UNIVERSITY of RWANDA

*Research and Postgraduate Studies (RPGS) Unit*

ACEIoT

# DESIGN OF AN ENERGY EFFICIENT SYSTEM FOR SMART HOME


**MEELA, Angel Gabriel**

**Ref. No: 219011247**


***A dissertation submitted in partial fulfillment of the requirements for the award of***

**MASTERS OF SCIENCE DEGREE IN INTERNET OF THINGS**

**In the College of Science and Technology**

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**MASTERS OF SCIENCE DEGREE IN INTERNET OF THINGS-WIRELESS INTELLIGENT SENSOR NETWORKS.**

**In the College of Science and Technology**

**Supervisor: Dr. Damien Hanyurwimfura**

**Co supervisor: Dr. Diwani Abbubakar**

**December 2020**

## Declaration

I solely declare that, this work is mine. No part of it or whole has been submitted anywhere for qualification of any academic award. The content of this work is the product of the project carried out since the approval of research activities. All the guidelines, ethics and procedures has been followed during it's preparation.

Signature: 

Name: ANGEL GABRIEL MEELA(Reg. No.219011247)

Date: 20th December 2020

# Bonafide Certificate

Bonafide Certificate

This is to certify that the dissertation report work is a record of the original work done by **Ms. Angel Gabriel Meela** a graduate in MSc in Internet of Things (IoT) with specialization in Wireless Intelligent Sensors Networks (WISeNet), at University of Rwanda – College of Science and Technology in African Center of Excellence in Internet of Things (UR/CEST/ACEIoT). We certify that the work reported doesn't form a part of any other research project.

**Co-supervisor:**

**Dr. Abubakar Diwani**

**Main Supervisor:**

**Dr. Damien HANYURWIMFURA**

| **The Head of Masters and Trainings** |
|---|
| **Name:** |
| **Signature:** |

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May God bless you all.

## Abstract

Technology has been developing every day in human life. The need for the advancement of technology is to lead human life comfortable. The use of Internet of Things is changing the face of development in all sectors of human life and it can be used for successful implementation of energy efficient buildings and hence lead to total reduction of electrical energy consumption in different aspect of human life. Due to presence and an increase in smart home technology it has led to increase of the need of intelligent learning of the inhabitant's and detecting their activities such as security, energy efficient automation, resource management. However, uses of IoT has not been effectively utilized in many developing countries in Africa where energy is not properly used for the domestic and other purposes. Power consumption has become a great problem due to inefficient use of appliances and unreliable occupancy detection. Therefore to provide the specified solution different smart sensors are installed in a house to automate the house and to detect motion and occupational of inhabitant in the room/house so that to make sure there is energy efficient. The energy usage is recorded and support vector machine (SVM) algorithm is used to predict the future usage of energy. The evaluation results of the system show that the proposed systems provide a smart home with energy efficient compared to the non-smart house energy system and thus the recommendations for smart house for household in developing countries in Africa.


Keywords: IoT, Smart Home, Energy Efficient, Energy Consumption Prediction.

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# CHAPTER 1 INTRODUCTION

## 1.1 Overview

Smart home is the house which is automated and can be controlled remotely and has ability to adapt the environment. By Adapting we mean that it can learn to identify the activities and change accordingy without human intervation. Therefore, an agent for smart home need to be caple to predict the movement of inhabitant and device occupation. By the use of prediction algorithms we can have an active and intelligent house hence making it more smarter. Smart home acts as a normal agent, observing the home by sensors and acting on through the actuators. The key purpose of a smart home are to use technology to provide residents with comfort and convenience, security, efficiency in management of various home resources such as electricity and water and to remove repetitive actions[1].

The recent discovery of other areas of research in Information and Communication Technologies have given rise to the use of IoTs as a tool that can be applied for implementing important projects such as efficiency energy supply, process large amount of data, automation and also used to increased security and privacy of data. According to [2], IoT is an aspect of ICT which uses various different algorithm together with methods to achieve communication in various things(physical devices) in order to achieve several aims. IoT technology involves the use of several sensors, communication infrastructure and physical equipment such as home appliances and industrial equipment to provide valuable data that allows professional in the field to offer different kinds of services to people in many forms. Due to rise of IoT there is a great emerging in smart homes in which energy efficiency is the key. A smart home is described as house which is automated and can be controlled remotely [3].

According to Paware et al [4], there is a major increase of power appliances which makes emergency concern in the energy sector and as a result brings inequality in the proportion of energy demand and energy supply. Inorder to deal with increase in energy demand there is a need to be a closer eye on demand energy management. There has been a greater focus on energy management with the goal of minimizing the total costs of power without affecting the consumption side by choosing to decrease electrical consumption throughout busy hours. Energy suppliers seek to design and develop variable and portable structures to provide for an extensive variety of customers for harmonizing the whole system. Cost cutting algorithms on the period of demand and user comfort ability level with bodily information features are embedded within different IoT environment.

IoT in recent times has been widely applied in the areas of smart homes, smart city, environmental monitoring system, health care systems and services, drone based-services and efficient management of energy buildings. It is changing the paradigm as regards to energy consumption based on human needs and sustainability. Demand for energy is expected to remarkably rise in the coming years due to population growth, the economy will rise and the need for comfortability as well. According to [5], energy consumption worldwide increased up to 2.3% in 2018 which has doubled since 2010.

The goal of the Smart Homes is to maximize comfort and safety, optimize energy usage and eliminate strenuous repetitive activities. It is high time for home owners to properly utilize the available electrical energy in an efficient manner so as to reduce costs while maximizing users comfort. Therefore, in this thesis we design a system that will ensure energy efficiency in smart homes.

## 1.2 Background and Motivation

To a great extent data is growning due to increase of the use of smart devices which collect, connect, transfer and exchange a large amount of data. Innovation is inevitable in this technology era (The fourth Industrial revolution).With the rise of technology smart home is a need and not an option, back in a time smart homes were for rich people or we can say it was a prestige but currently they have become more common and important due it’s advantages to peoples life.

Due to this rise of new technogies such as Cloud computing, Internet of things, data science, Artificial intelligence a large number of sectors benefit. By combining these technologies we get more improved results. As for our thesis we also use algorithms for prediction in Internet of Things so that we get an active smart home. For this case we will use Support Vector Machine algorithm to improve efficient of the smart home by predicting future use of electricity.

## 1.3 Problem Statement

The use of energy for various forms has become one of the main focuses of discussion in the world today while power consumption is a great problem due to the increasing number of IoT devices, inefficient use of appliances and lack of occupancy prediction. It is therefore imperative that we come up with improved algorithm for energy efficient in smart homes as the prediction results obtained from the prediction algorithm can be used to automate interactions with the home. A lot of electrical energy is wasted by leaving the room/house lights ON; TV's are left ON while they are not in use and other home appliances. Considering that energy efficiency being one of the key drivers of Sustainable Development Goals, it has being established that the use of sensor devices in the energy sector largely improves diagnostics, decision-making, analytics, optimization processes and integrates performance metrics. In order to address the problem identified above, this study proposes to use prediction algorithm to control and monitor appliances in smart home.

## 1.4 Study Objectives

### 1.4.1 General objective

To propose energy efficient algorithm for smart homes.

### 1.4.2 Specific objectives

i. To review energy usage and cost implication in homes.
ii. To review the existing energy efficient algorithms and smart home architectures in IoT .
iii. To design improved energy efficient system for homes.
iv. To predict forthcoming energy usage in homes and how they can bring energy efficient by the use of algorithm.

## 1.5 Study Scope

Our focus in this thesis is to propose improve energy efficient for smart homes. The study will cover, review of the existing smart homes and their cost implication, review smart home architectures and their application and also reviewing existing energy efficient algorithms. The study will use algorithm to ensure the smart home is automated and active and also it observe energy efficient. Some sensors and actuators are used for data collection and questionnaire will be used to get users opinion. This work can be used  in all existing smart home to improve energy efficient.

## 1.6 Significance of the Study

This study  enable us to enable us to collect data and to do evaluation if the proposed energy efficient algorithm, also it will provide an education tool for other students doing projects related to smart home. We also expect that this work will benefit  smart home users and hotels. Also successful completion of this thesis will lead to publication and award of Masters degree.

## 1.7 Thesis contribution

This study designs of an intelligent smart house systems and predicting future Energy usage in smart homes which helps in maintaining efficient use of devices as most of the existing works did't observe inhabitant's movements/behaviour in the whole house to obtain energy efficient.

## 1.8 Organization of the Study

This document will be organized as follows chapters:

1. Deals with different effort done by other researchers on appliactions and services of smart home. Various prediction model and activity recognition methods. Specially, we emphasis more on theworks done on sequential prediction models, as it relates to our proposed algorithm.
2. Chapter two reviews various smart home projects and architectures done by other researchers, methodologies and technologies used in there projects.
3. Chapter three demonstrates smart home testbed model, The researcher also discusses the physical components and architecture of the smart home testbed in deep.
4. The researcher focus on data analysis and the prediction model, collects raw data from the testbed and then do preprocessing of the collected data to be made suitable for the prediction model.
5. Shows the results obtained from the data collected and analyse them. The resercher also shows the data collected by running tests on the smart home testbed and the results obtained after pre-processing data for testing the prediction model.
6. Summarizes the work done in the thesis and recommendation for future improvement.

## 1.9 Conclusion

The use of energy has become the main focus since a lot of electrical energy is wasted by inefficient energy use incorporated with inhabitant habits. With the rise of technology this problem is solved by the introduction of the Smart home which is automated and can be controlled remotely and has the ability to adapt to the environment, this is done by the use of prediction algorithms and thus brings about the proper energy use. Therefore Smart homes will bring significance via the collection of data and evaluation of the energy usage and thus support individual buildings and the hotels in an effective sustainable way.

# CHAPTER 2 LITERATURE REVIEW

## 2.1 Overview

In the most recent years, there has been an expanding energy cost due to factors such as weather issues, demand and supply, economic issues and others. Despite of this users are not aware of analysing their energy usage to make sure that there is energy efficiency and to save costs [6]. For example, in the United States, in any event 30% of the energy consumed by private and business customers is wasted[7]. These motivate scientists and energy industry to concentrate on creating solutions that help clients to analyse, control, and spare energy at home, just as to discover elective energy sources, for example, wind and sun [8].

We briefly review various research areas interconnected to building smart homes with an emphasis on the efforts related to the work presented in this thesis. As it's known the purpose of a smart home is to provide the residents with a better home life experience, a more sustainable smart home by using dynamic and adaptive computing algorithms and technologies which respond to the needs of the residents. With the pervasive sensors in place in the smart homes for monitoring occupants' activities, behaviors of utilizing resources, users' comfort and resources stored, several research efforts focus on analyzing the collected data to develop occupation and utilization pattern recognition and prediction as well as adaptive algorithm design to react to active occupants needs. In this chapter we will focus on the following;

- smart home application areas,
- occupancy prediction, and
- adaptive algorithms.

Mind you that, we do not review technological aspects of related works such as smart home architectures, hardware, or the communication system. We will briefly talk about that in next Chapter.

## 2.2 Smart home application areas

One way of categorizing smart home research efforts is based on the services or application area that can be offered by the smart home technologies to their users. These works focus on improving or optimizing such services based on the application areas. At this point, we concisely revise three main application areas of smart homes including management of resources, security and healthcare.

## 2.3 Resource Management

Basic resources in smart home environments comprise energy such as water,gas and electricity. Effective managing of such resources are essential for making more sustainable and cost efficient smart homes[9]. As such, many research efforts in the area of smart homes focus on analyzing resource demands of residents, predicting demands and proposing new algorithms for improving the resource utilization in the smart homes. More recently, researchers have proposed using energy storage in presence of real time electricity prices to cut costs. The basic idea in most of these works is to store cheap electricity during low-price off-peak periods and then later use the stored energy during peak periods, thereby cutting costs. There has also been work on economics of scaling energy storage across a number of homes with today's variable pricing plans[10] .

A large portion of such works address automation and optimization of the heating/cooling systems [11] and lighting systems [12] for smart homes. Besides the heating/cooling and lighting systems, a large body of work is emerging in general electricity consumption management for smart homes, while considering the smart grid status, renewable energy availabilities and electric vehicle charging scheduling in smart homes[13]–[15] . In particular, energy is an important resource that is the key enabler of all the other smart home services and technologies. The electrical appliances, for instance, fridge, washer/drier, entertainment systems, HVAC (heating, ventilating and air conditioning) systems, sensors and communication devices, result in high-energy consumption in the home environment. Many smart homes have deployed renewable energy resources [13], [14] to help reducing the energy cost of smart homes as well as increasing their sustainability and reducing carbon. Incorporating weather prediction in resource management of smart homes has also been considered in recent works [14]. Here, we give few examples of specific approaches that address various aspect of resource management system. In [16], the authors proposed a heterogeneous hierarchical sensor network architecture to monitor resident behavior. Data collected by the sensors was used to create user profiles and based on the user profiles as well as the real-time data provided by the system the authors developed a prediction model for the residents' energy utilization behavior, which was then used to optimize energy consumption of the smart home using Device Virtualization Environment (DVE) to automatically set system parameters. In [17] the author presented an enhancement of an energy efficient algorithm for building HVAC control based on real time occupancy prediction, with this algorithm electricity bill will be reduced to some extent. To make it more energy efficient I suggest controlling also lights as a way of improvement. The idea behind smart home is using technology to get comfort, security, convenience, automation and efficient use of energy and other utilities.

Authors in [18] developed a Markovian model of the smart buildings for different periods in a day for predicting electricity consumption, which helps the home energy management system. Similarly, in this thesis we also provide an energy management example, which will be explained in detail later.

## 2.4 Classification-Based Models

Classification is the task of predicting the class label for a test dataset given a training dataset with defined class labels. The classification algorithm processes a training set of attributes and tries to discover relationships between them. For example, in [45], the authors used feature extraction and classification to predict user context based on past behaviors. Some examples of classification techniques are neural networks, decision tree classifiers, rule-based classifiers, and support vector machines. In smart home applications, neural networks can be used to predict the activities based on the values of each sensor. This can also be used to detect any

anomalous behavior [46]. Similarly, decision trees can be used to monitor the series of events within the smart home and allow the monitoring system to respond consequently [47]. Another classification technique called support vector machines (SVM) can be suitable in applications where the training sample is smaller. For example, the authors in [48] used SVM to classify the activities of daily living using the information collected from various smart home sensors and devices. As seen in the various techniques discussed above, in general, the classification model is trained on multiple attributes of training data and their respective classes, and is provided with the current state of attributes as the test data. So, they are more suitable for activity or

behavior prediction when there are multiple number of features to be considered.

Therefore, in smart home application, classification–based models can be used for activity prediction when the attributes of the smart home like device status, device usage patterns, etc. are taken into consideration. In this thesis, a classification-based model for prediction is not suitable as we consider only a single feature, which is the occupancy or mobility of the smart home inhabitant.

## 2.5 Security

Security is another important service that the smart home technology can offer to its residents. Conventional home security systems help in securing the home from intruders, whereas, smart home security systems offers more benefits like fire and smoke detection, intruder detection, and home monitoring and surveillance. Here, we briefly review few of works related to the smart home security. In [19], the authors discuss the smart home security application and review tools and technologies to provide security services for the smart home residents. Devices like fire and smoke sensors and alarms can protect the residents by notifying them in case of an emergency. Motion detectors, cameras, security codes, etc. provide a means of securing the smart home premises by determining whether the person is a resident or an intruder. These passive sensors can also learn the normal movements of the residents like elderly people, and thus, notify the users or family members in case of an emergency or odd movement patterns. Other works such as [20] [21], [22] introduce and review technologies such as ZigBee, GSM (Global System for Mobile Communications), WLAN (Wireless Local Area Network) and RF (Radio Frequency) wireless to provide a surveillance for security applications. There have been several research efforts e.g. [23] to provide data privacy in these pervasive computing environments. While people want to benefit from the services of the smart home, privacy turns out to be a serious concern, as the residents are not assured of discreetness of their activities, movements, etc.

## 2.6 Health care and Elderly care Applications

Sick people and elders needs to remain free at home, guaranteeing their security at home requires checking and tele mindful, which could be executed by depending on keen home advances. Identifying falls, wellbeing observing and coordinated drug are a couple of instances of social insurance and older consideration administrations. These administrations ought to be performed without upsetting the client, and without being meddlesome or bringing about any development limitations. There have been a few research endeavors concentrating on different kinds of these administrations, and we quickly audit a couple of models here. In [24], the author proposed a framework for crippled individuals to caution them about episodes that can happen in their home. The framework utilizes information from sensors and plays out an investigation to distinguish episodes. The occupants are told of these episodes by their cell phones. An utilization of brilliant home innovation in old consideration is proposed in [25], which attempts to distinguish strange conduct of the old individuals. Repeating neural systems are utilized to foresee estimations from the sensors dependent on the development conduct of the inhabitant. The guardian is educated in the event that any abnormal conduct is anticipated in not so distant future. The authors of [26] propose an execution of a smart home condition to enable older and impeded individuals to live in ease. The different gadgets in brilliant home like lights, HVAC framework, temperature and smoke sensors, security and crisis frameworks, and so on can be controlled and worked by a solitary controller. Along these lines, individuals with inabilities or headway troubles can without much of a stretch work all appliances utilizing this controller from any place in the home.

## 2.7 GatorTech Smart House

The Mobile and Pervasive Computing Laboratory at the University of Florida developed a smart home project known as GatorTech Smart House [27]. It consists of a number of smart devices such as smart mailbox, smart front door, smart mirror, smart bed, etc. The main objective of this smart environment is to assist the elderly and disabled residents and make their life more comfortable. To create this smart home, they developed an architecture as shown in the Figure 1 below.

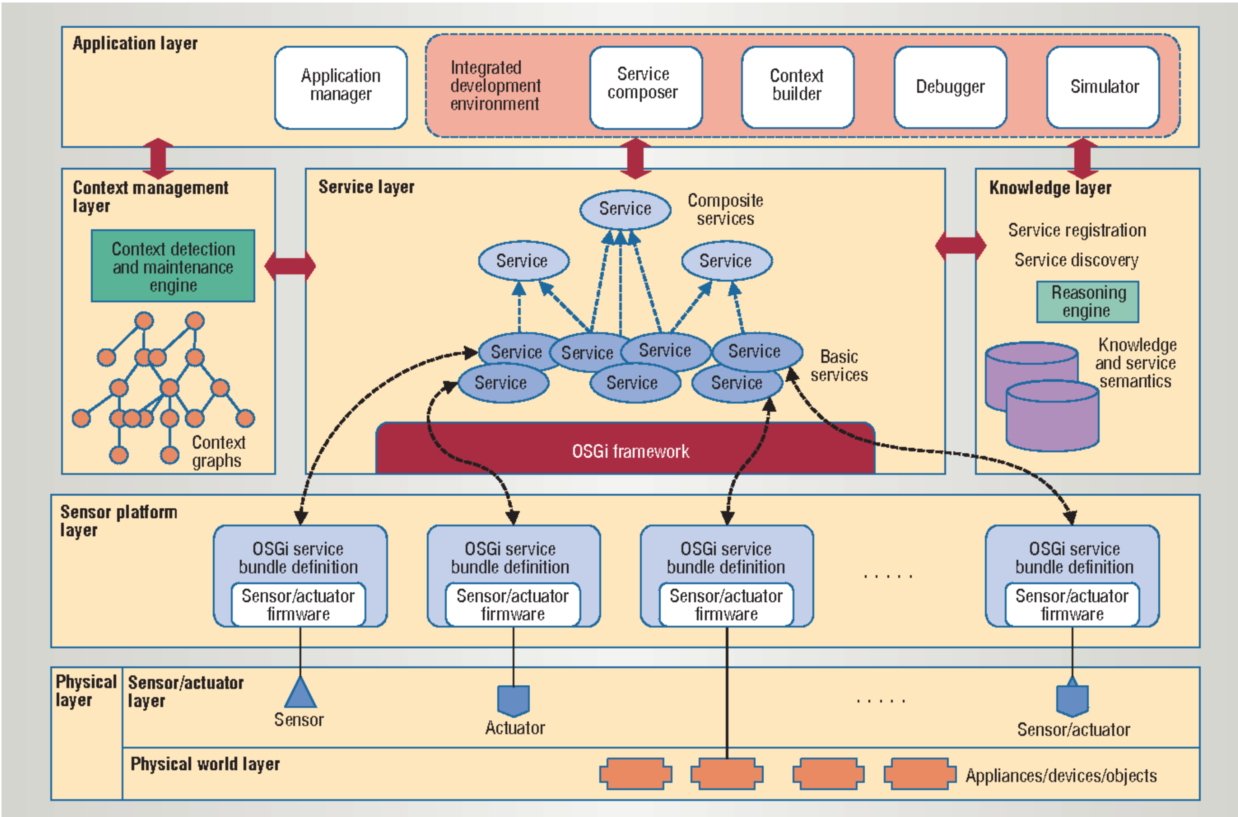


***Figure 1: Gator Tech Smart Home***

Specifically it was designed to assist the elderly and the disabled, the goal of this project is to create assistive technology using smart devices that can sense themselves and the residents, and create mappings between the physical space, remote monitoring and the intervention services.

## 2.8 The Adaptive House

M. Mozer et al. [28] at the University of Colorado, Boulder have built an adaptive smart home that can program itself based on the lifestyle of the residents. A residence in Colorado fitted with the necessary equipment like HVAC system, various sensors, lighting systems, etc. was chosen as the house for the experiment. The house monitors the environmental parameters and observes the actions of residents. It learns the residents' preferences, schedules, and occupancy patterns and uses this information to anticipate their needs. The house also learns their comfort levels using setpoints manually set by the residents. Using the knowledge of residents' schedules and comfort levels, it can make decisions to conserve energy and cut costs without causing any uneasiness. The general architecture of the control model for this house has modules such as occupancy model, predictors, state transformation and device regulators. Specifically, the prediction model used in this testbed is based on neural networks trained with self-supervised learning.

## 2.9 MavHome (Managing An Intelligent Versatile Home)

The MavHome smart home is a research project at the University of Texas at Arlington, focused on creating a smart home that acts as a rational intelligent agent with an objective to maximize inhabitant comfort and minimize operation costs [29].

MavHome has four layers of operation to achieve its purpose. Thus, MavHome smart environment uses this hierarchical architecture, as shown in Figure 2 below, to gather information and use this knowledge to improve the inhabitant experience. As a part of the MavHome architecture, they introduce prediction algorithms such as LeZi Update algorithm for location management that can be used to determine the location of the inhabitant.

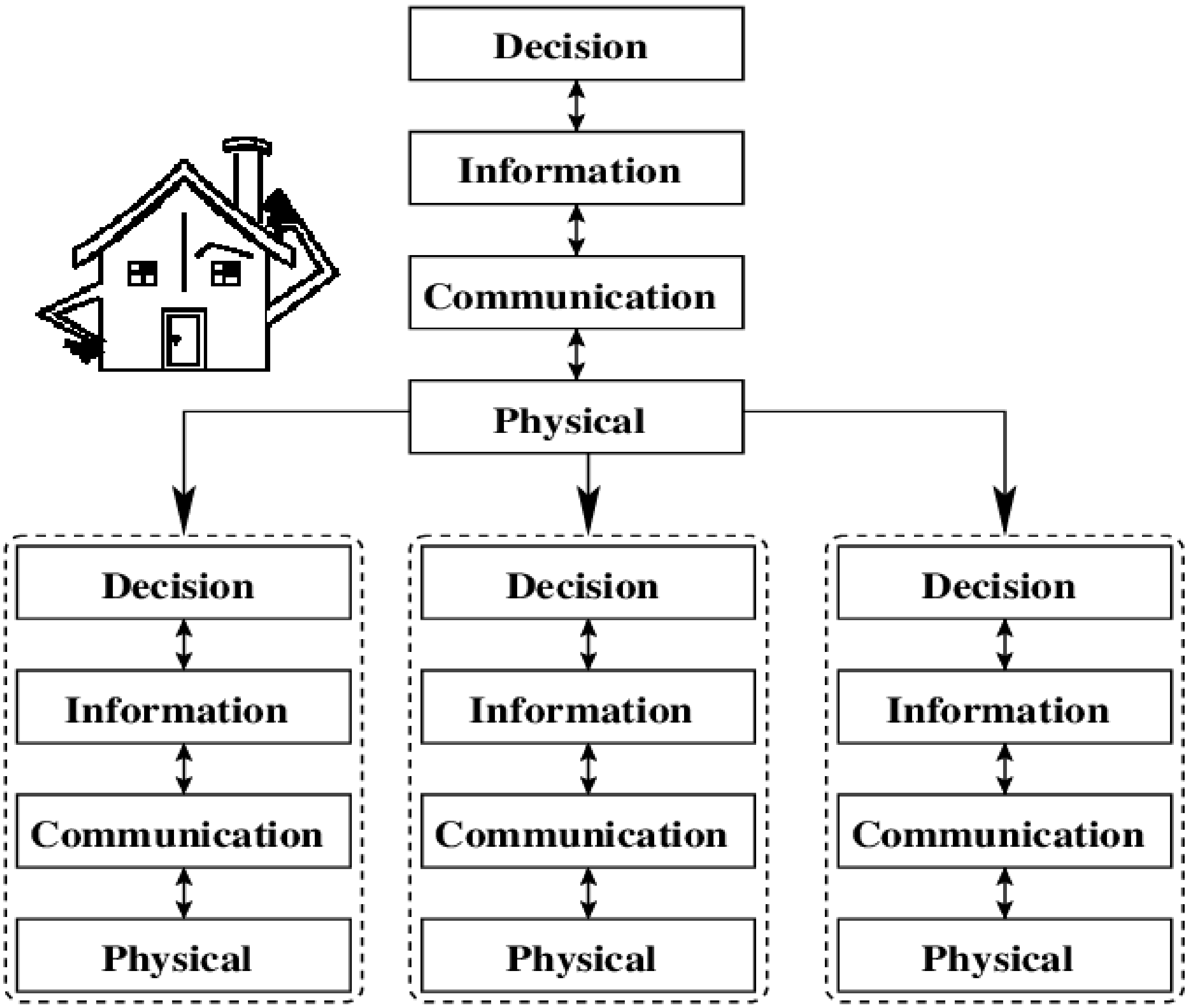


*Figure 2: Architecture of MavHome*

## 3.0 Conclusion

The above existing works have been dealing with smart home in different ways but no one proposed a suitable system design to automate the house and to ensure efficiency of devices/appliances. So, this work targets to provide the specified IoT solution to the problem where an intelligent energy efficient system is proposed for efficient energy management.

# CHAPTER 3 AN IMPROVED ENERGY EFFICIENT SYSTEM FOR SMART HOME

## 3.1 Architecture for smart home test bed

This thesis focuses on obtaining more energy efficient system for smart homes. In this thesis, we have reviewed different designs and architectures for smart homes developed by several researchers and the applications of their approaches on various aspects on these environments. For this study we  use four layers architecture, See figure 3 below:

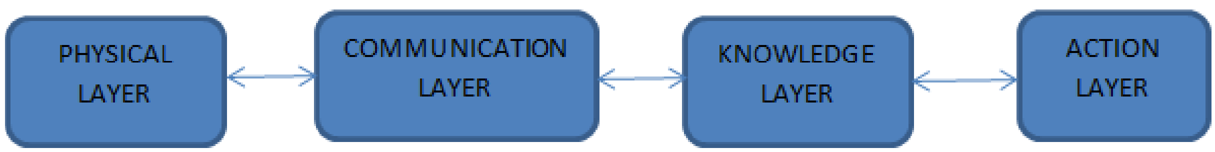


***Figure 3: Architecture for smart home testbed***

It operates following a right-left method. The sensors will be generating data at a certain time interval. The analog readings is passing through the communication layer to the microcontroller and then to the software module. Here preprocessing of data is done and then convert them to time series of events suitable for knowledge layer processing.

The converted data is in the form of a string of sequential symbols with their time stamps, which is suitable, specifically, for the prediction algorithms used in the model. Different algorithms, depending on the applications, is used in the prediction knowledge to optimize various operations in the smart home. The decisions made by the action layer are translated into actions using the coordinator, which sends the necessary control signals through the communication layer to the actuators such as the lighting system and fans. The following devices/equipments in figure 4 are used: Arduino uno, PIR, current and voltage sensor, relay and others.

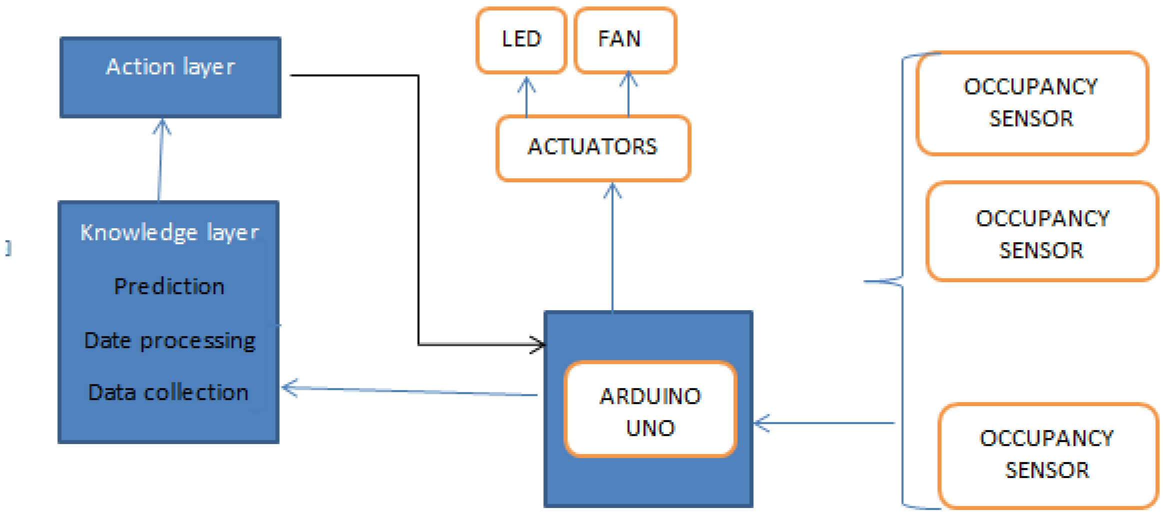


***Figure 4: Opeartion model of the smart home***

## 3.2 System Block Diagram

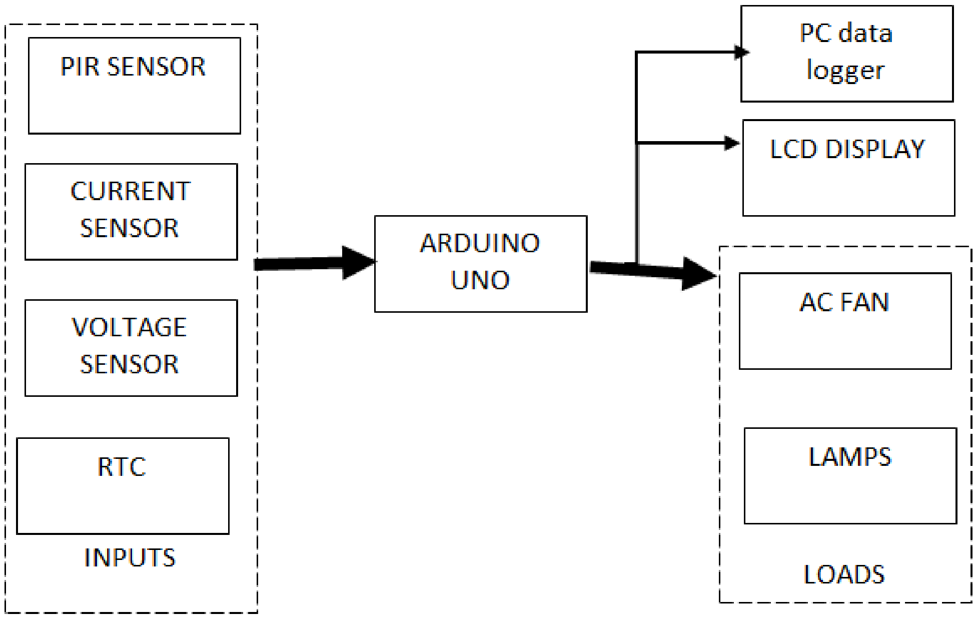


***Figure 5: System block diagram***

## 3.3 Components description

The main objective function of the proposed system prototype is to control electricity consumption by automatically turning off appliances and lights when the room is unoccupied. The system is made up of diffent devices as shown above in figure 5.

- Input components
    - Input sensors
        - PIR sensor: Passive Infrared Sensor is used to detect presence of a person in a room.
        - Current sensor: ACS712 module uses hall effect to detect current consumption of the loads. Its output signal is fed to the ADC pin of Arduino. See the current sensor below in figure 6.

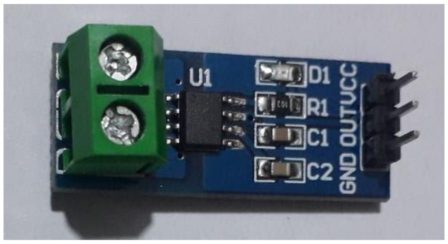


***Figure 6: Current sensor***

- Voltage sensor in figure 7 shows a combination of step-down transformer, diode and voltage divider resistors forms the AC voltage sensing part of system.

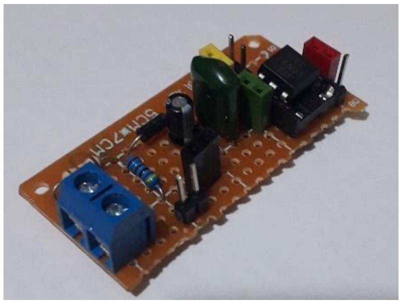

***Figure 7: Voltage sensor***

- Real Time Clock (RTC): provides accurate timing for different events and tasks in the microcontroller. Below in figure 8 is the diagram for RTC.

***Figure 8: Real Time Clock***

- Processor/controller
    - Arduino uno microcontroller: is the brain of the system, it performs various decisions and calculation based on the input signal from sensors. Arduino also interfaces with the PC for data logging.
- Output components
    - LCD display: provides a visual status information about the system status. When motion is detected by PIR it is displayed on the LCD along with voltage and current levels. See figure 9 below:

***Figure 9: LCD display***

- Electrical loads: electrical loads are represented in the system by lamps and AC fan. These are used to represent appliances that may be found in a household and to facilitate studying how the system can increase energy efficiency when used.
- PC data logger: The system's Arduino board is also interfaced to computer for data logging function, whereby system data such as voltage, current, power, person presence status are logged into an excel spreadsheet along with each data sample time stamp.

### 3.4 System Circuit Diagram

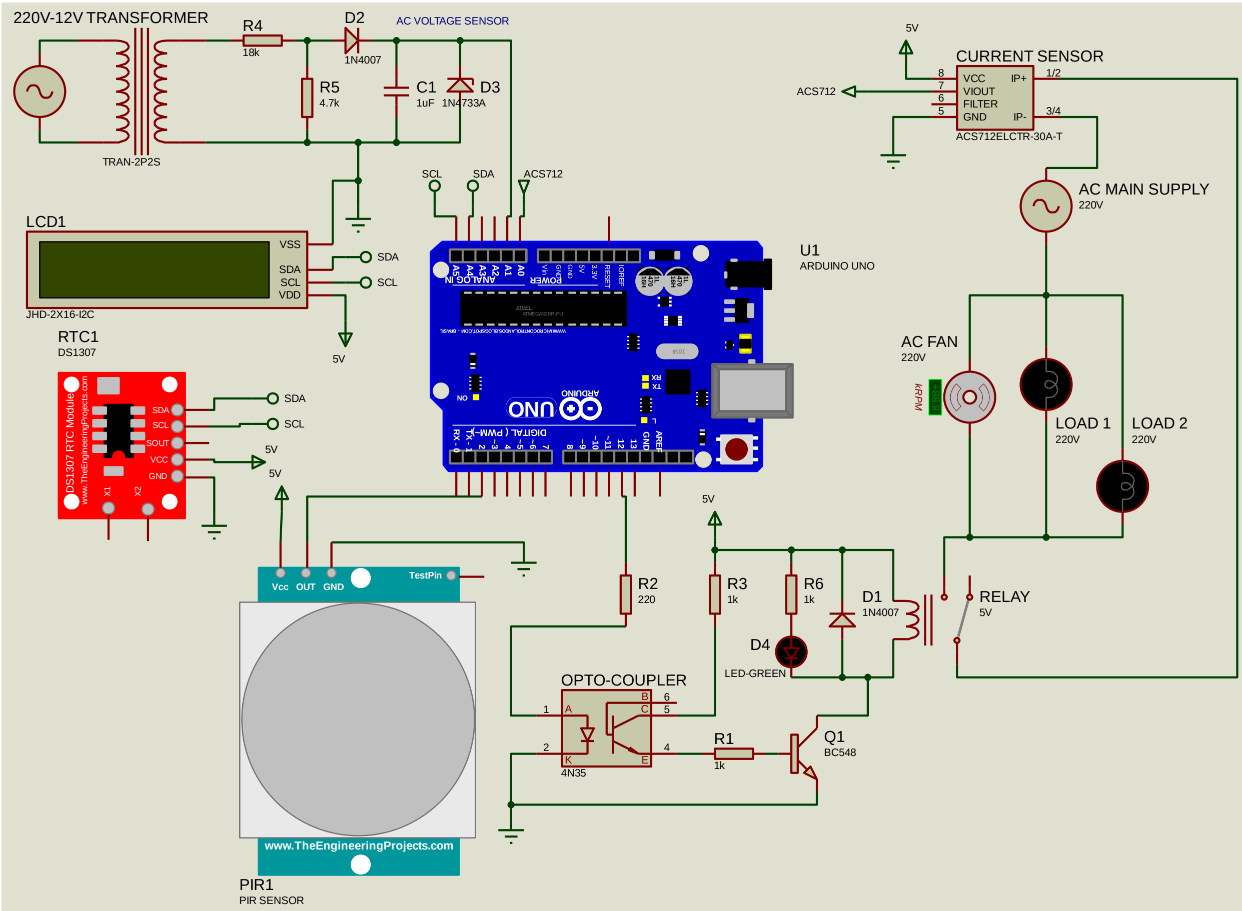


***Figure 10: System Circuit Diagram***

### 3.5 System operation

The Arduino uno microcontroller receives signals from the PIR sensor of logic 1 (high volts or 5V) each time the PIR module detects motion in a room. Otherwise Arduino senses LOW (0V) from the PIR module in absence of persons in a room. When a room is occupied and the PIR has detected presence of a person, Arduino turns on loads via opto-coupler isolator and 5V relay module. The ACS712 current sensor module gives current reading through hall effect. It actually sends voltage signals to Arduino which corresponds to current consumed. ACS712 module is interfaced to the Arduino through pin A0 which performs analog to digital conversion (adc). Voltage less than 5V from the voltage sensor sub-circuit is detected by Arduino from pin A1.

The voltage sensor circuit has a 5.1V Zener diode that protects Arduino input pin A1 against any over-voltage that may damage the module.  A 12V step down transformer is used to bring down AC voltage from typical 220V value to around 12V.  Thereafter signal passes through an 18k and  4.7k voltage divider circuit before being rectified by a diode to DC signal. Arduino then calculates the corresponding AC voltage given the ADC value sensed from pin A1. See the prototype diagram below in figure 11 and 12:

***Figure 11: Prototype outer view***

***Figure 12: Prototype inner view***

## 3.6 Machine learning selection and experimental setup

A case study of a smart home was used in this study. The house had 3 rooms where different sensors, appliances and data logger for experimental data collection were installed. Two types of data are being collected: total energy consumption data by using current sensor and voltage sensor and movement of a person by using PIR sensor. Data collected from the sensors through the micro controller are stored in excel sheet every 15seconds for further processing. Later, the data from the excel sheet are analyzed hourly for further interpretation.

Communication between arduino and the data log spreadsheet is achieved through the Arduino to PC usb programming cable which inherently sends data to the excel program though computers serial port. For this work, just the data that are identified with lighting energy utilization and fan to represent other appliances were used. The utilized dataset thusly comprised of lighting energy utilization and fan in 15 seconds interval and later converted to hourly basis for the purpose of data analysis.

For energy consumption and system experimentation, this research uses the energy data that was collected for a period of 3months (90 days) as shown in the table below. The energy consumption for smart hours and non smart house were collected for the purpose of validation of the proposed energy prediction algorithm. Figure below presents the power consumption in Smart home compared to Non smart home for the whole period of experiment. The results show that there is a significance decrease of power consumption when there is efficient use of appliances. A set of 63 days of data was randomly selected from the 90 days of data and was used for model training. The rest of the data were used for testing. The model was trained by using R programming language. The authors tried various kernels and algorithm parameters to increase the prediction performance. As outcome, the following parameters were used SVM-Type: nu-regression, SVM-Kernel: linear, cost: 150, gamma: 1, nu: 0.5, Number of Support Vectors: 33.

Procedure summary:

Data divided into two set:

1. Training set of 63 (randomly selected from 90 days of data collected)
2. Test set 27

Model used: Support Vector Machine (nu-SVM regression)

Summary(model)

Call:

svm.default(x = x, y = Training_set, type = "nu-regression", kernel = "linear",
  cost = 150)

## 3.7 Conclusion

Many research teams have developed smart home models to learn, and study various aspects of smart homes, develop new algorithms and technologies and to evaluate the efficiency of their proposed techniques. In this chapter, we reviewed some of the famous academic smart-home testbeds and their architectures. For our research purpose, we implemented a small-scale, smart-home testbed. We discussed the architecture and some of the physical components of this implementation.

# CHAPTER 4 SYSTEM PERFORMANCE EVALUATION

## 4.1 Perfomance Evaluation, Results and Discussion

### 4.1.1 Root Mean Squared Error

We evaluate the performance of our model by using Root mean square error (RMSE) and coefficient of variation (CV). Root mean squared error (RMSE) is the square root of the mean of the square of all of the error. RMSE is a good measure of accuracy, but only to compare prediction errors of different models or model configurations for a particular variable and not between variables, as it is scale-dependent. From the model we obtained RMSE of 176.87. Lower values of RMSE indicate better fit as RMSE is a good measure of how accurately the model predicts the response, and it is the most important criterion for fit if the main purpose of the model is prediction.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(x_i - \hat{x}_i)^2}{N}}$$

### 4.1.2 Coefficient of Variation

The coefficient of variation (CV) is the ratio of the standard deviation to the mean, where by the higher the coefficient of variation, the greater the level of dispersion around the mean. It is generally expressed as a percentage. The lower the value of the coefficient of variation, the more precise the estimate. From this study, the model has archived coefficient of variation (CV) =1.8%.

CV (%)=(SD/Mean)*100

$$CV(\%) = \frac{\sqrt{\frac{\sum_{i=1}^{n}(X_{predict,i} - X_{data,i})}{n-p}}}{\bar{X}_{data}} \times 100$$

Where

Xpredict,i=forecasted energy usage

by Xdata,i =actual energy usage

data X(mean)=mean energy usage

n= number of days selected randomly

p= total number of days

The figure 13 below shows the energy consumption in smart house compared to non smart house. As we can see in smart home there is efficiency usage of power and hence leads to low usage.

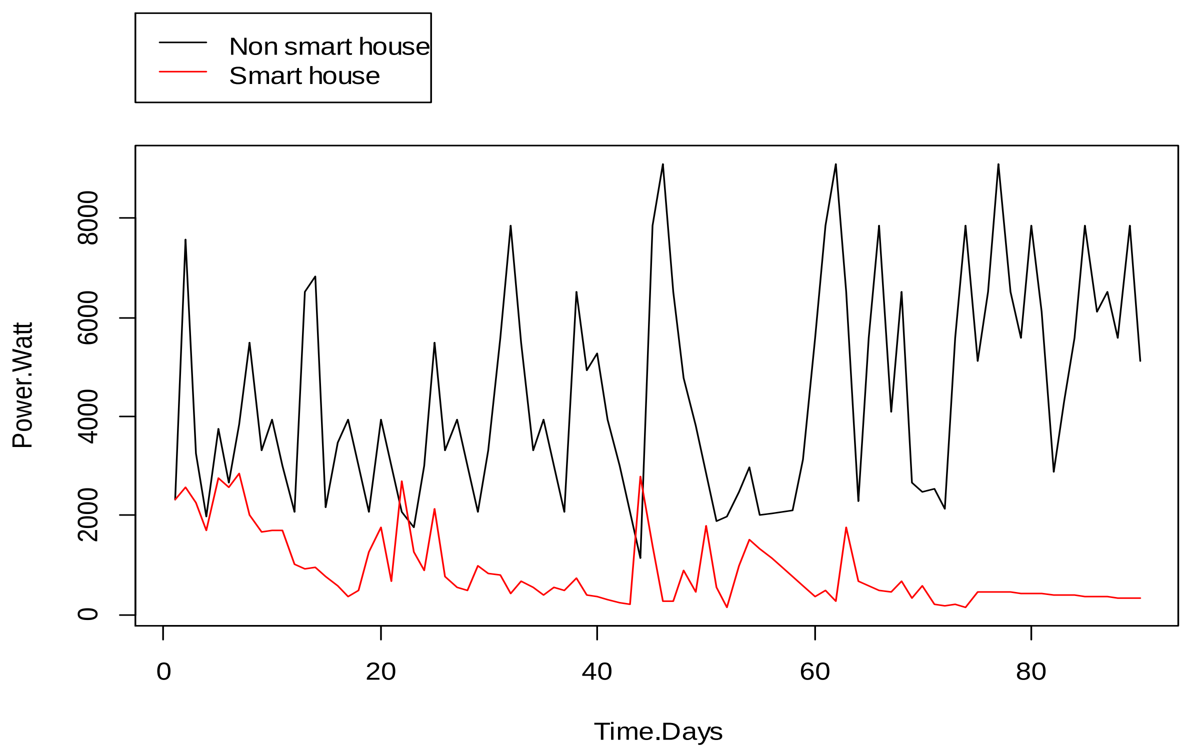


***Figure 13: Power consumption in smart home compared to Non smart home***

In this work we predicted energy consumption for the period of 27 days. It is then compared to the actual power consumption for smart house as shown in figure 14. The forecast outcomes demonstrated that the SVM model can possibly be effectively utilized for power consumption prediction.

For the future work it can be improved by considering behaviors of inhabitant's because they have a very big impact on energy consumption and also data from different homes can be used. Inhabitant behavior and actions can really affect energy consumption [30].

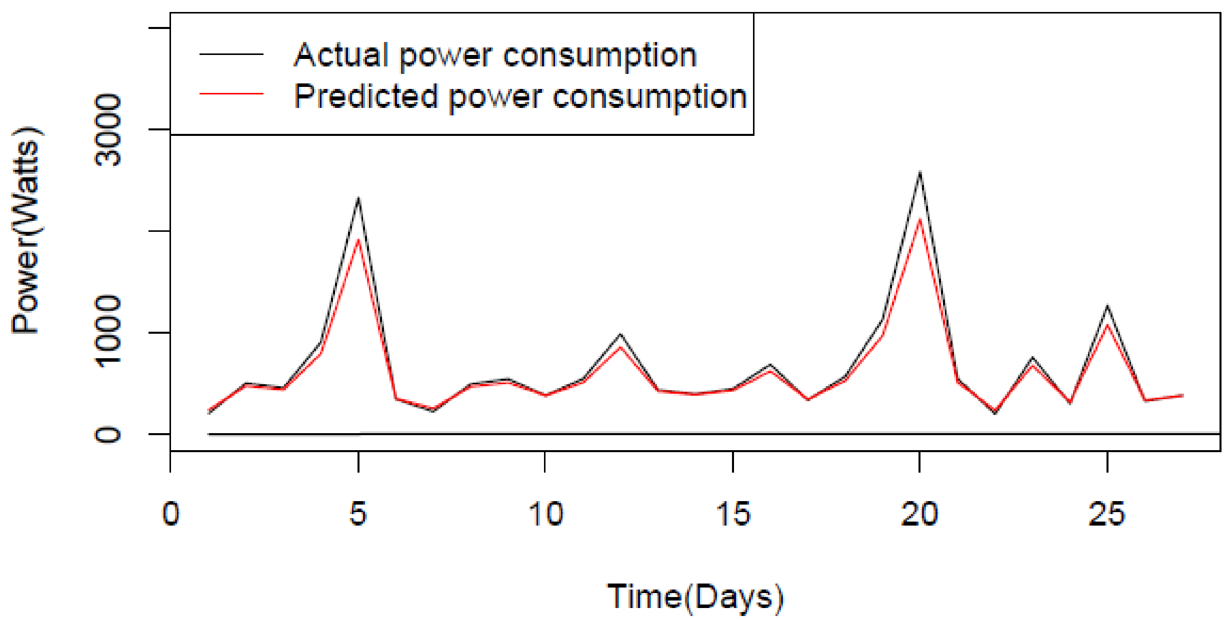


***Figure 14: Prediction results***

## 4.2 Conclusion

In this chapter, the researcher presented the performance evaluation results to compare smart house and non smart house and the results show that smart house can significantly reduce energy usage.

# CHAPTER 5 CONCLUSION AND FUTURE WORK

This study aimed at identifying the efficient solution by introducing the IoT devices taking consideration of inhabitant's movements for the problem of higher energy consumption which is due to inefficient use of appliances and lack of occupancy detection, and also prediction of power consumption. With respect to the contextual investigation introduced in this thesis, we found there is significance decrease of power consumption in smart house using the proposed method. In the future, we are planning to monitor other devices in the whole house through the mobile device and measure the energy usage of all appliances so that we can identify where they are spending more electricity. The captured data will be saved in the cloud for remote energy monitoring. This will motivate other people about the concept of smart home and the intelligent building, which is of more eco-friendly and thus saves energy for the future generation.

# Appendices

## Appendex A

Model

Summary(model)

```
Call:
svm.default(x = x, y = Training_set, type = "nu-regression", kernel = "linear",
    cost = 100)



Parameters:
   SVM-Type:  nu-regression
 SVM-Kernel:  linear
       cost:  100
      gamma:  1
         nu:  0.5

Number of Support Vectors:  33
```

## Appendex B

**Codes**

```
library(e1071)

library(rlang)

library(readxl)

smart_home_Data_hourly_SET <- read_excel("E:/ UNIVERSITY OF RWANDA/Angie_RWANDA/smart_home_Data_hourly_SET.xlsx",sheet = 'SMARTHOUSE')

View(smart_home_Data_hourly_SET)
```

```
attach(smart_home_Data_hourly_SET)

names(smart_home_Data_hourly_SET)

Training_set=sample(Power.Watt,63,F)

write.table(pred*1.5, file = "TrainsetNEW23.csv", sep = ",", col.names = NA,

        qmethod = "double")

Test_set=Power.Watt[1:27]

Test_set1=Power.Watt[1:45]

x=c(1:63)

model=svm(x,Training_set,type = 'nu-regression',kernel = 'linear',cost = 100)

print(model)

summary(model)

pred=predict(model,Training_set,decision.values = T)

pred

attr(pred, "decision.values")[1:4,]

plot(x, Training_set,type = "l",xlab = "Time(Days)",ylab = "Power(Watts)",col=c(1,2),ylim =
c(0,4000))

points(x, log(x), col = 1,type = 'l',lwd=1)

points(x, pred/3, col = 2,type = "l",lwd=1)

legend('topleft',legend = c("Actual power consumption",'Predicted power consumption'),col =
c(1,2),lwd = c(1,1))


Summary(model)
```

Call:

```
svm.default(x = x, y = Training_set, type = "nu-regression", kernel = "linear",
    cost = 500)


Parameters:
   SVM-Type:  nu-regression
 SVM-Kernel:  linear
       cost:  500
      gamma:  1
         nu:  0.5

Number of Support Vectors:  33
```

Prediction

```
library(e1071)

library(rlang)

library(readxl)

library(caret)

attach(NEW_DATASET)

names(NEW_DATASET)
```

```
smart_home_Data_hourly_SET <- read_excel("E:/UNIVERSITY OF RWANDA/Angie_RWANDA/smart_home_Data_hourly_SET.xlsx",sheet = 'SMARTHOUSE')

View(smart_home_Data_hourly_SET)

attach(smart_home_Data_hourly_SET)

names(smart_home_Data_hourly_SET)

Training_set=sample(Power.Watt,63,F)

write.table(pred*1.5, file = "TrainsetNEW23.csv", sep = ",", col.names = NA,

            qmethod = "double")

Test_set=Power.Watt[1:27]

Test_set1=Power.Watt[1:45]

x=c(1:63)

model=svm(TIME,ACTUAL,type = 'nu-regression',kernel = 'linear',cost = 500,metric='RMSE')

print(model)

summary(model)

model$residuals

model$labels

ModelMetrics::mse(ACTUAL,PREDICTED)

ModelMetrics::rmse(ACTUAL,PREDICTED)

ModelMetrics::

pred=predict(model,Training_set,decision.values = T)

pred
```

```
attr(pred, "decision.values")[1:4,]

plot(x[1:27], Training_set[1:27],type = "l",xlab = "Time(Days)",ylab =
"Power(Watts)",col=c(1,2),ylim = c(0,4000))

points(x, log(x), col = 1,type = 'l',lwd=1)

points(x[1:27], (pred/8)[1:27], col = 2,type = "l",lwd=1)

legend('topleft',legend = c("Actual power consumption",'Predicted power consumption'),col =
c(1,2),lwd = c(1,1))

ModelMetrics::rmse(ACTUAL,PREDICTED)
[1] 176.8718


table(pred,Training_set)
```

## Appendix C

ENERGY USAGE DATA IN WATTS FOR 90 DAYS

| Dates | Non smart house | Smart house |
|---|---|---|
| 21/07/2020 | 2329.578 | 2329.578 |
| 22/07/2020 | 7589.281 | 2589.281 |
| 23/07/2020 | 3260.204 | 2260.204 |
| 24/07/2020 | 1997.135 | 1697.135 |
| 25/07/2020 | 3747.577 | 2747.577 |
| 26/07/2020 | 2664.067 | 2564.067 |
| 27/07/2020 | 3847.241 | 2847.241 |
| 28/07/2020 | 5496.792 | 2017.015 |
| 29/07/2020 | 3320.795 | 1681.461 |
| 30/07/2020 | 3935.138 | 1698.04 |
| 31/07/2020 | 3001.515 | 1710.236 |
| 01/08/2020 | 2067.892 | 1022.431 |
| 02/08/2020 | 6516.737 | 934.6269 |
| 03/08/2020 | 6840.74 | 946.8225 |
| 04/08/2020 | 2164.742 | 759.0182 |
| 05/08/2020 | 3488.745 | 571.2138 |
| 06/08/2020 | 3935.138 | 383.4094 |
| 07/08/2020 | 3001.515 | 495.605 |
| 08/08/2020 | 2067.892 | 1267.801 |
| 09/08/2020 | 3935.138 | 1781.461 |
| 10/08/2020 | 3001.515 | 688.0401 |
| 11/08/2020 | 2067.892 | 2689.281 |
| 12/08/2020 | 1756.764 | 1260.204 |
| 13/08/2020 | 3008.767 | 907.1346 |
| 14/08/2020 | 5496.792 | 2147.577 |

| | | |
|---|---|---|
| 15/08/2020 | 3320.795 | 784.0669 |
| 16/08/2020 | 3935.138 | 547.2407 |
| 17/08/2020 | 3001.515 | 500.0147 |
| 18/08/2020 | 2067.892 | 989.0266 |
| 19/08/2020 | 3320.795 | 840.2528 |
| 20/08/2020 | 5589.281 | 791.4791 |
| 21/08/2020 | 7848.985 | 442.7054 |
| 22/08/2020 | 5496.792 | 693.9317 |
| 23/08/2020 | 3320.795 | 545.158 |
| 24/08/2020 | 3935.138 | 396.3842 |
| 25/08/2020 | 3001.515 | 547.6105 |
| 26/08/2020 | 2067.892 | 498.8368 |
| 27/08/2020 | 6516.737 | 750.0631 |
| 28/08/2020 | 4940.808 | 401.2894 |
| 29/08/2020 | 5264.811 | 382.5156 |
| 30/08/2020 | 3935.138 | 303.7419 |
| 31/08/2020 | 3001.515 | 254.9682 |
| 01/09/2020 | 2067.892 | 206.1945 |
| 02/09/2020 | 1134.27 | 2781.461 |
| 03/09/2020 | 7848.985 | 1388.04 |
| 04/09/2020 | 9108.688 | 289.2813 |
| 05/09/2020 | 6516.737 | 260.2041 |
| 06/09/2020 | 4785.833 | 907.1346 |
| 07/09/2020 | 3818.836 | 447.5765 |
| 08/09/2020 | 2850.839 | 1784.067 |
| 09/09/2020 | 1888.841 | 547.2407 |
| 10/09/2020 | 1995.844 | 150.0147 |
| 11/09/2020 | 2476.847 | 989.0266 |
| 12/09/2020 | 2980.85 | 1510.236 |
| 13/09/2020 | 2024.852 | 1322.431 |

| | | |
|---|---|---|
| 14/09/2020 | 2044.855 | 1134.627 |
| 15/09/2020 | 2077.858 | 946.8225 |
| 16/09/2020 | 2096.86 | 759.0182 |
| 17/09/2020 | 3140.863 | 571.2138 |
| 18/09/2020 | 5589.281 | 383.4094 |
| 19/09/2020 | 7848.985 | 495.605 |
| 20/09/2020 | 9108.688 | 267.8006 |
| 21/09/2020 | 6516.737 | 1781.461 |
| 22/09/2020 | 2304.877 | 688.0401 |
| 23/09/2020 | 5589.281 | 590.785 |
| 24/09/2020 | 7848.985 | 504.8451 |
| 25/09/2020 | 4108.688 | 448.9053 |
| 26/09/2020 | 6516.737 | 692.9655 |
| 27/09/2020 | 2660.891 | 337.0256 |
| 28/09/2020 | 2484.893 | 581.0858 |
| 29/09/2020 | 2530.896 | 225.1459 |
| 30/09/2020 | 2132.899 | 169.2061 |
| 01/09/2020 | 5589.281 | 203.2663 |
| 02/09/2020 | 7848.985 | 157.3264 |
| 03/09/2020 | 5108.688 | 477.3804 |
| 04/09/2020 | 6516.737 | 467.3726 |
| 05/09/2020 | 9108.688 | 457.3649 |
| 06/09/2020 | 6516.737 | 447.3572 |
| 07/09/2020 | 5589.281 | 437.3495 |
| 08/09/2020 | 7848.985 | 427.3418 |
| 09/09/2020 | 6108.688 | 417.3341 |
| 10/09/2020 | 2872.926 | 407.3263 |
| 11/09/2020 | 4299.929 | 397.3186 |
| 12/09/2020 | 5589.281 | 387.3109 |
| 13/09/2020 | 7848.985 | 377.3032 |

| | | |
|---|---|---|
| 14/09/2020 | 6108.688 | 367.2955 |
| 15/09/2020 | 6516.737 | 357.2878 |
| 16/09/2020 | 5589.281 | 347.2801 |
| 17/09/2020 | 7848.985 | 337.2723 |
| 18/09/2020 | 5108.688 | 327.2646 |

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