

IOT and Machine Learning based Building Energy Management

Leo Raju¹, Vallaba Gurunath² and Roshan Darran R³

¹⁻³Department of Electrical and Electronics Engineering, SSN College of Engineering, Kalavakkam, Chennai, India - 603110
Email: leor@ssn.edu.in, ²hemamurugan2000@gmail.com, ³roshandarran193001087@eee.ssn.edu.in

Abstract—One unit of energy saved is two units of energy produced. There is more talk on new energy generation and renewable energy than Energy conservation. This paper implements the building energy management and conservation using advanced technologies like Internet of Things (IOT) and Machine Learning. This paper mainly focuses on energy conservation through building automation and energy management through sensors and actuators using advanced IOT technologies. The building appliances are sensed through various types of sensors and controlled using Arduino for optimal use of electricity in the building. Monitoring and control of all the electrical appliances of the building is done through the handheld devices. The unnecessary use of electricity due to carelessness of the customers is identified and controlled remotely using the mobile application. As the energy consumption is monitored continuously all the time which eventually brings awareness about use of energy. Machine learning algorithms are used for accurate load forecasting leading to effective building energy management.

Index Terms— Building Energy Management, Internet of Things, Arduino, Machine Learning, Energy Management.

I. INTRODUCTION

The importance of green building is increasing predominantly. In previous decades the use of energy was less compared to the present usage of it. People mercilessly use it without knowing the future consequences. Building automation is where living is made comfortable and more efficient and economical. It is easy to operate and optimize energy consumption. Excess energy consumption led to various effects like global warming and less availability of energy in successive decades. The term “economical” refers to giving value to money spent on this system and mainly makes sure efficient and sustainable usage of energy. Internet of Things (IoT) is emerging as one of the important concepts for bringing the idea of "Smart City" into existence. It finds applications in various sectors including health, retail, automobile, agriculture, energy etc. The most popular application of IoT is found in smart grids and building automation. The review of home energy management system is given in [1]. Here, various home energy management papers are discussed. Various home automation and energy management methods and concepts are discussed here. The performance improvement in home energy management is discussed in [2]. Here, the energy savings due to improved performance is discussed. Implementation details of IOT and cloud are discussed in [3]. Here, IOT based energy management is discussed. Building energy management using IOT is discussed in [4]. Here how the energy usage in building is reduced is discussed in detail. Details of various sensors used in IOT is discussed in [5]. Here, various sensors and actuators

used for IOT are discussed. Zigbee and PLC for home energy management is discussed in [6]. Here, ZigBee as a communication medium to sense and actuate through PLC are discussed for home automation. But the distance of control is limited in ZigBee. Various technologies for home automation and energy management are discussed in [7]. IOT for building energy management is discussed in detail in [8]. Energy management in smart cities are discussed in [9]. Mobile based Home Automation using Internet of Things (IoT) is discussed in [10]. In all the references building automation and energy management is not comprehensively discussed to improve the energy efficiency. IOT based home automation using Rasberri Pi is discussed in [11]. Here energy is measurement is not implemented but only automatic control of appliances is discussed. Machine learning for prediction of energy is discussed in [12]. Various algorithm of machine learning for energy prediction is discussed here.

This paper presents an advanced method of building automation by using Arduino as the microcontroller and also energy is measured for individual appliances. Arduino is used along with several sensors, actuators and mobile application which enables the user to control the electrical appliances and thereby controlling energy consumed in their building. The user can check the energy consumption through the mobile application, and the application also gives constructive suggestions to conserve energy utilization. Also, machine learning is used for accurate load prediction for optimal usage. The paper contains information about the proposed system, hardware and software requirements and implementation.

II. HARDWARE REQUIREMENT

A. Arduino UNO

Arduino Uno is a microcontroller with 14 GPIO pins and an operating voltage of 5V. This microcontroller acts as a central link of communication between the sensors, actuators and mobile application as shown in Fig 1

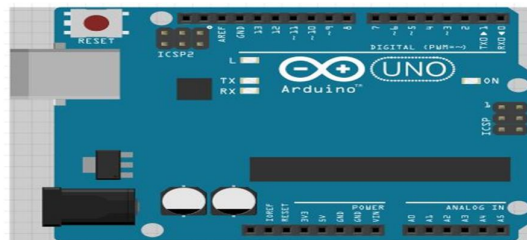


Figure 1. Arduino Uno

B. ACS712 current sensor

ACS712 is a hall-effect based current sensor which gives voltage output equivalent to the current flowing through the circuit. It is connected in series with the load to find the amount of current flowing through the circuit, thereby we can find the power and energy consumption of the load as shown in Fig 2.



Figure 2 ACS712 current sensor

III. PROPOSED MODEL

Here we consider two classrooms of the building with all the appliances as shown in the Fig 3. We measure energy using IOT and it will be displayed on the mobile to create awareness about the consumption of the electricity and also we can control the appliances to stop the unnecessary usage. Arduino receives input from all the sensors and send it to cloud (Ubidots) through NodeMCU.. Then the energy is measured and displayed in the mobile device using Blynk App. The App is also used to control all the appliances of the building.

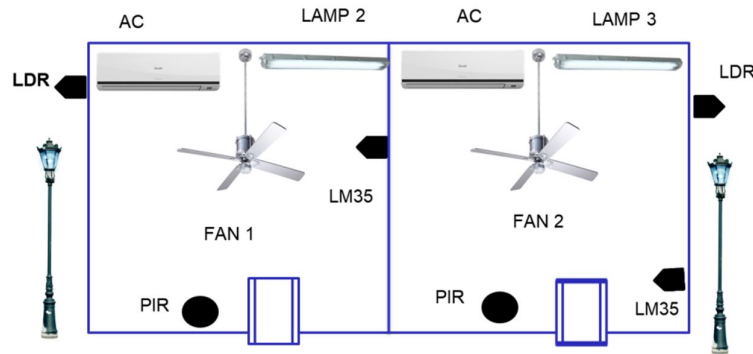


Figure .3 Proposed Prototype model

This is only sample of the whole building and so the work can be extended for the whole building. Then, we use machine learning to predict the load of the building so as to plan well ahead for optimal use of energy

A Proposed system and block diagram

In this system, Arduino is used as a microcontroller which controls the entire automation process. The Arduino board is connected to sensors, actuators via GPIO pins and to mobile application as shown in Fig 4. The sensors detect the physical quantities of the surrounding like temperature, light, motion, current etc. and communicates with Arduino. The microcontroller will act on the received data and accordingly control the actuator, i.e., the relay, which in turn switches ON/OFF the appliance.

The control can be either Automatic or User Defined. In Automatic control, the Arduino controls the appliances on its own depending on the predefined conditions set, whereas, in User Defined mode full control of the appliances lies with the user. The energy consumed by each appliance is measured and then displayed to the user via the mobile application. At any point of time the user will be able to see the energy consumed in their smartphone.

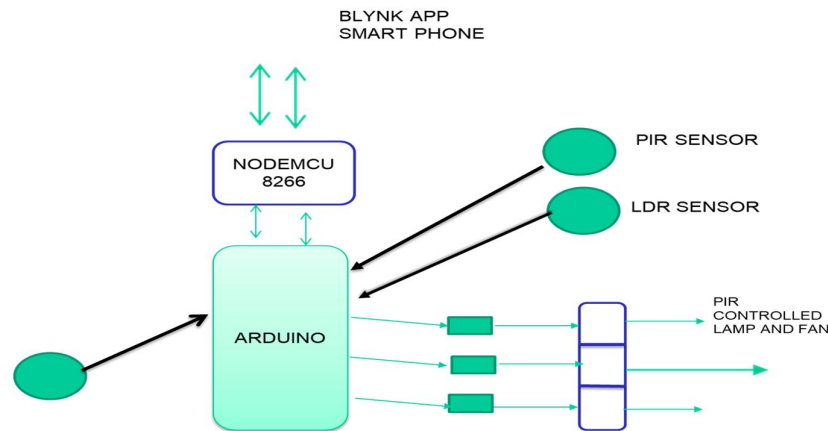


Figure. 4 The block diagram of the system

The data sent to Arduino from the sensors is analyzed using Machine Learning algorithms to create a predictive model which will tell the user constructive suggestions like areas of high-power consumption, minimization of electricity consumption etc. to optimize energy usage.

IV. HARDWARE IMPLEMENTATION WITH AC LOAD

The hardware circuit is shown in the Fig 5. The load used is 0.5W, 240V, 50Hz Lamp. To measure the current flowing through the circuit, the current sensor (ACS712) is connected in series with the load and supply. The

output from sensor is connected to analog pin A0 of the Arduino Board, which is then connected to a laptop/PC. The code is entered in Arduino IDE software and executed.

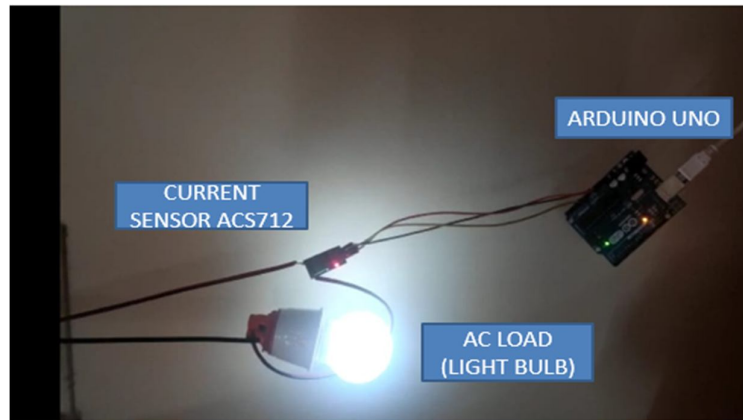


Figure 5. Hardware Implementation for AC Loads

The RMS value of current consumed by the load is obtained in real-time. Power consumed by the load can be found by multiplying the current value obtained with rated voltage value (which is, 230V constant). The output obtained from the hall sensor is displayed on Arduino IDE is shown in Fig.6,

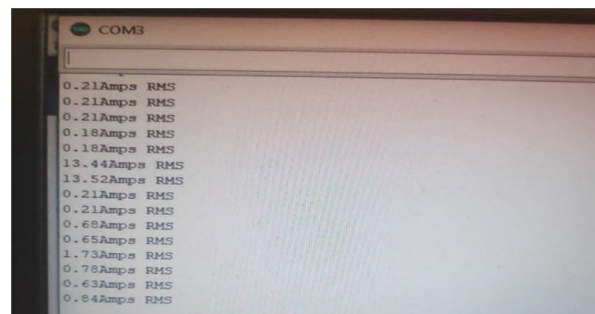


Figure 6 Output obtained from current sensor on Arduino ide

V. SOFTWARE IMPLEMENTATION: CONTROL USING MOBILE APP

The Arduino is connected to sensors which read the real time data from the environment and sends it to NodeMCU, which in turn sends the data to cloud Ubidot. This data stored in the cloud platform is accessed through Bylnk app. Initially Bylnk app is authorized using a token and all the libraries of the app is installed in the Arduino. Arduino IDE programming is done with all the necessary conditions and uploaded. Thus, the app obtains the current status of the house i.e. all the devices which are currently using electricity and also the power consumed by each, and shows that to the user. Then the user can control which appliances to on or off with the app based on the logics provided in the program. Thus, we provide an app-based user control as well as power measurement of individual appliances. Hence, we can optimize energy consumption in the building and regulate the electricity bill. The 8-channel relay is connected to Arduino to include 8 loads which are represented as buttons in smart phone as D0 to D7.

VI. MACHINE LEARNING

Artificial Intelligence (AI) is creating impact in many fields. AI mimics the human brain. Machines can emulate actions of human brain. They have capacity to learn and solve problems like human being. They also have the ability to think rationally and act. Machines are able to think and make smart decisions. AI can be used to optimize learning outputs. Machine learning is a subset of artificial intelligence. It allows software applications

to predict the outcome from the given datasets by understanding their pattern. Different algorithms are used based on the type of datasets.

A. Load Details

We have calculated all the loads in Electrical department building in our institution. Depending upon the lab and lecture schedule the load are calculated. The load curve for the EEE block is shown in below in Fig .7.

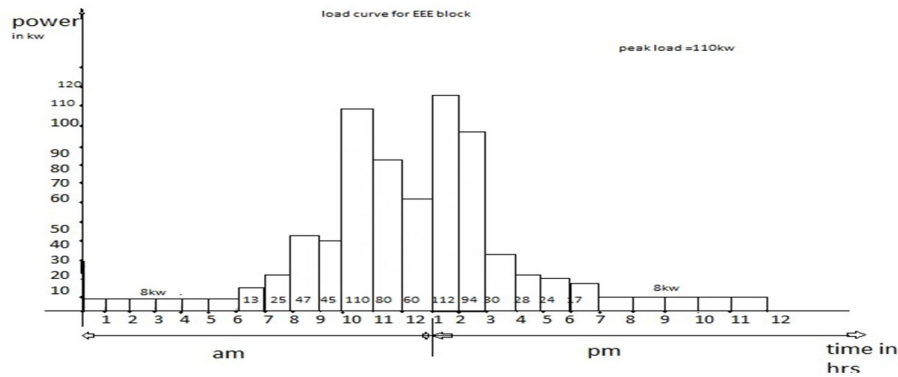


Figure 7. Load pattern

B. Load Prediction using Machine Learning

Machine Learning (ML) refers to the ability of systems to learn and improve from experiences or data without being explicitly programmed. In general, data or examples are observed to learn patterns and then, improved decisions are made using the learned patterns or features. ML algorithms are generally categorized as supervised learning (SL), unsupervised learning (USL), semi-supervised learning (SSL), and reinforcement learning (RL).

C. Supervised Learning

Mach In supervised learning, the output for given input is known and the algorithm learns the mapping function from input variable to output variable. Full set of labelled data is used to train a supervised learning algorithm. Prediction and classification problems are generally solved using supervised learning algorithms. Some popular supervised learning algorithms are linear regression, support vector machine, neural networks, decision trees, random forest etc.

D. Unsupervised Learning

Unsupervised learning algorithms extract useful features and patterns in the given data. Afterwards, data can be organized in various ways. One of the most common applications of unsupervised learning is clustering, where the algorithm looks for data that are similar to each other and groups them together. Unsupervised learning is also used to detect anomalies and to reduce the number of features. Unsupervised algorithms includes k-means clustering, hierarchical clustering, and principal component analysis (PCA).

E. Semi-Supervised Learning:

Semi supervised learning algorithms are trained on a combination of labelled and unlabelled data. Typically only a small portion of the data is labelled. Many of the real world machine learning problems fall under this category. Transductive support vector machines (TSVM), artificial neural network are examples of commonly used semi supervised learning algorithms.

F. Reinforcement Learning:

Reinforcement learning trains an algorithm with a reward system. An agent (learning algorithm) performs an action in an environment (object). The environment provides feedback consisting of next state and reward. The agent updates its knowledge and evaluates its last action based on the reward. Examples of reinforcement learning algorithms include q-learning, state action reward state action (SARSA), deep q network (DQN).

G. Dataset and Data Pre-processing:

The dataset consists of 5 columns namely the Date, Time, Load, Day, Temperature recorded in Electrical and Electronics Department. And Time (in hours), Load (in KW), Day (1 for Working, 0 for Holiday) and Temperature (in Fahrenheit). The feature 'Day' is taken in numeric values as a Regression model accepts only numeric values to train upon. Identifying null values is an important aspect in data pre-processing as it might lead the model to underfit. There are two main ways to avoid these null values, either remove the entire row containing null values or replace the null value with the mean of the entire column. Now the data is ready to be trained. The split up of data for training and testing is in the ratio 1:4 for all models.

VII. MACHINE LEARNING ALGORITHMS

The Regression algorithms used for predicting and forecasting load are Decision Tree, Random Forest, Gradient Boosting and Support Vector Machine (SVM). All the algorithms are implemented on Jupyter Notebook in Python Language. Accuracy of each model is depicted using Mean Absolute error and Mean square error.

A. Decision Tree Regression

Decision Tree is a decision-making like algorithm that uses a flowchart-like tree structure. It is a model of decisions and all their possible outcomes. Decision-tree algorithm comes under the category of supervised learning algorithms. It works fine on both continuous and categorical output variables. Decision tree regression identifies features of an object and then trains a regression model similar to a structure of a tree to predict data in the future to produce continuous meaningful output. Continuous output denotes that the output is not discrete. The model runs excellent on Decision Tree Regressor giving 0.1722 MAE and 0.5537 MSE. The prediction and actual value plot is given below in Fig.8.

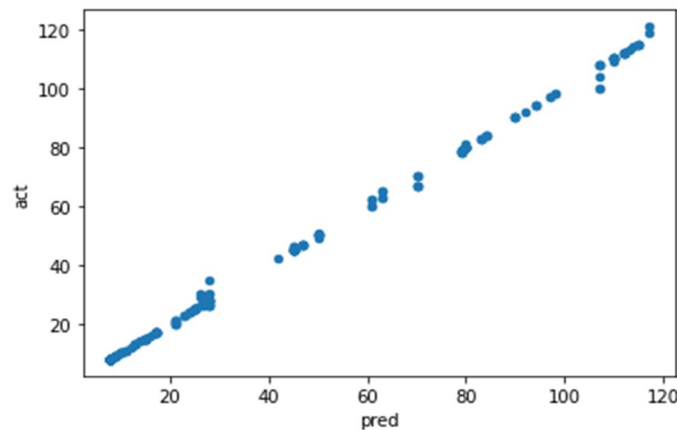


Figure.8. Decision Tree Regression output

B. Random Forest Regression

A Random Forest is a combination technique which is capable of performing both regression and classification tasks/models with the use of many decision trees. This is achieved by the techniques called Bootstrap and Aggregation, more commonly known as bagging. The formal idea behind this is to group multiple decision trees in order to determine the final output rather than depending on individual decision trees. In simple terms, Random Forest has multiple decision trees as base learning models. Initially, we randomly perform row sampling and feature sampling from the dataset forming sample datasets for every model. This part is called Bootstrap. On the given data this model performs even better than Decision Tree giving us 0.0219 MAE and 0.1308 MSE. The plot of predicted and actual values are shown below in Fig.9.

C. Support Vector Machine

Support Vector Machine(SVM) is a supervised machine learning algorithm used as both classification and regression models. It's best suited for classification. But many prefer it for regression models too. The aim of

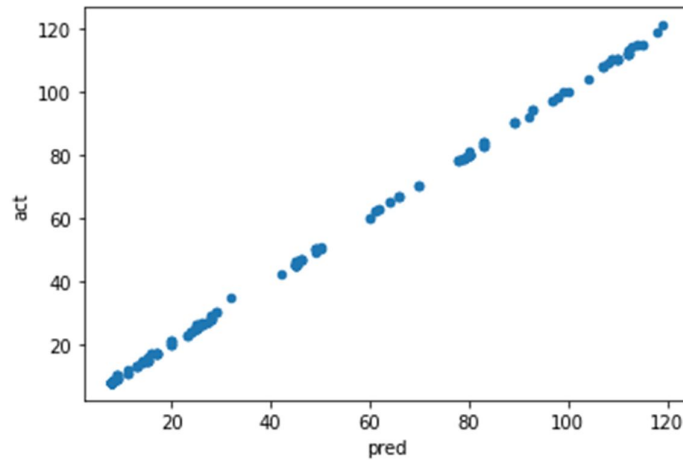


Figure.9 Random Forest Regression Output

SVM algorithm is to find a hyperplane in a N-dimensional space that definitely classifies the data points. The dimension of the hyperplane depends upon the number of features. If the number of input features is two, then the hyperplane is a line. If the number of input features is three, then the hyperplane becomes a 2-D plane. It is difficult to imagine when the number of features exceeds three or even more. In our case SVR doesn't give the required results as the MSE and MAE were a bit too high than Decision Tree And Random Forest Regressors..The plot between predicted and actual values are depicted below in Fig 10.

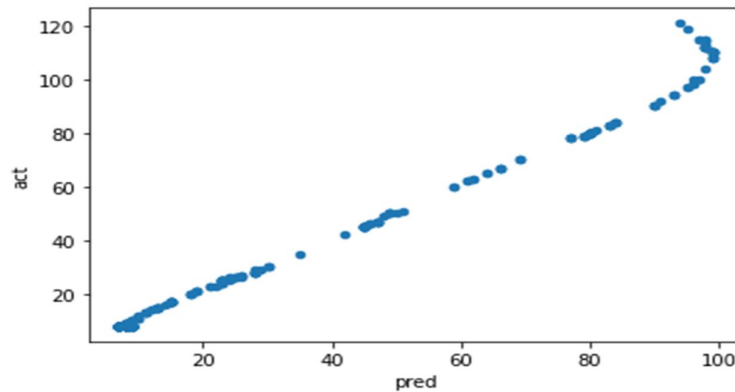


Figure 10. Support Vector Machine(SVM) output

It was found during visualisations that the higher values i.e., Load>100KW.Thus, giving us lower performance. This might be due to high number of features. The recorded values are 10.672 MSE and 1.158 MAE.

D. Gradient Boosting

Gradient Boosting is a popular boosting algorithm. Gradient boosting is one of the boosting algorithms it is used to minimize bias error of the model. In gradient boosting, there exists a lot of predictors wherein, each predictor corrects its predecessor's error. In distinct to Adaboost, the weights of the training initiatives are not tweaked, instead, each predictor is trained using the residual errors of predecessor as labels and the base estimator is not mentioned by us. There is also a technique called the Gradient Boosted Trees where the base learner is CART (Classification and Regression Trees). Among all four non-linear algorithms Gradient Boosting came out to be the best with 0.003 MSE and 0.0053 MAE. The plot between predicted and actual values is given in Fig 11.

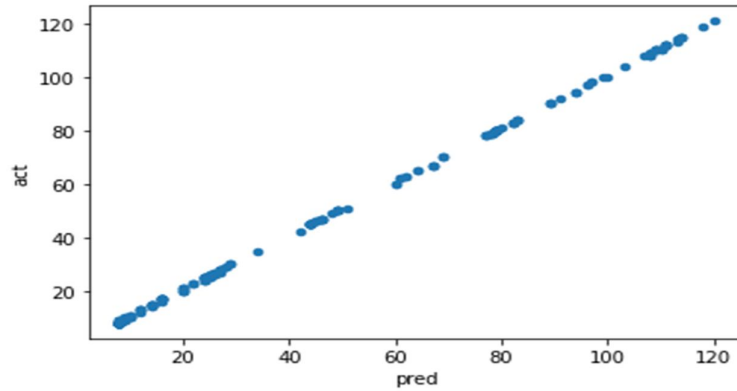


Figure 11 Gradient Boosting

TABLE I. COMPARISON OF ALGORITHMS

DECISION TREE	RANDOM FOREST	SUPPORT VECTOR MACHINE	GRADIENT BOOSTING
MSE:0.5537	MSE:0.1308	MSE:10.672	MSE:0.003
MAE:0.1722	MAE:0.0219	MAE:1.158	MAE:0.0053

From table I from the values of MSE, MAE we can say that Gradient Boosting regression is the best algorithm when compared to other three algorithms.

VIII. CONCLUSION

Building automation and energy management is implemented in this paper using Internet of Things. By continuously monitoring the energy usage, an awareness is created about the usage of energy. Moreover, warning messages force the consumer to be more economical towards the use of energy. The customer controls the appliances with convenience and hence improves energy efficiency of building by remotely powering off systems and appliances when they are not in use. Machine learning is used to predict the energy consumption accurately to plan well ahead for the future loads. Recent research trends involving various machine learning techniques in load prediction have been discussed. A Regression model's accuracy is generally depicted by the terms Mean squared error (MSE), Mean Absolute error (MAE), Root mean squared error (RMSE) and R-squared. We have successfully trained our data on decision tree, random forest, support vector machine and gradient boosting algorithms. Out of which, from the above values of MSE, MAE we can say that Gradient Boosting regression is the best algorithm for our given data Energy saving leads to economic utilization and environmental benefits. This work can be expanded with advanced communication and internet technologies for optimal use of energy in university campuses.

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