully extracted and selected features in Recurrent Neural Network (RNN)-based classification approach. We demonstrate that employing frequency-domain features as opposed to using time-domain features alone enhances classification performance. We use a realistic electricity consumption dataset released by the State Grid Corporation of China (SGCC) accessible at [1]. The dataset comprises electricity usage statistics recorded from January 2014 to October 2016. The main contributions are as follows:

- We propose a unique RNN classification-based electricity theft detection method using extensive time-domain features. We further propose using frequency-domain features to enhance performance.
- We optimize the hyperparameters of the model for overall improved performance using a random search that can be employed to obtain good outcomes with optimal model training speed.

II. RELATED WORK

Use either SI (MKS) or CGS as primary units. (SI units are strongly encouraged.) English units may be used as secondary units (in parentheses). This applies to papers in data storage. For example, write "15 Gb/cm^2 (100 Gb/in^2)." An exception is when English units are used as identifiers in trade, such as "3$^{1/2}$-in disk drive." Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity in an equation.

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III. PRELIMINARIES

Recurrent Neural Network is referred to as RNN. It is a kind of neural network with memory that works best with sequential data. Google Voice Search and Apple's Siri both employ RNN. Let's explain the basic basics of RNN and understand Forward Propagation and Backward Propagation before diving deeper.

A. FORWARD AND BACKWARD PROPAGATION

1) Forward Propagation

The simplest kind of neural network is this one. Data flows only in forward direction from input layer to hidden layers to the output layer. It could have one or more secret layers. Each node has complete connectivity.To obtain the output of the model, assess its accuracy, and determine the error, we use forward propagation.

2) Backward Propagation

Training neural networks is done using the back propagation approach. Deep neural networks may be used if there are numerous hidden layers. We compute the error when forward propagation is finished. The network then receives a back-propagation of this error to update the weights. We move backward through the neural network to get the partial derivatives of the error (loss function) with respect to the weights. To determine step size, this partial derivative is now multiplied by the learning rate. To determine new weights, the step size is applied to the initial weights. A neural network learns in this manner while being trained.

B. WHAT IS RNN?

A feed-forward neural network with internal memory is referred to as a recurrent neural network. The result of the current input depends on the previous computation, making RNNs recurrent in nature because they carry out the same function for every data input. The output is created, copied, and then delivered back into the recurrent network. It takes into account both the current input and the output that it has learned from the prior input when making a decision.

RNNs can process input sequences using their internal state (memory), in contrast to feed-forward neural networks. They can therefore be used for tasks like connected, unsegmented handwriting recognition or speech recognition. All of the inputs in other neural networks operate independently of one another. However, with RNN, every input is connected to every other input.

1) Best suited for sequential data

Sequential data is where RNN shines the most. Any input or output length is supported. RNN processes arbitrary input sequences using its internal memory. RNNs are therefore the most effective in predicting the following words in a string

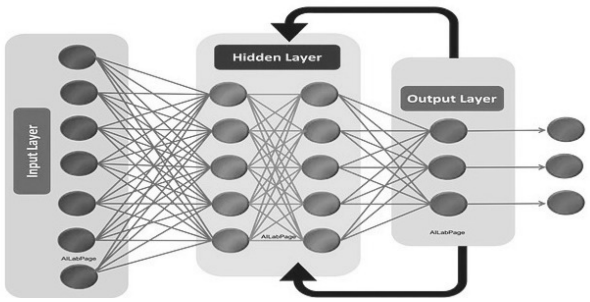

FIGURE 1. Recurrent neural network.

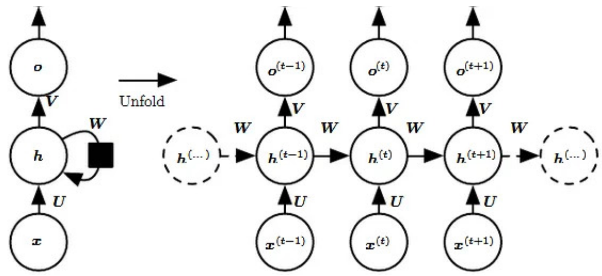

FIGURE 2. Architecture of Recurrent neural network.

of words. Like a human brain, particularly in dialogues, more weight is given to recency of information to predict sentences. A RNN that has been taught to translate text might discover that the word "dog" should be translated differently if the word "hot" comes before it.

2) RNN has internal memory

RNN is capable of having memory. Data from the past is retained. While making a decision, it takes into consideration the current input and also what it has learned from the inputs it received previously. A feedback loop is created when the output from the previous step is used as the input for the current step. As a result, it uses the set of current input and the past state to determine its current state. In this way, the information cycles through a loop. In a nutshell, we can say that RNN has two inputs, the present and the recent past. This is significant because the sequence of data carries crucial information about what is coming next, which is why an RNN can achieve things other algorithms can't.

C. HOW DOES RNN WORK?

Recurrent neural networks (RNNs) are a subclass of neural networks that are capable of processing sequences of inputs, such as time-series data or text written in English language, by maintaining a state that stores details about the previous inputs. In order to create an output, this state and the current input are both sent across the network. An RNN can learn to predict the future or produce output sequences based on the context of its prior inputs in this fashion.

RNNs can be visualised as a series of repeating modules, where each module accepts the input and output from the module before it as input. The recurrent link, which permits information to be transmitted from one time step to the next, is the essential component that allows RNNs to capture sequential data.

The simple recurrent unit, or SRU, is the most fundamental type of RNN module and is defined as follows:

$$h_t = f(Wx_t + Uh_{t-1} + b)$$

where h_t is the hidden state at time step t, x_t is the input at time step t, W and U are weight matrices, b is the bias vector, and f is the activation function, such as the sigmoid function or the hyperbolic tangent function.

This equation describes how the hidden state h_t is computed as a function of the input x_t and the previous hidden state h_{t-1}, using a linear transformation of the inputs and the previous hidden state, followed by a non-linear activation function.

In order to train an RNN, we need to compute the gradient of the loss function with respect to the parameters of the network, and update the parameters using an optimization algorithm such as stochastic gradient descent. The challenge in training RNNs is that the gradient can become very small or very large over time, due to the repeated multiplication of the weight matrices W and U. This can lead to the vanishing or exploding gradient problem, which makes it difficult to learn long-term dependencies in the input sequence.

One solution to this problem is to use a variant of the SRU called the Long Short-Term Memory (LSTM) unit, which uses gates to control the flow of information through the network. Another solution is the Gated Recurrent Unit (GRU), which uses a simpler gating mechanism than the LSTM.

Overall, RNNs are a powerful tool for processing sequential data, but require careful tuning and regularization to avoid the vanishing or exploding gradient problem.

IV. RNN-BASED ELECTRICITY THEFT DETECTION METHOD

The electricity theft detection method outlined in this section consists of the following three steps: Data Analysis and Preprocessing, Feature Extraction, and Classification

A. DATA ANALYSIS AND PRE-PROCESSING

We used a realistic electricity consumption dataset released by SGCC, which can be accessed at [1]. The dataset consists of daily electricity consumption data taken from January 2014 to October 2016, summarized in Table 1.

The sampling rate of the data is uniform for every customer, it is one measurement per day, which corresponds to the total power consumption for that day. The used dataset consists of 42372 observations, of which 3615 observations are electricity consumption data of unfaithful customers and the remaining observations are electricity consumption data of faithful customers.

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Figures that are meant to appear in color, or shades of black/gray. Such figures may include photographs, illustrations, multicolor graphs, and flowcharts. For multicolor graphs, please avoid any gray backgrounds or shading, as well as screenshots, instead export the graph from the program used to collect the data.

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The word "data" is plural, not singular. The subscript for the permeability of vacuum μ_0 is zero, not a lowercase letter "o." The term for residual magnetization is "remanence"; the adjective is "remanent"; do not write "remnance" or "remnant." Use the word "micrometer" instead of "micron." A graph within a graph is an "inset," not an "insert." The word "alternatively" is preferred to the word "alternately" (unless you really mean something that alternates). Use the word "whereas" instead of "while" (unless you are referring to simultaneous events). Do not use the word "essentially" to mean "approximately" or "effectively." Do not use the word "issue" as a euphemism for "problem." When compositions are not specified, separate chemical symbols by en-dashes; for example, "NiMn" indicates the intermetallic compound $Ni_{0.5}Mn_{0.5}$ whereas "Ni–Mn" indicates an alloy of some composition Ni_xMn_{1-x}.

Be aware of the different meanings of the homophones "affect" (usually a verb) and "effect" (usually a noun), "complement" and "compliment," "discreet" and "discrete," "principal" (e.g., "principal investigator") and "principle" (e.g., "principle of measurement"). Do not confuse "imply" and "infer."

Prefixes such as "non," "sub," "micro," "multi," and "ultra" are not independent words; they should be joined to the words they modify, usually without a hyphen. There is no period after the "et" in the Latin abbreviation "*et al.*" (it is also italicized). The abbreviation "i.e.," means "that is," and the abbreviation "e.g.," means "for example" (these abbreviations are not italicized).

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VI. CONCLUSION

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If you have multiple appendices, use the \appendices command below. If you have only one appendix, use \appendix[Appendix Title]

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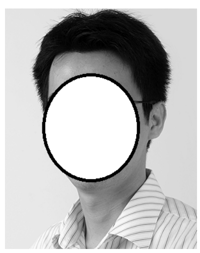
Dr. Author was a recipient of the International Association of Geomagnetism and Aeronomy Young Scientist Award for Excellence in 2008, and the IEEE Electromagnetic Compatibility Society Best Symposium Paper Award in 2011.



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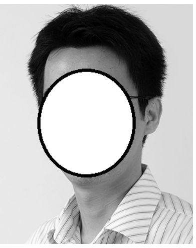
Mr. Author's awards and honors include the Frew Fellowship (Australian Academy of Science), the I. I. Rabi Prize (APS), the European Frequency and Time Forum Award, the Carl Zeiss Research Award, the William F. Meggers Award and the Adolph Lomb Medal (OSA).



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From 2008 to 2009, he was a Research Assistant with the Institute of Physics, Academia Sinica, Tapei, Taiwan. His research interest includes the development of surface processing and biological/medical treatment techniques using nonthermal atmospheric pressure plasmas, fundamental study of plasma sources, and fabrication of micro- or nanostructured surfaces.

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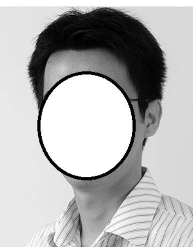

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