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Naive Bayesian decision model for the interoperability of heterogeneous systems in an intelligent building environment

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ABSTRACT

The environment of an intelligent building includes systems and sensors with significant heterogeneity. With the growth of heterogeneous devices and sensor technologies in intelligent buildings, designers are often faced with more interoperation complexities among heterogeneous systems that are data-intensive in nature. Conversely, performing decision making on these systems with a variety of building data is not efficient in terms of adapting to a changing environment. Current interoperation solutions for intelligent buildings focus on dry-contact and static rule-based systems to solve interoperability in intelligent buildings. Although static rule-based systems are efficient, the bottleneck can be in the area of the scalability of heterogeneous systems that will affect the efficient performance of interoperations. Therefore, to ensure a timely decision-making mechanism among heterogeneous systems, the performance delay and interpretation capability of systems should be improved. This paper offers a framework that improves the communication responses and the ability of automated decision support among the heterogeneous systems with a rule-based repository for the management of intelligent buildings. The implementation of the framework was performed with several systems to show their adaptation to joint interoperation. It is also interwoven with Web services to offer unified integration among heterogeneous systems. Testing of the framework was performed in a local area network (LAN) setting and proved to be reliable in solving interoperation problems for intelligent buildings.

1. Introduction

The definition of an intelligent building refers to space equipped with devices and sensors as a single entity to control and monitor the environment [1]. In recent years, the development of intelligent buildings has become a popular topic. An intelligent building assists inhabitants in living comfortably and safely. In this environment, intelligent control is used to gather information and to convey instructions. In addition, devices and sensors should be networked to allow message exchange among the systems and devices. Currently, intelligent buildings are connected to external networks and resources via the Internet [2]. Therefore, many devices such as CCTV and audio paging are frequently provided with more sensing, computation and communication capability. In general, an intelligent building should be capable of endowing efficient information regarding the environment. Nevertheless, this capability can be developed if there is efficient cooperation among devices in the intelligent building environment [3]. Furthermore, increasing the number of devices and sensors in an intelligent building prioritizes the requirement to monitor building settings [4].

Conversely, in an intelligent building, devices and systems are not homogeneous. Hence, due to the need for mutual interoperation, it is not easy to achieve fully efficient interoperation particularly when attaining the preferred functions of building owners and residents. The complexity of the interoperation is one of the major causes of ambiguity in interoperation among heterogeneous systems in an intelligent building [5]. In an intelligent building, the approach is usually not integrated but is varied by the dissimilarity of the systems, designs, applications and purposes. Intelligent buildings have front-end modules such as the automation system, main door sensor system, digital entertainment system, digital surveillance system, energy management system, and fire alarm system [5].

Furthermore, with the growth in the number of devices in intelligent buildings, a number of difficulties emerge, one of which is the adaptation of the system model to a constantly changing environment. The ideal system should be capable of interpreting, understanding, and making automated decisions in intelligent building environments and of performing the proper actions to trigger systems rather than relying on user intervention. Another issue is communication delay among systems. As already mentioned above, to have an efficient and intelligent building, the control and communication capability among devices and sensors should be improved. The system model of an intelligent building should make quick decisions. To overcome these problems, a convergence of technology in the field of machine learning and accessibility to sensors is emerging in these environments [2]. Machine learning can provide these systems with reasoning abilities while facilitating

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decision making with incomplete and uncertain knowledge in various areas such as communication, environment, and safety.

In this work, we applied a classifier using the Naive Bayesian (NB) technique. It is a machine learning technique that can provide a reasoning method with probabilities that are efficiently utilized in intelligent building systems [2]. Moreover, the NB classifier has been used with great success in intelligent building research projects. The statistical nature of the Naive Bayesian classifier is its reliability in predicting and performing decisions in intelligent building environments [6].

2. Related works

Current literature on intelligent building research studies has highlighted the importance of system integration instead of achieving overall interoperability using decision models. This section is divided into two sub-sections that explain interoperability in intelligent buildings and review machine learning in intelligent buildings.

2.1. Interoperability for intelligent buildings

Doukas et al. emphasized the importance of decision support models for intelligent building energy management systems [7] that could sustain a desirable level of living quality. Their work also focused on the use of intelligent rule sets to predict the logic of the proposed model in energy management.

Another ideal solution for intelligent building system integration was recommended by Wang et al. [8], who discussed the implementation of middleware based on Web services in the combination of OLE with process control (OPC) supporting various communication layers in building environments. OPC uses a stateful message exchange mechanism that shows when a building's operation is disconnected and is unable to restart the connection. For intelligent building requirements, this condition is crucial because all data types from heterogeneous systems must be delivered uninterrupted to be reliable [9]. Another weakness of the OPC technology is the unavailability of bespoke designed interfaces for data exchange, which can provide a common interface that allows repeated operation. The recommended method, however, lacks scalability because the number of gateways increases significantly depending on the number of systems to be connected. Work models are regularly designed to concentrate on the integration of heterogeneous systems with detached functionalities as mentioned in [7–10]. It is believed that decision-making models are not supported as highlighted by the works mentioned above or are confined to single systems. Therefore, common data format transportation could be performed for intelligent building integration, while full-scale interoperation is still open for research and needs more investigation. Recently, residents of buildings have realized the significance of integrating building applications with intelligent systems and enterprise infrastructure. Web services are an essential way to solve this integration, and the new mode of Web services provides direct interaction among heterogeneous systems [11,12]. The omnipresent nature of Web services has led to the development of integration techniques for distributed platforms. Employing Web services technology, the integration of dissimilar systems from various manufacturers on various operating platforms can be achieved without any problems.

Because the requirement for integration can be met with the use of Web services, there is still a necessity to achieve total interoperability. Deploying the event-condition-action (ECA) rule is a possible way to manage heterogeneous systems. The following section describes in detail the ECA deployment and system architecture of the proposed framework.

2.2. Machine learning in intelligent buildings

Over the past few years, a number of different machine learning methods have been proposed to identify the activities of daily life (ADLs). Tang et al. utilized a decision tree classifier to identify activities such as running and walking [13]. The support vector machine (SVM) approach was used by Moradshahi et al. in activity identification to discriminate and recognize cough sounds [14]. Fleury et al. proposed a multiclass one-vs.-one SVM to recognize daily activities such as eating and sleeping by integrating prior knowledge. The performance was improved using time information [15]. Fergani made a comparison among machine learning approaches such as C-support vector machine (C-SVM), linear discriminant analysis (LDA) and conditional random fields (CRF) for imbalanced datasets to recognize activities in an intelligent building automatically [16]. The result showed that the performance of C-SVM is higher than CRF and LDA, while CRF over fit the dominant class [16]. Hyuk Shin et al. used the support vector data description to analyse the behaviour of the elderly [17].

Conversely, Zheng proposed self-organizing maps to monitor the daily activities of life [18]. An artificial neural network (ANN) was applied by Chatterjee et al. to monitor daily activities and to access the blood glucose level of diabetic patients [19].

There are several studies that have conducted activity recognition and monitoring of daily life in intelligent buildings. Naïve-Bayesian classifiers have been widely used with promising results for activity recognition [20–22] by recognizing the activity that corresponds with the maximum probability to the set of sensor values triggered. Brennan et al. (2008) proposed a static classification to analyse the sensor signal stream by utilizing a floating time frame to create attribute vectors, which are classified by a Naive Bayesian classifier for activity recognition [23].

Ehsan et al. applied a sequenced-based activity prediction model that used a Naive Bayesian network in a two-step process, which was constraint-based (CB) Bayesian structure learning and several search and score-based (S&S) models, to predict activity in intelligent buildings [24]. The method was compared with the genetic algorithm, hill climbing, tree augmented Naive Bayesian and ICS approaches with five-month collection data in an intelligent building. The results showed better performance in the next activity prediction [24].

Another important work by Suryadevara et al. used the wireless sensor network (WSN) based system to monitor daily activity recognition and elderly health perception by applying a hybrid method of naïve Bayesian and the added Delta smoothing technique to identify daily activity and to develop a flexible, robust and low cost intelligent system capable of remotely communicating with the WSN coordinator. This hybrid technique can foresee unusual changes of elderly residents in physiological and physical terms. However, this method cannot be applied for interleaved activities [25].

Fahad et al. presented a method for long term monitoring of daily activities to support the independent inhabitant, especially elderly people. This approach is divided into two parts, which are the feature extraction part and learning part, to identify activities by a probabilistic neural network. Later on, the identified activities are used to determine the daily routine based on k-mean clustering. This approach is able to distinguish between a deviation routine and a normal routine. This approach was tested on the Kasteren dataset. A drawback of this approach is that it cannot be applied in online activity monitoring [26].

The techniques mentioned above have been used in the activities of daily lives (ADLs) to predict and make decisions in an intelligent building. The works discussed above did not consider the decision support ability in terms of response time, communication delay and interoperability among heterogeneous systems in an intelligent building. However, the latest work performed in [5] addressed the issue by using ECA rules and the XML SOAP protocol to provide mutual interoperation and decision support among heterogeneous systems in an intelligent environment. However, it still does not fulfil the requirements such as automated decision making to trigger systems in an intelligent building environment. Moreover, with the growth of devices and sensors in intelligent buildings, it causes a delay in the communication response among systems. Hence, there is a need to implement machine learning based decision modelling to achieve a unified integration of heterogeneous devices in an intelligent building environment. In this