CLASSIFICATION OF DOMESTIC ELECTRICAL APPLIANCES BASED ON STARTING TRANSIENT USING ARTIFICIAL INTELLIGENCE METHODS

NAME:	ONG SZE MUN
MATRICS NUMBER:	B011310018
SUPERVISOR'S NAME:	EN. TARMIZI BIN AHMAD IZZUDDIN

"I hereby declare that I have read through this report entitle "*Classification of Domestic Electrical Appliances Based on Starting Transient Using Artificial Intelligence Methods*" and found that it has comply the partial fulfilment for awarding the Degree of Bachelor of Electrical Engineering (Control, Instrumentation & Automation)."

Signature :

Supervisor's Name :

Date :

CLASSIFICATION OF DOMESTIC ELECTRICAL APPLIANCES BASED ON STARTING TRANSIENT USING ARTIFICIAL INTELLIGENCE METHODS

ONG SZE MUN

A report submitted in partial fulfilment of the requirements for the Bachelor of Electrical Engineering (Control, Instrumentation & Automation)

Faculty of Electrical Engineering
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

“I declare that this report entitle “*Classification of Domestic Electrical Appliances Based on Starting Transient Using Artificial Intelligence Methods*” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.”

Signature :

Author :

Date :

This report is dedicated to my parents who have been my constant source of inspiration. Secondly, this report is dedicated to my project supervisor, Mr. Tarmizi Bin Ahmad Izzuddin, for he has given me the drive and discipline to tackle any task with enthusiasm and determination. Without their support this project would not have been made possible.

ACKNOWLEDGEMENT

I would like to express my gratitude to all those who gave me the possibility to complete the "*Classification of Domestic Electrical Appliances Based on Starting Transient Using Artificial Intelligence Methods*" project. I am deeply indebted to my supervisor, Mr. Tarmizi Bin Ahmad Izzuddin, who helped stimulating suggestions and encouragement in all time of project completion and writing of the report. The supervision and support that he gave truly help the progression and smoothness of the project completion. The co-operation is much indeed appreciated. I also wish to express my appreciation towards Universiti Teknikal Malaysia Melaka for giving me this opportunity to apply my knowledge during project completion. Besides, the university's technicians also have been a great guidance in teaching me and suggesting what alternative components can be used in this projects. Last but not least, I am grateful to my friends and family. They have been a great moral support to complete this project with great success.

ABSTRACT

With the rising implementation of Home Energy Management Systems (HEMS), active studies had been done relative to power monitoring alternatives. Load monitoring is an essential block of HEMS, therefore the improvement of simplicity and convenience in load monitoring is crucial for the HEMS market expansion. This paper aims to research and analyse the performance of Artificial Neural Network models for classifying the electrical appliances based on the extracted distinctive current starting transient features of electrical appliances. The main challenges present in this research are: conducting reliable instrumentation practice with appropriate choice of instruments, extracting distinctive features contained in the current transient and analysing the ANN classifier for good performance using artificial intelligence methods. The analysis would compare the performance of time-domain inputs and frequency-domain inputs to the ANN classifier. The system consists of three phases: data acquisition, feature extraction and development of ANN model. The main hypothesis of this research was successfully demonstrated and supported by results of computer simulation and data acquisition. The hypothesis is: every appliances exhibits unique transient features that can be extracted and differentiated by an artificial intelligence classifier.

ABSTRAK

Pada masa kini, dengan penggunaan *Home Energy Management System* (HEMS) yang kian meningkat, kajian aktif telah dilakukan demi mengkaji alternatif untuk cara-cara pemantauan kuasa. Salah satu elemen yang penting dalam HEMS adalah pemantauan beban, oleh itu peningkatan kesederhanaan dan kemudahan dalam pemantauan beban adalah penting untuk mengembangkan pasaran HEMS. Kertas kerja ini bertujuan untuk mengkaji dan menganalisis prestasi model Artificial Neural Network untuk mengklasifikasikan peralatan elektrik berdasarkan arus kilasan apabila peralatan elektrik mulakan operasinya. Sistem tersebut akan menggunakan kaedah kepintaran buatan. Cabaran utama dalam kajian ini ialah: pemilihan alat pengukuran dan instrumen yang sesuai supaya data yang diperolehi boleh dipercayai, mengekstrak ciri-ciri tersendiri yang terkandung dalam arus kilasan dan menganalisis sistem ANN untuk mendapatkan prestasi yang baik menggunakan kaedah kepintaran buatan. Metodologi projek ini terdiri daripada tiga fasa: perolehan data, pengekstrakan ciri, pembangunan sistem ANN. Analisis itu akan membandingkan prestasi penggunaan ciri-ciri domain masa dan domain frekuensi dalam sistem ANN. Hipotesis utama kajian ini berjaya dipamerkan dan disokong oleh simulasi yang telah dijalankan menggunakan alat perisian dan keputusan pengambilan data. Hipotesis tersebut adalah: setiap peralatan electrik mempamerkan ciri-ciri unik sementara yang boleh diekstrak dan dibezakan oleh perisikan pengelas tiruan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter is intended to provide a rationale for the research by highlighting the importance, depth, content, structure and complexity of the research. This chapter includes the general overview, objectives, research motivation, problem statement and scope of work.

1.1 General Overview

Over the past decades, many servicing companies are being set up to address the consumers' desire to manage their home environment, no matter in terms of energy efficiency, low carbon consumption or convenience of home appliances control. According to [1], these companies have been actively introducing the smart home concepts into the mainstream market, causing the smart home market to expand rapidly, marking the growing phase which results in millions of consumers being subscribed to these services. Home Energy Management System (HEMS) is one of the most popular smart home concept, which have been widely studied for its application in smart home environments, emphasizing in the optimal use of energy by controlling appliances via home automation. HEMS encompasses systems and services to monitor, analyse and control energy consumption in the home.

The rapid rate of construction of residential area and the increasing need for electrical appliances among consumers indicate that total energy consumption for residential sector will increase in years to come. For residential consumers, the understanding of consumption practices can be improved via energy monitoring for appliance level, which in turns reduce energy consumption by 5-15% [2, 3]. Monitoring of appliances is an essential building block for HEMS by providing appliance-level consumption information to consumers. Studies are being carried out to discover power monitoring alternatives and investigate on the effectiveness of such systems.

Appliances monitoring are carried out via either intrusive load monitoring (ILM) or non-intrusive load monitoring (NILM). ILM is known as distributed sensing which requires one or more sensing elements installed for every appliances or electrical outlets [4]. ILM is widely implemented in HEMS products, with the sensors communicating with main system via wired or wireless connections. NILM on the other hand implements single meter per house. In other words, it uses only a sensor installed at the main power input in the distribution board and records the power consumption attributes, no matter as whole house monitoring or individual load analysis [4].

ILM wins over NILM due to its accuracy and effectiveness in measuring appliance-specific energy consumption, however the ILM possess limitations, which include the expensive and complex multiple-sensor installation, favouring the NILM for large-scale deployment due to its simplicity. Not only that, ILM requires the monitoring of appliances to be done in parallel, which means parallel meters and sensors are needed to be installed, thus causing disruption in users' consumption behaviour due to its inconvenience.

Appliance load monitoring provides energy usage feedback to create awareness of energy usage among consumers. Moreover, it has high potential to be applied in fault detection and remote controlling of load, which is beneficial for industrial applications. Thus, this paper aims to propose for a research to classify electrical appliances based on starting transient using artificial intelligence methods. At the end, the research is expected to analyse the performance of the Artificial Intelligent model of using only single sensor installed at power input to classify the electrical events by matching the input to the target output being fed into the Artificial Intelligent model.

1.2 Research Motivation

Despite of the success overseas, HEMS market has not yet make an impact in Malaysia due to its very high implementation cost, complexity of operations and the lack of awareness of energy saving among Malaysians [5]. As stated by Malaysia's national research agency MIMOS at the National Innovation Conference Exhibition [6], Malaysian companies are encouraged to research, develop and commercialize advanced technology solutions in home management, including home automation, energy conservation, security features and many more. Therefore, there is a demand for such field of knowledge to be explored.

Majority of HEMS for appliance-level monitoring are using ILM, which involves installation of multiple sensors at the desired sensing points or electrical outlets, then connect these sensors using internet. This installation increases the cost and complexity of the overall system. ILM also interrupts consumers' usage behaviour and causes inconvenience. The primary motivation for this research is to eliminate the complex sensors network along with the complicated configuration effort made to cope with the sensors.

According to the statistics provided by The Malaysia Energy Information Hub in [7], the total electricity consumption in Malaysia has been increasing. This shows that there is a need in developing a relatively low cost and simple-to-operate smart load monitoring system because there is a surging demand. The increase in electricity consumption from year 1998 to 2014 is shown in Figure 1.1 below.

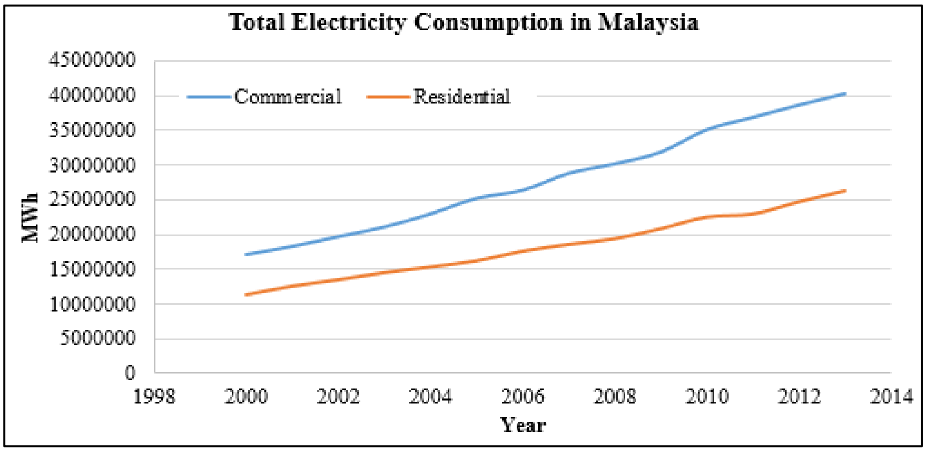

Figure 1.1: Total electricity consumption in Malaysia from year 1998 to 2014 (source: The Malaysia Energy Information Hub, retrieved from [7])

1.3 Problem Statement

Based on available products in the market, the appliance-level monitoring systems are ILM which require the sensors to connect via a wired or wireless network. Only sophisticated appliances such as television, washing machine and refrigerators are equipped with internal-built network interface, meanwhile other appliances rely on the network interface provided on the specially-designed electrical outlet sensors. Therefore, it is rational to investigate on the potential of single-point sensing (NILM) for appliance-level monitoring system.

Generally, past researches regarding NILM systems were carried out similarly aiming to use only one sensor to differentiate the load operated. The previous studies emphasised on the simplicity and convenience of system, however those researches mainly focused on macroscopic energy consumption data analysis, which considered only low frequency data acquisition to obtain data at 1 Hz or lower measurement frequency. Some of the works conducted for microscopic data analysis, which considered higher frequency data contained in kHz to MHz frequency range, were impractical as they were limited to laboratory experiments under controlled environment.

To ensure the relevance of this research in improving past methods, this research will incorporate common household appliances for microscopic data analysis. These household appliances are heating, lighting, motor and electronics, which are common among majority home users. Microscopic data analysis is possible with the use of high sampling rate data acquisition instruments to collect abundance of data at high frequency. Besides, a proper distribution board equipped with appropriate circuit breakers and wiring configurations mimicking reality home electricity distribution networks will be set up, so that the research outcome can be found useful for future reality works, not only limited to laboratory environment.

In previous studies [4, 6, 7], false identification occurs if NILM uses the steady-state power signatures because there will be certain loads with similar power consumption ratings, thus confusing the classifier (overlapping). The primary hypothesis of this research is that starting states of different appliances have specific and unique transient load signatures, whereby if the features of such signatures are extracted, classification of appliances is possible. Thus, it is proposed that starting transient waveforms to be used to identify loads.

In order to classify the appliances effectively, it is a challenge to analyse the distinctive transient features for the appliances, especially when abundant data are to be collected for effective machine learning phase. Fast Fourier Transform (FFT) is proposed to extract the transient features for its frequency-domain because it decomposes complex time-based signals into its individual frequency components. In this research, Artificial Neural Network (ANN) model facilitates the recognition of distinctive characteristics for the frequency-domain and time-domain signals, the machine then learns the grouping and clustering of these similar stimuli, finally identifying the appliances based on the learnt characteristics. ANN can improve the performance of the appliance-classification system, with minimal control knowledge from consumers and end users.

1.4 Objectives

There are several objectives to be fulfilled through this project to make sure the relevance of project. This project aims to:

i. Investigate on the possibility of using artificial intelligence in identifying and classifying electrical appliances based on aggregated transient measurements from a single sensing point.
ii. Extract and analyse the distinctive features of the obtained transient data of electrical appliances, in both time-domain and frequency-domain.
iii. Develop Artificial Neural Network models for classifying the electrical appliances based on the extracted distinctive transient features of electrical appliances.
iv. Analyse and compare the performance of ANN model using time-domain and frequency-domain inputs.

1.5 Scope of Work

This project focuses on classification of electrical appliances based on starting transient signatures, using current data obtained from current measured from the main supply. The proposed system consists of three phases as shown in Figure 1.2 below.

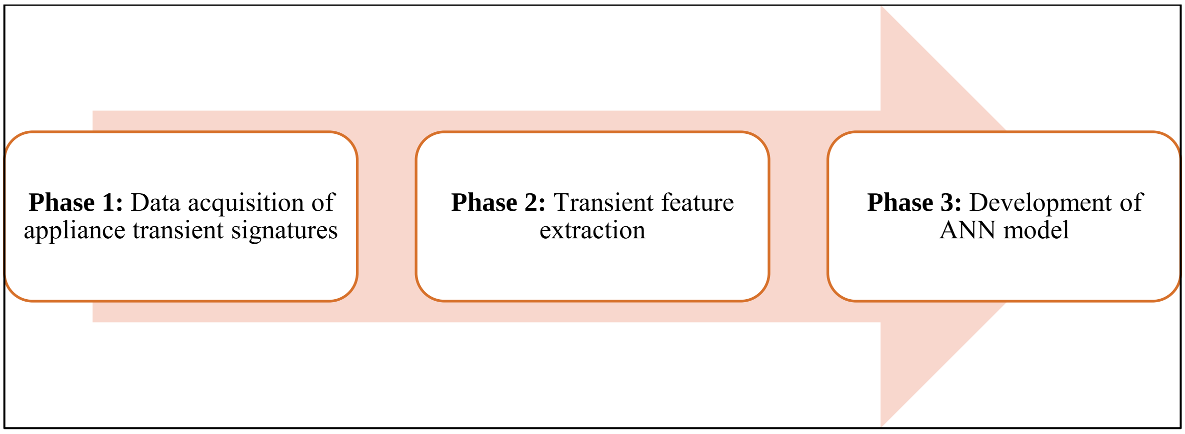

Figure 1.2: Three phases of proposed system

In Phase 1, the project implements NILM whole house monitoring using single sensing point involving oscilloscope current probe, instead of circuit level measurement or intrusive load monitoring which uses complex installation of sensors at every individual electrical outlet. The proposed system emphasizes on the acquisition of relatively high frequency transient behaviour during starting of appliances, whereas the steady-state characteristics are not included. Keysight U2701A USB Modular Oscilloscope will be used to acquire the load consumption because it has maximum sample rate of 1GSa/s and bandwidth of 100MHz (refer Appendix A).

In Phase 2, FFT mathematical operations offered by Keysight U2701A USB Modular Oscilloscope will be used to get the frequency-domain representation of transient current. VEE software will be utilized to extract the transient features using graphical programming means. ANN will be focused as the machine learning method. The Neural Network Toolbox in MATLAB will be used to construct the classifier model for this research.

The selected appliances under test were chosen based on [8], which stated that heating appliances contribute to 25% of typical household energy consumption, motor loads contributed 25%, lighting account for 10% and electronics consumed 15%. For the sake of simplicity, the amount of electrical appliances were restricted to five appliances, which are: toaster, study lamp, electrical fan, LCD monitor and refrigerator. These appliances are common among home users, and they can be categorized as resistive heater (water heater), motor (refrigerator and electrical fan), lighting (lamp) and electronics (LCD monitor), which these categories are sufficient for analysis purposes. The overall configuration of the proposed system is as shown in Figure 1.3 below.

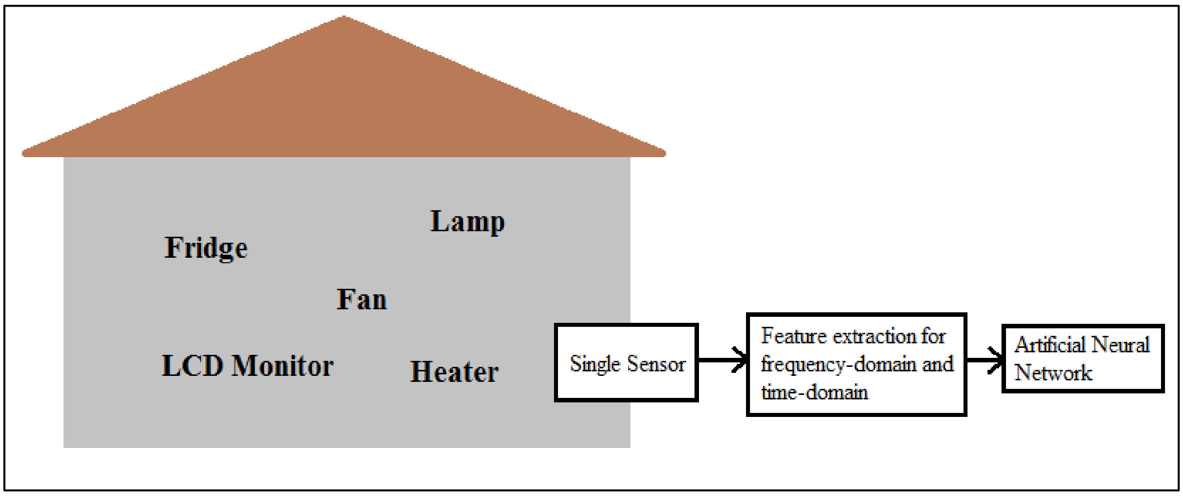

Figure 1.3: Proposed Appliance Load Monitoring System

CHAPTER 2

LITERATURE REVIEW

This chapter serves to establish theoretical framework to identify the research area and provide case studies on previous works to support this research. This chapter defines key terms and definitions which serve as basic understandings towards the research. Previous works are studied in terms of research theories, research methodologies and gaps or challenges of the research.

2.1 Definitions and Terminologies

In this section, several important terms that will be used throughout the research paper are defined and explain theoretically. These terms include: Artificial Intelligence (AI), and Artificial Neural Network (ANN). Moreover, general information regarding current sensing is included in this section, as well as comparisons between solid core CTs and split core CTs.

2.1.1 Artificial Intelligence (AI)

Formally introduced in 1955 as an intelligent entity [9], artificial intelligence (AI) can be defined as computational models of problem solving for complex problems that are usually solved by human brains. Scientists and researchers believe that computers are capable to think and work like human brains, thus the development and design of AI are based on human brains. Usually AI models are evaluated in terms of how well they match the human brains. The development of cognitive science helps scientists to construct precise theories of human brains and then incorporate it into a computational or artificial cognitive model.

In recent years, AI had been introduced to wide varieties of applications, serving for no matter general or specific purposes [10]. AI is used in the National Association of Securities Dealers Automated Quotation (NASDAQ) for the finance field, purposed to monitor stock exchange and check on any insider trading. Besides, AI is adopted by the American multinational financial service VISA Inc. to detect fraudulent transactions, especially cell phone frauds. AI is a useful tool in scheduling operations in big manufacturing plant, such as the National Aeronautics and Space Administration (NASA) space shuttle preparations. Ventilator monitoring and settings for pressure and level of gas in medical field are also using AI as well.

2.1.2 Artificial Neural Network (ANN)

Artificial Neural Network (ANN) is an artificial intelligence developed to be similar to biological neural systems, however in simpler computational terms with numerous nerve cells working in parallel and most importantly, it has the capability to learn [11]. ANN is basically divided into networks and nodes. Networks are the decomposition of complex system into simpler parts, whereas nodes are computational units where the in-between connections determine information flow between nodes. ANN can differ in terms of topology, functions, hybrid models, accepted values, learning algorithm and many more.

Generally, ANN features varieties of benefits and functions for artificial intelligence purposes. ANN has the automatic learning capability which it does not need to be program explicitly, whereby they learn through training examples. Its learning strategy uses simple algorithm or mathematical formula and good training examples to train ANN to give the desired output for given input. It is also able to generalize and associate the data, and then find universal rule for it to stop and give reasonable solutions for the similar problems even if the problems are not exactly related to the training examples [11, 12]. Moreover, ANN is good in fault tolerance thus it can handle any type of data including noisy input data, and it has huge capacity in prediction, pattern recognition, data compression and decision-making tasks.

One of the application of ANN is fault diagnosis applications in rotary machines, whereby they were developed for decision-making and identification purposes by learning the status of operation of the machines [12]. There are several network parameters that should be set before designing the ANN model, which are the network model or topology, network size, activation function, learning parameters and number of training samples [13]. Moreover, ANN may have multiple layers including the input layer, hidden layer and output layer.

Neural network can have either scalar or vector input with the similar proceeding neuron functional operations. There are three distinctive functional operations: the weight function (matrix multiplication), the net input function (summation) and the transfer function. The array of inputs is not included in the layer of a neuron. When considering network with many neurons, the network tends to become complicated with the multiple layers of many neurons, thus Figure 2.1 shows the abbreviated notation of neural networks for general understandings towards the functional operations of the network.

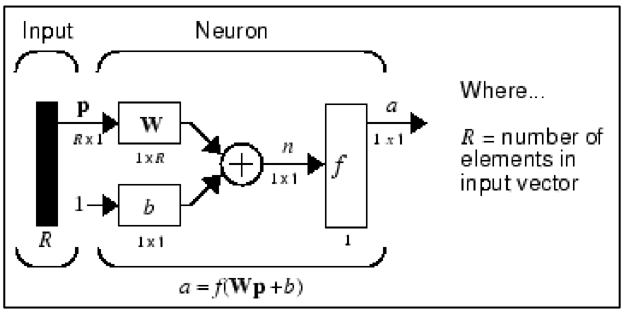

Figure 2.1: The abbreviated notations for neural networks with many neurons [14]