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NAIVE BAYESIAN DECISION MODEL FOR INTEROPERABILITY OF HETEROGENEOUS SYSTEMS IN AN INTELLIGENT BUILDING ENVIRONMENT

AHMAD SHAHI

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By

AHMAD SHAHI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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DEDICATION

TO MY BELOVED MOTHER AND BROTHER

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

NAIVE BAYESIAN DECISION MODEL FOR INTEROPERABILITY OF HETEROGENEOUS SYSTEMS IN AN INTELLIGENT BUILDING ENVIRONMENT

By

AHMAD SHAHI SOOZAEI

September 2015

Chairperson : Md.Nasir bin Sulaiman, PhD
Faculty : Computer Science and Information Technology

The growing number of devices and heterogeneity of systems in intelligent building leads to establish an intelligent interoperability framework among heterogeneous systems in a federated manner. Interoperation complexities are often faced among heterogeneous systems that are data-intensive in nature. Moreover, automated decision making and communication response time are not efficient due to the heterogeneous systems and high load of receiving events lead to systems faults in terms of conflict occurrences. In typical heterogeneous systems, conflicts could be occurred when more than two events are simultaneously activated. In addition, another challenge in interoperability with growth of devices in intelligent building is a poor performance in intelligent building environment that can be a bottleneck and will limit the performance of an intelligent space as well. In such a case, the model encounter with latency prediction, while the goal of the model is to roughly predict and trigger the activated events in right time.

As response to the aforementioned problems, many studies have been carried out in the area of Activities of Daily Lives (ADLs). These studies deal with user preferences and intentions as well as activity recognition which is based on processing data obtained through sensors reading that is needed more investigation in lower layers (e.g. sensor layer) of intelligent building. Nevertheless, most researchers of ADLs did not consider the decision support ability in lower layers of intelligent environment in terms of delay in response time and interoperability. Although there are some recent achievements in lower layers which focused on rule-based system namely Event-Condition-Action (ECA) model by providing mutual interoperation and decision support among heterogeneous systems, it still does not fulfil the requirements in terms of delay in communication response time, automated decision-making without any external intervention, conflict occurrences and minimizing latency prediction.

As part of our findings to improve the state of the art in ECA-based model, an effective method based on Naive Bayesian classifier (NB) has been proposed. In addition, to ensure timely automated decision mechanism, achieving sustainability and efficient interoperability among heterogeneous systems, NB model is integrated with weighted priority scheduling and minimizing latency prediction techniques with the availability of dataset from five systems. The proposed approach consists of offline and online phases. In the offline stage, after the preprocessing step, Naive Bayesian model is created. In the online stage, the NB model along with conflict resolution and minimizing latency prediction methods is performed to formulate an efficient interoperability decision model and trigger the related system based on receiving events through the server using the XML SOAP protocol and web services.

A comprehensive experimental study is carried out to investigate the effectiveness of interoperability decision model among five available heterogeneous systems. For this purpose, testing of the approach was done in Local Area Network (LAN) setting which interwoven with XML SOAP protocol and web services. Experimental results show a superior effectiveness of proposed approach in comparison with the previous study.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

MODEL KEPUTUSAN NAIF BAYES UNTUK PENGENDALIAN SISTEM-SITEM PELBAGAI DI DALAM PERSEKITARAN BANGUNAN PINTAR

Oleh

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Dengan bertambahnya alat-alat dan kepelbagaian sistem dalam bangunan pintar menjurus pembangunan sejenis rangka kerja yang pintar yang mampu mengendalikan pelbagai sistem secara teratur. Kerumitan dalam mengendalikan pelbagai sistem adalah selalunya disebabkan oleh data yang sangat intensive secara semula jadi. Tambahan lagi, membuat keputusan secara automatik dan masa tindak balas komunikasi tidak berkesan disebabkan kepelbagaian sistem dan beban yang tinggi dalam menerima aktiviti-aktiviti yang menyebabkan kegagalan kepada sistem dalam maksud kemunculan konflik. Dalam kepelbagaian sistem yang biasa, konflik boleh muncul apabila dua acara diaktifkan secara serentak. Tambahan lagi, cabaran lain dalam mengendalikan alat-alat yang sentiasa meningkat di dalam bangunan pintar adalah keupayaannya yang lemah dalam persekitaran bangunan pintar yang boleh menjadi cerutan dan juga akan menyekat keupayaan ruang pintar. Kes yang sebegitu, model tersebut akan menjumpai jangkaan tempoh pendaman, sambil objektif model tersebut untuk menjangkakan secara kasar dan mengaktifkan acara-acara pada masa yang sesuai.

Berdasarkan masalah tersebut, banyak kajian telah dilakukan di dalam aktiviti-aktiviti hidup seharian (ADL). Kajian-kajian ini melibatkan keutamaan dan tujuan pengguna di samping mengenalpasti aktiviti berdasarkan memproses data yang didapati melalui bacaan penderia-penderia yang diperlukan lagi dalam menyiasat lapisan bawah (lapisan penderia) untuk bangunan pintar. Walaubagaimanapun, kebanyakan penyelidik ADL tidak menghiraukan kemampuan bantuan keputusan di dalam lapisan rendah untuk persekitaran pintar di dalam konteks kelengahan dalam masa tindakbalas dan pengendalian. Walaupun terdapat beberapa kejayaan baru-baru ini dalam lapisan bawah yang memberi tumpuan kepada sistem yang berasaskan peraturan iaitu model Acara-Keadaan-Tindakan (ECA) dengan membekalkan kerjasama dan bantuan keputusan di kalangan sistem-sistem yang pelbagai, ia masih lagi tidak mencapai keperluan dalam konteks kelengahan masa tindakbalas komunikasi, automatic membuat keputusan tanpa sebarang campur tangan dari luar, kewujudan konflik dan meminimumkan jangkaan tempoh.

Sebagai sebahagian daripada penemuan kami untuk memperbaiki keadaan seni dalam model berasaskan ECA, kaedah yang lebih berkesan berdasarkan pengelas Bayesian Naif (NB) telah dicadangkan. Di samping itu, untuk memastikan mekanisme keputusan automatik tepat pada masanya, mencapai kemampuan dan pengendalian yang efisyen dengan sistem-sistem yang pelbagai, model NB disepadukan dengan penjadualan keutamaan wajaran dan meminimumkan teknik-teknik tempoh pendaman dengan set data yang tersedia daripada 5 sistem. Pendekatan yang dicadangkan terdiri daripada luar talian dan fasa dalam talian . Pada peringkat luar talian , selepas langkah pra pemprosesan , model Bayesian Naif dicipta . Pada peringkat dalam talian, model NB berserta dengan penyelesaian konflik serta teknik meminimumkan jangkaan temph pendaman dilakukan untuk mencari keputusan pengendalian model yang efisyen dan mengaktifkan sistem yang berkaitan berdasarkan penerimaan acara-acara melalui pelayan yang menggunakan protocol XML SOAP dan perkhidmatan sesawang.

Satu kajian eksperimen yang menyeluruh dijalankan untuk melihat keberkesanan antara keputusan operasi model dengan lima sistem heterogen yang telah tersedia. Untuk tujuan ini , ujian pendekatan itu dilakukan dalam suasana Rangkaian Kawasan Tempatan (LAN) yang terjalin dengan protokol XML SOAP dan perkhidmatan web. Hasil uji kaji menunjukkan pendekatan yang dicadangkan mempunyai keberkesanan yang unggul dibandingkan dengan kajian sebelumnya.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ECA	Event-Condition-Action
NB	Naive Bayesian
ANN	Artificial Neural Network
BAS	Building Application Server
SOAP	Simple Object Access Protocol
XML	EXtensible Markup Language
BEMS	Building Energy Management System
LAN	Local Area Network
ADLs	Activities of Daily Livings
AI	Artificial Intelligence
HMM	Hidden Markov Model
BP	Back Propagation
ANFIS	Adaptive Neuro-Fuzzy Inference System
FS	Fuzzy System
HBAS	Home and Building Automation System
MLWPS	Machine Learning Weighted Priority Scheme

CHAPTER 1

INTRODUCTION

1.1 Motivation

The domain of intelligent building environments is becoming kind of prevalent implementation in our corporate and personal lives. An intelligent building is a system equipped with advanced sensors, automated devices and electronics, which is designed for several purposes such as remote monitoring, care delivery, safety, detection of problems or emergency cases and specially for automated living (Cheng & Kunz, 2009; Friedewald, Costa, Punie, Alahuhta, & Heinonen, 2005; Rashid et al., 2013). Moreover, with the introduction and increasing the number of advanced technologies in building environment, it becomes more intelligent, useable, comfort and secure and also the inhabitants and appliances are observed and monitored more precisely (Armac, Kirchhof, & Manolescu, 2006; van Kasteren & Krose, 2007). Therefore, many different devices and sensors are installed to improve the efficiency of intelligent automation building (Armac, et al., 2006).

In such environment, an intelligent control is used to gather information and to convey instructions. In addition, devices and sensors are needed to be networked to allow message exchange among the systems and devices in intelligent building. Currently, intelligent buildings are connected to external networks and resources via the Internet (Carner, 2009). Therefore, intelligent building should be capable of endowing efficient information about the environment. Nevertheless, such capability can be developed if there could be efficient cooperation among devices in the intelligent building environment (Kleiminger, Santini, & Weiss, 2011).

However, with the growth of devices and sensors in such an environment, the processing and management of large quantities of events generated from devices and sensors is identified as one of the most considerable challenge in intelligent environment (Lee, 2010) and particularly with heterogeneous systems in intelligent building (Armac, et al., 2006). The system is heterogonous in terms of configuration, installation and interaction (Bucceri, 2003; Carreira, Resendes, & Santos, 2013). In intelligent building, devices and sensors are installed with different software, drivers and services. Therefore, due to different operating system (OS), frameworks, implementation, interfaces and different protocols, there would be some lack of interoperation capability among heterogeneous systems in intelligent building that (Perumal, Sulaiman, & Leong, 2013) solved the problem by proposing the ECA-based interoperability framework with web services and XML SOAP protocol (Perumal, et al., 2013).

As mentioned above, in intelligent building, devices and systems are heterogeneous. Hence, due to performing mutual interoperation, it is difficult to perform interoperation particularly in attaining the preferred functions of building owners and tenants. The complex interoperation is one the major causes of ambiguity in interoperation among heterogeneous systems in intelligent building. In such building there is an approach which usually not integrated but varied by their dissimilar systems, design, application and purposes (Perumal, et al., 2013). Intelligent building have front-end modules such as the automated system of the building, main door sensor system, digital entertainment system, digital surveillance system, energy management system, and fire alarm system which those systems are applied in this research.

Therefore, with the growth number of sensors and devices in intelligent building with dissimilar systems, a number of difficulties emerge. One of the problems is self-automated system without external intervention. The system model should be capable of interpreting, understanding, making automated decisions in intelligent building environments and take proper action to trigger systems rather than rely on user actions. Another issue is a delay in response time among heterogeneous systems. As already mentioned above, to have efficient and intelligent building, the control and interoperation capability among devices and sensors should be improved. The system model of intelligent building should make efficient decisions to have quick communication and appropriate action among heterogeneous systems.

In addition, there are some issues regarding interaction among heterogeneous systems in intelligent building that has been unmet in lower layers of intelligent building and particularly in benchmark work (Perumal, et al., 2013). By increasing the number of devices and sensors in building automation systems and multi-platform heterogeneity, many systems react beyond schedules of actions and decisions. Systems interact with various devices within a time-domain with different actuators and sensors. An automatic decision-making system controls these sensors and devices and determine what action should be triggered.

In an intelligent building, numerous actions may coexist, requiring distinct reaction that can conflict with each other. For instance, events might be implied from sensors and more than one system might be activated in the same time, this system behaviour and activation is called conflict. In an ideal world, this conflict should be resolved automatically by intelligent automation building.

In addition, to achieve an efficient interoperability among heterogeneous systems, latency prediction is required to be minimized. What is common to all prediction problems is that their goal is to predict what is going to happen in the near future. The inputs of the model to predict are not necessarily direct sensor readings but they can be pre-processed. However, event prediction where the objective is to predict the most probable or subsequent event, while latency prediction is a regression problem in which the output – the latency value – takes on continuous values (Stenudd, 2010). It is obvious that a poorly performing in intelligent building environment can be a bottleneck and will limit the performance of an intelligent space as well (Stenudd, 2010).

In this thesis, in order to overcome the aforementioned problems, a new interoperability decision model is designed and proposed. The model consists of machine learning and conflict resolution approaches with minimizing latency prediction. Machine learning can provide such systems with reasoning abilities which facilitate the interoperation and decision making capability in even-condition-action (ECA) with incomplete and uncertain knowledge in various areas such as communication, environment, safety and so on, which offer interoperability via Simple Object Access Protocol (SOAP) and Web Services technology for heterogeneous systems.

In this research, a classifier known as Naive Bayesian (NB) classifier is applied. It is a machine learning technique that can provide a reasoning method with probabilities to be efficiently utilized in intelligent building environment. Moreover, NB classifier has been used with great success and effect in intelligent building research projects (Carner, 2009). The statistical nature of Naive Bayesian classifier is fast in prediction and making decisions in intelligent building environments (Crandall & Cook, 2008).

Therefore, in comparison to rule-based systems such as Even-Condition-Action (ECA)-based Model, machine learning techniques namely Naive Bayesian classifier has a capability of learning method as well as efficient decision-making that omit the shortcoming of rule-based systems. Rule-based systems in terms of search strategy are ineffective and it is needed exhaustive search through large amount of rules during each request which make the system slow and unstable. Another drawback of the rule-based systems is inability to learn and the knowledge engineer is still responsible for revising and maintaining the system (Negnevitsky, 2005). However, Naive Bayesian classifier solves the shortcoming of rule-based systems and improves the interoperability among heterogeneous systems without any external intervention.

Moreover, to solve the unpredictable behaviour of the system model, with that aim, a conflict resolution model based on weighted priority scheduling is proposed. The model is able to automatically detect and resolve conflicts among heterogeneous systems in intelligent building without any external intervention. In this model, when events are activated at the same time, the activated system(s) with high weighted priority is triggered and lower weighted systems are queued based on weight and priority. In addition to achieve the competent interoperability, rather than machine learning that can enhance the prediction, heap priority queue with priority aging methods are proposed to assist the decision making by improving the queue process and starvation of events with low priority. The proposed model facilitates the decision-making to work efficiently and improves the system satisfaction.

In such circumstances, in this thesis, an efficient and stable Naive Bayesian classifier as an interoperability decision model is proposed. The proposed model is able to speed up decision making among heterogeneous systems as well as stabled interoperation to attain systems satisfaction and minimize latency prediction in an intelligent building environment.

1.2 Problem statement

An intelligent building environment mainly is divided into two layers such as application and sensor layers. Application layer deals with the Activities of Daily Lives (ADLs), while interoperability among devices and sensors are happened in the lower layer (Baldauf, Dustdar, & Rosenberg, 2007).

Most of the works have been widely used in the Activities of Daily Lives (ADLs) to predict and make a decision in an intelligent environment. In addition, the problem of activity recognition based on processing data obtained through low-level sensors, which is needed more investigation in lower layer (e.g. sensor layer) of intelligent building (L. Chen, Hoey, Nugent, Cook, & Yu, 2012).

However, the works done in ADLs, did not consider decision support ability in terms of interoperability and response time among heterogeneous systems in intelligent building. So far the works on lower layers deployed Event-Condition-Action (ECA) rules paradigm to manage the interoperability among heterogeneous systems. The latest works in this model are done in (McDonald, Nugent, Hallberg, Finlay, & Moore, 2014; Perumal, et al., 2013). Particularly, (Perumal, et al., 2013) solved the interoperability issue by incorporating with XML SOAP protocol and web services but only with three heterogeneous systems. However, it still does not fulfil the requirements such as efficient response time and interoperations due to bottleneck in the case of receiving bunch of events from heterogeneous systems in intelligent building.

On the other hand, most of the researches have been focused on higher layer of intelligent building which dealt with user preference and intentions. Therefore, there are some issues regarding interaction among heterogeneous systems in intelligent building that has been unmet in lower layers of intelligent building. By increasing the number of devices and sensors in building automation systems and multi-platform heterogeneity, numerous actions may coexist and many systems react beyond schedules of actions and decisions. This multi-platform type of heterogeneous systems leads to system faults in terms of deadlocks and unpredictable behaviour. Those error conditions is called conflict occurrence. However, it is worth to mention that some conflicts and unpredictable behaviours arisen in lower layers of intelligent building might broadcast or even leave behind undetected and unresolved as an outcome of the lower layer's constraints (Resendes, Carreira, & Santos, 2013).

In addition, by increasing the number of devices and receiving bunch of sensors' events cause a poor performance in intelligent building environment that can be a bottleneck and will limit the performance of an intelligent space as well (Stenudd, 2010). However, decision making process to interoperate among heterogeneous systems faces with latency prediction in order to trigger subsequent systems. Latency prediction is occurred due to preprocessing of sensor readings and decision making process. (Stenudd, 2010).

Therefore, with growth of heterogeneous systems in intelligent building, numbers of difficulties have aroused which are summarized:

- Inefficient decision making due to rules-based search strategy as well as bottleneck in the cases of receiving events from heterogeneous systems that affect the performance of interoperation and increases the response time among heterogeneous systems.
- Conflict occurrence and coexisting actions of systems due to multi-platform type and increased number of heterogeneous systems.
- Latency prediction due to decision-making process, queue process as well as starvation of system with low priority in priority scheduling processes in intelligent building environments.

1.3 Research Objectives

The objective of this research is to improve the effectiveness of interoperability decision model in terms of response time, reliability and to attain efficient interoperability and stability among heterogeneous systems in intelligent building. In particular, this research focuses on designing model and implementing methods to overcome aforementioned problem statements in intelligent building environment. In achieving the objective, the following objectives are adopted:

1. To propose Naive Bayesian Classifier that consists of offline and online stages to model and improve decision support ability, interoperation capability and response time among heterogeneous systems based on rule repository in intelligent buildings.

2. To propose an algorithm to detect and resolve the conflict occurrence for sustaining the interoperability as well as reliability among heterogeneous systems in order to maximize system satisfaction in intelligent building environment.

3. To propose an approach to minimize the latency prediction in terms of decision making process, queuing process and the starvation of events with low priority process in the queue in order to achieve efficient performance of interoperation among heterogeneous systems in intelligent building environment.

1.4 Research Scope

Previous work (Perumal, et al., 2013) used ECA-based model along with XML SOAP protocols and web services to interoperate among three heterogeneous systems. But their work has been improved using one of the machine learning method and published in (Babakura, Sulaiman, Mustapha, & Perumal, 2014). In this research, we extend from three to five systems because these systems are available from public domain data. Besides, the interoperability decision model provides an automated way of triggering the relevant operations for heterogeneous systems. The outcome clearly justifies the importance of such classifier in ensuring timely triggering of systems in order to handle those events as per the requirement stipulated in intelligent building scenario.

Due to exploit a system model in such environment, it is worth to mention some critical assumptions about using proposed model which are as follows:

- In this research, due to availability of devices and collected dataset from five systems, we work with five systems to show the interoperation capability among heterogeneous systems in intelligent buildings.
- This research focused on interoperability among heterogeneous systems in intelligent building environment.
- In intelligent building environment, to add new systems or introduce new applications directly, separate modules called Service API and Service Stub is deployed to enable new dependencies of heterogeneous system into the framework.

1.5 Research Contributions

The main contribution of this research work is to devise an effective decision method to get most accurate model, speed-up response time, maximize system satisfaction, sustainability and attain efficient interoperability among heterogeneous systems in intelligent buildings. The novel features of the proposed approach are as follows:

- Proposing an approach to improve the effectiveness of decision-making model among heterogeneous systems in intelligent buildings.
- Proposing a decision model to provide the ability to ensure heterogeneous system interoperation without external intervention.
- Improving the response time among heterogeneous systems in intelligent buildings by speed-up decision making using machine learning.
- Proposing a classifier which is a suitable method to be used as a decision model due to its robustness and simplicity in real time system.
- Proposing a conflict resolution approach to avoid the unpredictable behaviour among heterogeneous systems.
- Proposing a method to improve the process of starvation of events with low priority in the queue in order to maximize system satisfaction.
- Proposing a data structure technique to enhance search queue strategy for triggering events in almost right time as well as achieving efficient interoperability.

1.6 Organization of the Thesis

This thesis is included a five chapters. Chapter 1 was Introduction and the remainder of this thesis is organized as follows.

Chapter 2 provides background knowledge of interoperability and machine learning techniques in intelligent buildings. Moreover, related studies and mechanism for conflict resolution approaches were reviewed.

Chapter 3 presents the first part of methodology applied in this research. It specifies the research design, introduces proposed framework, ECA rules, justify and explaining the methods of the study.

Furthermore, the second part of proposed method is introduced in this thesis. In chapter 4, a details of proposed interoperability decision model are elaborated. We explained a weighted priority scheduling which is capable to avoid the conflict occurrence among heterogeneous systems. In addition, we proposed the priority aging and heap priority queue to improve the starvation low priority of system events and search queue strategy which are elaborated in this chapter.

Chapter 5 is dedicated for experimental results for the proposed method. Identifying the selected performance metrics and evaluation of the proposed method are elaborated in this chapter. Furthermore, some experimentation will be run for evaluating the proposed method in different directions. In this chapter, the proposed method will be compared with previously reported major works.

The last chapter covers the conclusions of the current study and having spot light on some gaps and open issues which can be followed in the future studies.

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