**UNIVERSITI PUTRA MALAYSIA**

***HIDDEN MARKOV MODEL FOR DECISION MAKING AMONG HETEROGENEOUS SYSTEMS IN INTELLIGENT BUILDING***

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HIDDEN MARKOV MODEL FOR DECISION MAKING AMONG HETEROGENEOUS SYSTEMS IN INTELLIGENT BUILDING

By

BABAKURA ABBA

Thesis Submitted to the school of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

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## DEDICATION

This thesis is dedicated to the Almighty Allah who has been my help, sustainer, provider, guide, encouragement, keeper and my all in all throughout the course of my studies and also to my parents ( Alhaji Baba M. Abba and Hajja Hauwa Baba) whose prayers and support has kept me going. Finally to my brothers Baba Mohammed, Baba Shettima and Baba Gana who are always by my side and ready with any kind of assistance.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

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By

**BABAKURA ABBA**

**July 2014**

**Chair: Md Nasir Bin Sulaiman, PhD**

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The idea of intelligent building promises the ability to automate the environment by installing the needed devices for controlling context aware, personalized, adaptive and anticipatory services. Intelligent building can in this way be referred to a term normally used to characterize a building that incorporates technology and services through networking to improve power efficiency and enhance the nature of living. The inability of systems, devices and sensors to interoperate is the main drawback in intelligent building. They operate at different platform, different configuration and different languages. Hence it is difficult to perform intelligent building operations due to high heterogeneity. The idea behind this study is to design an effective model to resolve the difficulty of decision making among subsystems in a building environment. Existing work done by Perumal et al. (2013) had tackled the problem of interoperation using the Event Condition Action (ECA) mechanism to perform decision making among subsystems. The ECA mechanism uses the rule based to trigger actions and yet the model resulted in poor response time. In order to improve the response time a machine learning algorithm like Hidden Markov Model (HMM) instead of the rule-based is used. HMM is chosen due to the characteristics it possesses such as probabilistic, statistical, machine learning as well as its robustness and scalability has been seen as an efficient and effective model to tackle the problem of interoperation in the intelligent building. We hypothesized that the response time can be improved without sacrificing the system accuracy through machine learning. From our experimentation results showed that HMM managed to reach 95% accuracy on all the data set generated from the pre-defined rule-based and reduced the response time significantly. The model is compared with other selected machine learning such as Naïve Bayes and Fuzzy Logic to show the correctness of the system. The framework of Perumal et al. (2013) was improved by

replacing the ECA with the HMM and implementing the framework in the intelligent building.

Abstrak tesis yang dikemukakan kepada SenatUniversiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

**MODEL MARKOV TERSEMBUNYI UNTUK MEMBUAT KEPUTUSAN ANTARA SISTEM HETEROGEN DALAM BANGUNAN PINTAR**

Oleh

**BABAKURA ABBA**

**Julai 2014**

**Pengerusi: Md Nasir Bin Sulaiman, PhD**

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Idea bangunan pintar menjanjikan keupayaan untuk mengautomasikan persekitaran pemasangan alat-alat yang diperlukan untuk mengawal konteks sedar, peribadi, penyesuaian dan perkhidmatan yang dijangkakan. Bangunan pintar boleh dirujuk sebagai satu terma yang biasa digunakan bagi bangunan yang menggunakan gabungan teknologi dan perkhidmatan melalui rangkaian untuk memperbaiki kecekapan kuasa dan meningkatkan taraf hidup.Ketidakupayaan sistem, peranti dan pengesan untuk saling berhubung merupakan kelemahan utama dalam bangunan pintar.Ketiga-tiga komponen tersebut beroperasi dalam pelantar, konfigurasi dan bahasa yang berbeza.Oleh yang demikian, adalah sukar untuk melakukan operasi bangunan pintar disebabkan keheterogenan yang tinggi. Kajian ini bertujuan untuk membangunkan satu model yang berkesan bagi menyelesaikan kesukaran dalam membuat keputusan di antara subsistem yang berkaitan dengan bangunan pintar. Perumal et al. (2013) telah mengatasi masalah kesalingan operasi menggunakan mekanisma ECA (*Event Condition Actions*) untuk perlaksanaan pembuatan keputusan di kalangan subsistem.Walaupun mekanisma ECA menggunakan proses pratakrif peraturan untuk mencetuskan tindakan, tetapi model yang terhasil lambat bertindak-balas. Mekanisme ECA menggunakan peraturan-peraturan yang telah dipratakrifkan untuk mencetuskan tindakan namun model ini menghasilkan tindakbalas yang lambat. Oleh itu,untuk meningkatkan masa tindakbalas, algoritma pembelajaran mesin seperti model markov tersembungi (HMM) selain pratakrif boleh digunakan. HMM digunakan kerana ciri-ciri yang dimiliki, seperti kebarangkalian, statistik, pembelajaran mesin serta kemantapan dan berskala, dilihat sebagai model yang cekap dan berkesan untuk menyelesaikan masalah kesalingan operasi dalam bangunan pintar.Kami menggangap masa tindakbalas boleh dipercepatkan tanpa mengorbankan ketepatan system melalui pembelajaran mesin.Daripada keputusan eksperimen kami menunjukkan HMM mampu mencapai 95% ketepatan ke atas semua set data yang dijanakan dari pratakrif peraturan dan mengurangkan masa tindakbalas dengan ketara.

Model pembuatan keputusan berdasarkan HMM telah direka, dan persediaan eksperimen dijelaskan untuk memenuhi aspek pembuatan keputusan untuk sistem yang pelbagai kerana kepentingannya dalam merealisasikan kesalingan operasi. Perbandingan model ini dibuat dengan *Naïve Bayes* dan *Fuzzy Logic* untuk menunjukkan ketepatan sistem. Rangka model Perumal et al. (2013) telah dibaik-pulih dengan menggantikan ECA kepada HMM dan melaksanakannya dalam bangunan pintar.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirements for the degree of Master of Science.
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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ECA | Event Condition Action |
| HMM | Hidden Markov Model |
| NB | Naïve Bayes |
| ICT | Information and Communication Technology |
| MIT | Massachusetts Institute of Technology |
| ML | Machine Learning |
| CCTV | Closed-Circuit Television |
| XML | Extended Markup Language |
| API | Application Programming Interface |
| SOAP | Simple Object Access Protocol |
| CV | Cross Validation |
| SHE | Smart Home Environment |
| SHD | Smart Home Domain |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Smart Home

A “Smart Home” is frequently referred to as a home embedded with computing and information technology which responds to the need of the occupants, attempting to push their comfort, convenience, security and entertainment through the management of technology inside the home and connection to the external environment (Aldrich, 2003).Later developments in computer and communication technologies have reformed numerous new developing technologies for home users. The Internet and World Wide Web accelerated the accessibility of different multimodal sensory data and devices in home that could play, capture, store and process for particular services. It is normal that the environs of multimedia computing isn't in the research labs or data centers, however begins in the living room. Ever accelerating haziness of the line between individual and professional, and of excitement and work, represent the test of computing for home frameworks (Cook et al., 2003).

As contended by (Weiser, 1991) that "the most significant innovations are those that vanish" appears suits well the smart home environment qualities as we could feel the mix of intelligence and innovation concealing in the backend, outfitting solace to home occupants with various services and applications. Smart home systems could have huge impact on human lives in augmenting the comfort of home occupant, decreasing upkeep expense, enhancing safety and security, minimizing resources utilization in home and providing assistance to home occupants.

Usually, smart home could be seen as a structure which comprises of the service function of automation, communication and control of its environment, and is advantageous for intelligent activities (Wang et al., 2004). The field of smart home have typically not been a group approach yet differed by their design, dissimilar systems, distinctive application and purposes.  In smart home environment, the interest for minimal cost and high performance sensor technologies to be joined together is required. These technologies include the development of high capacity communication framework and guaranteed rapid development of heterogeneous systems. Figure 1.1 below depicts the heterogeneous systems (sub-systems) in a smart home environment.

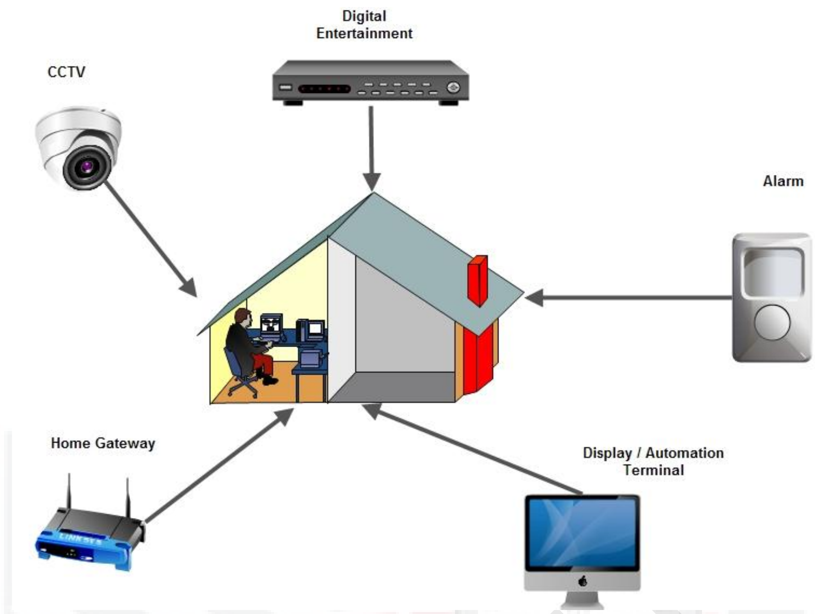


**Figure 1.1: Heterogeneous Systems in Smart Home Environment**

Heterogeneous systems in smart home environment consists of building automation system (BAS), fire alarm system, energy management system, digital surveillance system and other network based systems (Wang et al., 2004).

For the past two decades, most systems in smart homes were independent and are not capable to communicate with each other. The smart homes are not any more a spot in which various appliances carry on simple executions and tasks yet rather an appropriated entity with numerous subsystems working together. These subsystem are heterogeneous in nature that have to impart resources and may need to be "aware" about different systems and services and additionally what source of information that they can furnish with a specific end goal to execute particular operations. In smart home environment, the unpredictability of interoperation is one of the primary reasons behind uncertainty in interoperability among heterogeneous systems (Perumal et al., 2013).

The functionality of service in the smart home environment refers to the heterogeneous systems that are essential for a home to work in sustainable manner. Heterogeneous subsystems in smart home are complex and display enormous difficulty. These subsystems work under distinctive operating systems (OSs) and depend on diverse network architectures, bringing about difficulties of integration and its accomplishment uneven. These subsystems are confronted with a set of interdependent activities, all grating to be completed inside brief time limits. Interoperability is the primary concern here that could empower heterogeneous subsystems in smart home to "talk" one another and perform their operation in a proficient way. Therefore, Interoperability is the procedure by which systems from diverse specification exchange information without the utilization of gateways or protocol converters (Perumal et al., 2008). Therefore, there is a need to look at the artificial intelligence techniques to discover the reliable and reasonable algorithm.

The artificial intelligence (AI) is accordingly concerned with a system that is capable for displaying the characteristics of a human behavior, for example the capacity of learning, reasoning, problem solving. The point of artificial intelligence is therefore to simulate the human behavior on the computer, and it might be experimental knowledge (expertise) or essential description of fact (Kalpakjian, 1995). The AI additionally picks up popularity because of the solid provision of its thoughts in numerous common commercial products.

Moreover, AI techniques require the need for machine learning and the objective of machine learning is to automatically identify data patterns and after that utilize the uncovered patterns to predict the future data, or to perform other sort of decision making under certainty. The focal issues of this current decade-duration of research have been the advancement of viable decision making model for interoperation among heterogeneous system in smart home. With interoperability, all divergent subsystem of smart homes have the ability to exchange information between them, work together, share resources and utilize the exchanged information for task execution. However, it is tempting that heterogeneous subsystems in smart homes attain interoperability to give home inhabitants their needed requirements.

## 1.2 Problem Statement

The inability of systems, devices and sensors to interoperate is the main drawback in intelligent building. They are made of different operating platform, different configuration and different languages. Hence, it is difficult to perform smart home operations due to high heterogeneity. Decision making for heterogeneous systems is crucial for realizing interoperation. This research is mainly to improve the work done by (Perumal et al., 2013), they used static decision making model to perform interoperability. One drawback with the aforementioned work is that the rules are pre-defined and the actions performed are triggered manually using the ECA algorithm. However, the model resulted in no accuracy and low response time due to the characteristic of rule base in providing total interoperability among subsystems in the smart home environment, therefore there is the need to use a predictive decision making model to perform interoperability among subsystems in the smart home environment. Due to the fact that there is limited works on interoperability among heterogeneous systems in this field, this research has been utilized with great achievement to provide solution to the aforementioned problem.

## 1.3 Research objectives

The main objective is to propose a machine learning model, HMM to improve the decision making for the interoperation function among heterogeneous systems in the smart home environment in terms of accuracy and response time. The detailed objectives are as follows:

1. To apply a machine learning algorithm namely, Hidden Markov Model (HMM) to improve accuracy and response time.
2. To improve ECA framework by adopting the HMM and implement the functionality of the intelligent building.

## 1.4 Scope of the Study

This research is focused on the suitability studies of predictive (Hidden Markov Model) decision making model which is an enhancement of Perumal et al.(2013) work, based on static (ECA) decision making model for providing interoperation among the subsystems events in the intelligent building. Data set of about 200 samples of events has been utilized to test for the performance of the model and total of four subsystems are involved in the implementation of the model to examine or find ways in providing reliable decision making framework using HMM, evaluating the accuracy and response time of the model and managing the interoperation of subsystems.

## 1.5 Significance of the Study

The study would help provide comfort, security, convenience, and entertainment to people in general and more especially to the old age people. It might likewise be a simple means of tackling the issue of interoperability with capacity of adapting to changes over time. The study might be discovered functional to students and researchers who might need to do further studies on smart home utilizing other machine learning algorithm to perform interoperability smart home environment. The discoveries of this will help provide information on intelligent building for approach producers to plan arrangements and programs that will fortify the advertising of smart home items in country.

## 1.6 Organization of Thesis

This thesis presents the study in a top-down approach. It begins with the functional description of the subject on smart home systems and its existing technologies, and then elaborates on the heterogeneous subsystems in the smart home environment and how they are related.

Chapter 2 is mainly written for reviewing the methods used in this research and related applications for its use. HMM is used as a model for interoperation in this study. HMM and its use in related applications are delineated. Machine learning approach and its principles are discussed in this chapter.

In Chapter 3& 4 this study's methodologies are explained in detail, the training and testing of the data set are explained. The data set description as well as data preparation is elaborately explained. The general design of the model and the framework are briefly discussed in this chapter.

Chapter 5 discusses an original scope of the model design and the implementation framework is introduced together with the essential components that are part of the structure. The experimental setup and the performance results are reported.

Chapter 6 reports the experimental result of the research problem and implementation of the architecture are discussed in details.

Finally, chapter 7 summarizes the thesis, stating the achievements and also identifying the future research direction

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# LIST OF PUBLICATIONS

The following journal publications were achieved from the output of this research and during the period of candidature:

1. Abba Babakura, Md Nasir Sulaiman, Norwati Mustapha and Thinagaran Perumal. HMM-based Decision Model for Smart Home Environment. International Journal of Smart Home (Published).

2. Abba Babakura, Md Nasir Sulaiman, Norwati Mustapha and Thinagaran Perumal. HMM-based framework to improve interoperability for intelligent building. Automation in construction (Under review).

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