LOAD FORECASTING MODELLING OF DATA CENTERS AND IT SYSTEMS BY USING ARTIFICIAL NEURAL NETWORKS

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Abstract

A data center is a repository that houses computing facilities like servers, routers, switches and firewalls, as well as supporting components like backup equipment, fire suppression facilities and air conditioning. Data centers nowadays are proliferating all over the world because of increasing demand for Internet applications. Our goal is to find a way to optimize energy consumption of data centers by encompassing automation control system devices and load forecasting. In this paper, the authors prepared a server for modelling a data center and a software named DAEMS (Data Acquisition and Energy Management Software) to collect data for forecasting of electricity by using Artificial Neural Networks. The forecasting model is then used to produce a load profile of a server.

1. Introduction

Data centers consume about 3 percent of the global electricity supply and accounting for about 2 per cent of total greenhouse gas emissions. It is estimated that data centers will consume three times as much energy in next decade. 416.2 terawatt hours of electricity world's data centers used in 2015 was far higher than UK's total consumption of about 300 terawatt hours [1, 2] and TURKEY's total consumption of about 265.7 terawatt hours [3].

The development on Internet of Things (IoT), cloud-based systems and big data applications with digitalization, accelerate the growth of data centers (DCs) rapidly.

For those reasons, power management and optimization is crucial regarding environmental responsibilities and energy costs. 2 per cent of total greenhouse gas emission has led us to a heightened awareness of their increasing impact on climate change.

Overall research into the effect of the whole Information and Communication Technologies (ICT) industry on climate change has been dominated by Global e-Sustainability Initiative (GeSI) [4, 5], but has been strengthened by recent research by Malmodin [6].

In 2012 the growth in greenhouse gas (GHG) emissions (embodied and operational) from the ICT industry was projected to rise at a faster rate than the total global footprint [5]. Footprint and emissions are used interchangeably and refer to the GHG emissions including carbon dioxide and all GHGs converted to carbon dioxide-equivalent [4].

Three main sectors of the ICT industry, data centers are projected to have the fastest rate of growth at 7% per annum from 2011 to 0.29 GtCO2e in 2020 [5]. This growth echoes those found in an earlier study by GeSI [4] that suggested a rise in footprint of 7% p.a. from 2002 to 2020, but concluded a higher overall impact in 2020 due to an actual measured increase (rather than projected) of 9% p.a. from 2002 to 2011, and shown in Fig. 1 [4].

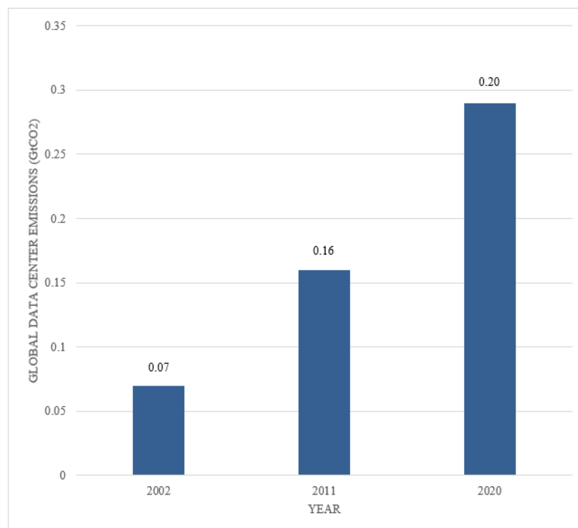

Fig. 1. Growth in data center GHG emissions – 2002 to 2020

The forecasting of the electric load at a future time is a challenging problem because of the diverse characteristics of the electrical load and the uncertainly associated with them [7]. Typical daily variation of electric loads vary frequently and is mostly unstable.

Earlier studies [8],[9], about load forecasting of data centers do not focus on the specific-internal parameters of individual server such as CPU usage, Ram usage rate and data traffic parameters like received data and sent data collectively.

The main purpose of this paper is to contribute a holistic approach to the literature by using an individual server model for implementing data centers.

An earlier study [9] about data center energy consumption, there had been a key problem that certain important system parameters such as the power consumption of a particular component in a data center cannot be measured directly. From a different point of view, it was implemented to produce a more accurate prediction system by implementing our design on an

individual server. The implementation could be extended all equipment used at the data centers.
One of our many advantages is that there has been used a power measurement device (power analyzer) to convert from analog power data to digital data via a local ethercat connection with high resolution and speed to measure a server's power consumption.
Another key contributions of this design to literature is that producing a software named Data Acquisition and Energy Management Software (DAEMS) which will gather all features together. In our research, load forecasting is used to predict the electricity demand for data centers in the means of these different kind of features.
The variables could be produced from both the physical connected device parameters (Temperature, Humidity...) and the internal parameters (CPU Usage, Received Data, Sent Data etc.) of the server.
Different kind of devices and software such as automation control device (PLC), appropriate actuators-sensors, custom designed software (DAEMS) and ANN implementation software were gathered all together.
There are many methods with respect to forecasting power consumption such as regression and artificial neural networks. One of the previous researches [10] compare linear, logarithmic, polynomial regression and artificial neural networks and conclude that ANN model maps most number of data points. According to this research, it could be accepted that ANN is one of the most reliable methods for forecasting processes.
The application of machine learning algorithms was used by implementing artificial neural networks. The details about the processes will be explained below sections and briefly;

- The method part of the paper mentions about the collection of needed parameters for ANN, collection methodology and project layout.
- Afterwards, the details about applied ANN method has been explained. Finally for this section, implementation part will lead us to achieve the results for ANN implementation.

2. Methods

2.1. Data Collection

In this paper, a server will be used instead of a complicated data centers to be able to predict load demand by implementing artificial neural networks.
Firstly, the variables which will be specific input parameters for the neural networks should be determined. Those features are listed below categorically;

- About the consumed energy at the Server;
  - Voltage, Current and Power
- About the ethernet connection at the Server;
  - Received Data and Sent Data
- About the ambient features;
  - Temperature and Humidity
- About the processor of the Server;
  - CPU usage rate, RAM usage and CPU temperature

Regarding these features, Table 1 and Table 2 are shown below as 20 sample sets of 7000 different feature sets. Table 1 is composed of Data Sent, Data Received, Ram Usage and CPU Usage data related with Power consumption. Table 2 is also arranged with same Power consumption feature including Room Temperature, Room Humidity and CPU Temperature.

Table 1. Feature Set Sample-1

Count	Data Sent	Data Rec.	Ram Usage	CPU Usage	Power
1	-1.00000	-1.00000	0.11995	-0.35276	-0.43816
2	-1.00000	-0.99999	0.12018	-0.35400	-0.43193
3	-0.99997	-0.99996	0.11973	-0.35027	-0.51395
4	-0.99901	-0.99643	0.11995	-0.29903	-0.65183
5	-0.99861	-0.93881	0.11551	-0.08696	-0.46395
6	-0.99566	-0.80287	0.12440	-0.06881	0.23755
7	-0.99540	-0.78507	0.13685	-0.20385	0.13330
8	-0.99450	-0.77065	0.13396	-0.10350	-0.02860
9	-0.99552	-0.80758	0.13574	0.04790	0.05235
10	-0.99628	-0.82394	0.13641	-0.08980	-0.22804
11	-0.99560	-0.79145	0.13952	-0.04284	-0.24032
12	-0.99521	-0.77360	0.13952	-0.26932	-0.20313
13	-0.99497	-0.76261	0.14064	-0.23213	-0.24050
14	-0.99450	-0.74063	0.14130	-0.29814	-0.35863
15	-0.99402	-0.72141	0.14419	-0.29013	-0.35560
16	-0.99412	-0.72264	0.14931	-0.08714	0.21336
17	-0.99338	-0.68808	0.15220	-0.34048	-0.09710
18	-0.99340	-0.68844	0.15220	-0.34066	-0.11863
19	-0.9909	-0.66381	0.15620	-0.32749	-0.19993
20	-0.99456	-0.80625	0.162221	0.05128	0.07032

Table 2. Feature Set Sample-2

Count	Room Temper.	Room Humidity	CPU Temper.	Power
1	-0.54152	-0.48942	-0.00370	-0.43816
2	-0.54152	-0.48915	-0.00370	-0.43193
3	-0.54152	-0.48876	0.03189	-0.51395
4	-0.54170	-0.48931	0.03189	-0.65183
5	-0.54134	-0.48828	0.04968	-0.46395
6	-0.54152	-0.48828	0.17422	0.23755
7	-0.54134	-0.48773	0.12084	0.13330
8	-0.54134	-0.48811	0.08526	-0.02860
9	-0.54152	-0.48757	0.15642	0.05235
10	-0.54134	-0.48779	0.12084	-0.22804
11	-0.54152	-0.48790	0.10305	-0.24032
12	-0.54134	-0.48795	0.08526	-0.20313
13	-0.54152	-0.48773	0.10305	-0.24050
14	-0.54134	-0.48714	0.13863	-0.35863
15	-0.54152	-0.48779	0.13863	-0.35560
16	-0.54134	-0.48795	0.12084	0.21336
17	-0.54152	-0.48757	0.15642	-0.09710
18	-0.54134	-0.48724	0.17422	-0.11863
19	-0.54134	-0.48811	0.12084	-0.19993
20	-0.54152	-0.48762	0.19201	0.07032

The 7000 feature sets of data will lead us to train and test our ANN. It could be noticed that Table 1 and Table 2 have different kind of parameters related with same power consumption rate.

The data is being derived simultaneously by means of Industrial PC and appropriate I/O connections as shown project layout at Fig.2 .This layout consists of a DAEMS, an industrial PC, a server , energy analyzer, temperature and humidity sensors, etc.;

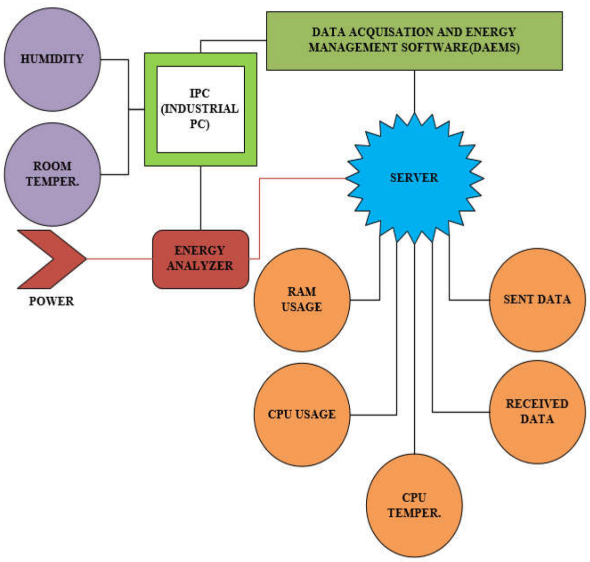

Fig. 2. Project layout

A developed software named as DAEMS (Data Acquisition and Energy Management Software) was created in C# programming language and will be used for collecting data which mentioned above. DAEMS works on the server and have connection with industrial PC. DAEMS has capability of accessing internal parameters of the server and runs simultaneously with all connected devices.

DAEMS is a basic server-client based program which could be used with many Industrial PC and many servers connected to it. DAEMS asks to industrial PC about temperature, humidity, power consumption and to server about its specific internal parameters. DAEMS fetches internal data from Server such that; Ram Usage, CPU Usage, CPU Temperature, Sent Data and Received Data.

Another software which works on industrial PC was developed in Structure Text programming language to read from ambient status (Temperature and Humidity) and power consumption. Structure Text is a kind of PLC programming language which is defined in the International Standard IEC61131-3.

Industrial PC has appropriate input and output modules which are used to interact with IPC and temperature and humidity sensors. Industrial PC is used to collect room temperature, room humidity and consumed power by server which was measured by an energy analyzer connected to power supply of the server.

Energy analyzer is used to measure not only power but also voltage and current data consumed by the server. Energy analyzer is directly connected to industrial PC via Ethercat interface.

Depending on the application, different kind of analyzers could be used at data centers or IT systems to record power consumption and other parameters. Analyzers could differ from the numbers of measurable energy phases, the accuracy of the measured parameters and some other criteria.

Fig.3 and Fig.4 show that the relations between input features and consumed power for 7000 independent data sets which were sampled at Table 1 and Table 2 before. These figures were implemented after some processes on data sets like normalization according to activation function.

According to these figures, there is no linear correlation between input features and output-power consumption.

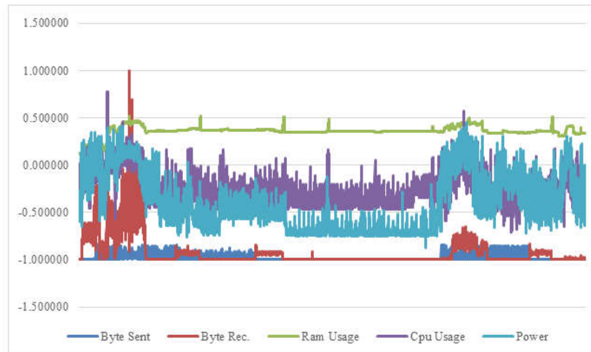

Fig. 3. Relations with power for Table 1.

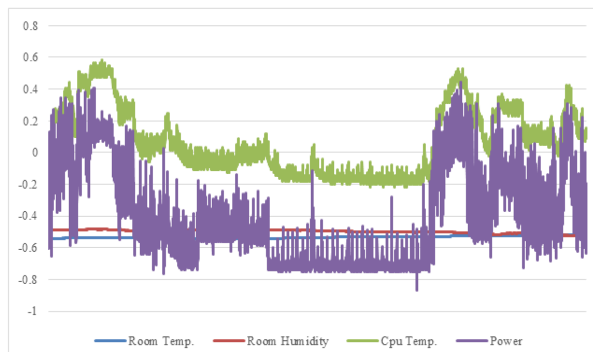

Fig. 4. Relations with power for Table 2.

2.2. Artificial Neural Networks

Neural networks are a class of machine learning algorithms that mimic cognitive behaviour via interactions between artificial neurons [7]. They are advantageous for modelling intricate systems because neural networks do not require the user to predefine the feature interactions in the model, which assumes relationships within the data. Instead, the neural network searches for patterns and interactions between features to automatically generate a best fit model. Common applications for this branch of machine learning include speech recognition, image processing and autonomous software agents [8].

A software which was created in C++ programming language was used for implementing a custom designed artificial neural networks.

In our multi-layered feed-forward Artificial Neural Network (ANN), the back propagation algorithm is used. This means that the artificial neurons are organized in layers, and transmit their signals forward, and then the errors are propagated backwards multi layer perceptron (MLP) model is composed of 3 layers named as input layer, hidden layer and output layer in our design. Backpropagation algorithm which is a popular neural network learning algorithm is used to teach neural networks. Eventually, the features derived by DAEMS before, will be input parameters for our neural networks.

2.3. Implementations

Many nonlinear interdependencies make difficult to understand and optimize energy efficiency to predict electric load. Therefore, a custom designed software (DAEMS) was developed for assessing the relevant parameters.
DAEMS links to industrial PC via ethercat connection and derive these parameters which are about temperature, humidity and voltage. Meanwhile, DAEMS works to read server parameters simultaneously and all logs were being saved external data record file. This file is used for training network and test the performance of the neural network. Training data is normalized depending on selected activation function which is hyperbolic tangent for this paper. To increase the efficiency of the learning algorithms some specific methods were implemented such that;

- Stochastic learning,
- Shuffling the examples,
- Normalizing the Inputs,
- Using hyperbolic tangent functions,
- Choosing target values,
- Initializing the weights,
- Choosing learning rates,
- Adaptive learning rates [11].

The neural network utilizes 7 normalized input variable-neuron at input layer, 32 nodes at hidden layer and 1 normalized output variable-neuron. %65 of the dataset is used for training with the remaining 35% used for testing. Totally, 250 initial weights were chosen between nodes for network.
The network repeats the process until the error reaches an acceptable value which means that the neural network is trained successfully or exceeds the target EPOCH quantity. In this paper 15000 Epoch numbers are used to end the process. After teaching neural networks Error/Epoch graph is shown as below;

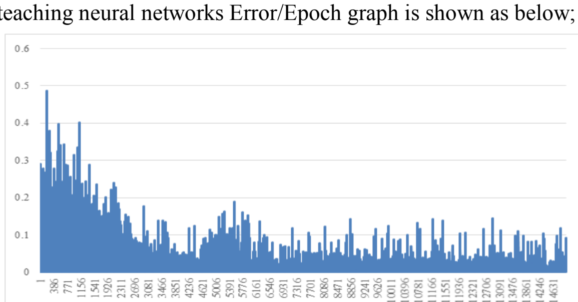

Fig. 5. Error / Epoch

Training procedure results with Error / Epoch graph and appropriate weight values.
Afterwards, test data set is used to verify the performance of the neural networks with real and forecasting consumed power. Test data set feeds input layer of the network and calculate the power output by means of the weight value of between of each neurons.

Finally, the neural network output demonstrates the predicted power consumption that have quite similar curves with the actual power as shown in Fig.6.

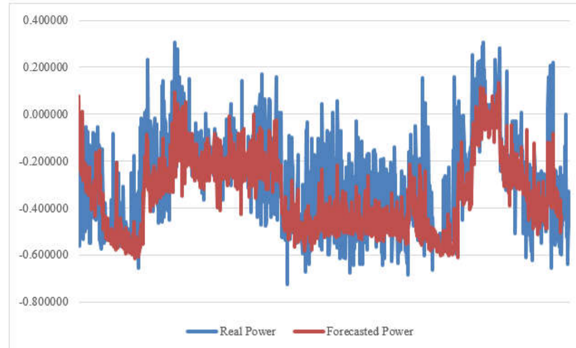

Fig. 6. Load forecasting

This model of application for data centers and IT systems indicate that it is possible to;

- predict load profile of the new or existent data centers and IT systems rely on independent variables,
- evaluate the energy efficiency performance,
- determine the optimization opportunities for energy consumption.

3. Conclusions

The application of artificial NNs to forecasting problems has been much studied in recent times, and a great number of papers that report successful experiments and practical test have been published.
The main purpose of this paper is to explain how to predict the energy consumption of a data center or an IT system by using appropriate devices and software. There are many economic and environmental reasons to optimize and reduce energy consumption of these big scale facilities. Our design was implemented in the means of an individual server because of applicability and reachability problems on a big scale data center.
To be able to accomplish our goal, many different kinds of products (Industrial PC, Server, Energy Analyzer, and Temperature Sensor etc.) has been brought together. Besides, three different software has been created for this project including an ANN implementation software as mentioned before.
There has been used a MLP model and some other specific and practical methods to teach our ANly.
All of them were gathered, designed, programmed or modified for succeeding to find a nonlinear interdependencies between input features and actual power which were independent variables.
In this paper, a method of application for modelling data centers in the means of a server was introduced and could be extended for big scale data centers and IT systems by using additional different features such that cooling system parameters, outdoor wind speed, pumps, etc.

4. Acknowledgements

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5. References

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