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A review on intelligent process for smart home applications based on IoT: coherent taxonomy, motivation, open challenges, and recommendations

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Abstract

Innovative technology on intelligent processes for smart home applications that utilize Internet of Things (IoT) is mainly limited and dispersed. The available trends and gaps were investigated in this study to provide valued visions for technical environments and researchers. Thus, a survey was conducted to create a coherent taxonomy on the research landscape. An extensive search was conducted for articles on (a) smart homes, (b) IoT and (c) applications. Three databases, namely, IEEE Explore, ScienceDirect and Web of Science, were used in the article search. These databases comprised comprehensive literature that concentrate on IoT-based smart home applications. Subsequently, filtering process was achieved on the basis of intelligent processes. The final classification scheme outcome of the dataset contained 40 articles that were classified into four classes. The first class includes the knowledge engineering process that examines data representation to identify the means of accomplishing a task for IoT applications and their utilisation in smart homes. The second class includes papers on the detection process that uses artificial intelligence (AI) techniques to capture the possible changes in IoT-based smart home applications. The third class comprises the analytical process that refers to the use of AI techniques to understand the underlying problems in smart homes by inferring new knowledge and suggesting appropriate solutions for the problem. The fourth class comprises the control process that describes the process of measuring and instructing the performance of IoT-based smart home applications against the specifications with the involvement of intelligent techniques. The basic features of this evolving approach were then identified in the aspects of motivation of intelligent process utilisation for IoT-based smart home applications and open-issue restriction utilisation. The recommendations for the approval and utilisation of intelligent process for IoT-based smart home applications were also determined from the literature.

Keywords Internet of Things · Intelligent home · Remote home · Smart home application · Home automation system · Automated home

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1 Introduction

Smart home technology is a current trend in modern society development that provides intelligent living environments for daily convenience and comfort (Kasnesis et al. 2015; Xiao et al. 2015; Dovydaitis et al. 2017; Bhole et al. 2015; Chen et al. 2014; Collotta and Pau 2017). Smart homes are automated buildings supported by control, monitoring and detection devices, such as heat and air conditioning, lighting ventilation, security systems and hardware. These modern systems contain sensors and switches that communicate via a central axis and are called gateways. These gateways are control systems that contain a user interface through mobile phone, tablet or computer, and the communication network is managed by Internet of Things (IoT). All digital devices in smart homes have access to the Internet, which allows users to monitor, manage, control and automate every piece of electronics in their smart homes. The interconnected physical digital devices via the Internet that enable them to send and receive data are referred to as IoT. IoT is widely used for home automation in activities regarding security and privacy, as well as network and health monitoring. The basic home automation functionalities aim to obtain a unified access that allows intuitive cross-component interaction and presentation of these devices to users on the basis of the concept of services. Automated homes can also be customised for improved efficiency in smart homes (Sun et al. 2014; Huynh et al. 2014; Ganz et al. 2015; Sasidharan et al. 2014; Li et al. 2013; Kim et al. 2015a; Mehrabani et al. 2015).

Intelligent processes for all the activities involved in the establishment of smart home applications using IoT are considered an important current aspect because they represent a possible order of data flow starting from the transformation of data into a useful form and ending at their usage to make changes on a system to achieve desirable specifications. The notion of intelligent process is the use of artificial intelligence (AI) algorithm, which includes machine learning, semantics and ontology (Miori and Russo 2012; Kibria and Chong 2014; Kim et al. 2014; Shamszaman et al. 2014; Sun et al. 2014; Huynh et al. 2014), collective intelligence environment (location and situation based) (Kasnesis et al. 2015; Sanchez et al. 2014), data abstraction (Ganz et al. 2015; Sasidharan et al. 2014), training algorithm, query base, context awareness (Li et al. 2012; Ghayvat et al. 2015; Wang et al. 2012) and prediction (Sun et al. 2014; Bhole et al. 2015). Several intelligent processes also involve behavioural detection (Wright et al. 2015; Lima et al. 2015; Du and Wang 2012), authentication (Hu et al. 2013), data mining (Li et al. 2013; Ye et al. 2012; Kim et al. 2015a; Bhide and Wagh 2015; Xiao et al. 2015), ruled-based analytical process (Biswas et al. 2011; Dovydaitis et al. 2017), recognition and recommendation system (Ukil et al. 2015; Schweizer et al. 2015), optimisation solutions (Huang et al. 2014) and complex event processing (CEP) (Chen et al. 2014). Other intelligent processes that are considered in the current study include the introduction of an autonomous and intelligent agent (Yang et al. 2014; Kim et al. 2015b; Perešíni and Krajčovič 2017; Peng et al. 2015; Oriwoh and Sant 2013), hierarchical control (Yin et al. 2017; Zhao et al. 2017; Mehrabani et al. 2015) and the use of fuzzy logic (FL) and intuitive control (Collotta and Pau 2017; Yao et al. 2015; Lee et al. 2016). Intelligent process is applied in various security aspects, such as privacy, identification and authentication in a smart home network level to minimise leakage and breach risks (Sanchez et al. 2014; Ghayvat et al. 2015; Ukil et al. 2015); healthcare for special needs (Miori and Russo 2012; Bhide and Wagh 2015; Biswas et al. 2011); and energy saving, money and management in the smart home application level (Li et al. 2012; Ghayvat et al. 2015; Ye et al. 2012; Huang et al. 2014; Kim et al. 2015b; Yao et al. 2015; Lee et al. 2016).

Since 2011, researchers have analysed the intelligent process for IoT-based smart home applications by utilising numerous studies. Existing research articles with various categories have concentrated on the limitations and challenges that restrict the complete utilisation of the intelligent process for IoT-based smart home applications and recommendations have been suggested to overcome these issues. Intelligent process research on smart home applications is active and varied. The current study contributes to (1) deliver valuable insights on technical environments and researchers by analysing the current gaps related to this topic; (2) emphasise the efforts regarding the recent technology; and (3) illustrate the landscape of research towards a coherent taxonomy and determine the characteristics that describe this tremendous approach of research on intelligent process for smart-home-based IoT technology.

This paper is organised into six sections as follows. Section 1 introduces the intelligent process for smart-home-based IoT technology. Section 2 describes the research scope and methods, literature sources and filtering steps in research articles. A coherent taxonomy from the research landscape is also outlined. Section 3 presents the outcome of this survey in the form of results with statistical analysis on the final set of reviewed articles. Section 4 describes the distribution results for the number of involved papers in various categories based on authors' nationality, year of publication and publication journals. Section 5 discusses and classifies the benefits, issues and recommendation from the articles on intelligent process for IoT-based smart homes from 2010 to 2017. Section 6 provides the conclusion of this study.

2 Method

In this work, the principal keyword in the database research was 'Internet of Things (IoT) and its applications in smart homes'. The search excluded any related article on IoT-based smart home applications, such as smart grids, and any non-related articles on IoT application utilisation of smart cities. Furthermore, the scope of this research was limited to English articles that consider IoT applications in smart home automation.

2.1 Information sources

Three article databases were utilised for the related article search, namely, (1) Web of Science, which provides cross-disciplinary research in various topics, including sciences and social sciences, electrical and electronics approaches and humanities and arts; (2) IEEE Xplore, which is a scholar database that provides consistent and wide-ranging articles in computer science and electronic and electrical engineering; and (3) ScienceDirect, which is a large scientific technique database. These databases cover IoT applications in smart home technology and investigate a wide range of related approaches.

2.2 Procedure of study selection

Research variety involves a literature source search and is grouped into two rounds. In the first round, three screening and filtering iterations were performed by first author to determine the studies related to IoT-based smart home applications. Duplicates were removed in the first iteration. Next, all unrelated articles to IoT-based smart home applications were removed by investigating the titles and abstracts. Finally, an intensive review on full-text articles was screened in the second iteration. The three iterations utilised similar criteria of eligibility, followed by author. In the second round, the second author performed single iteration of screening and filtering based on the intelligent process for all papers obtained from the first-round iteration. Subsequently, the final included set was related to the intelligent process of IoT-based smart home technology through different topics.

2.3 Search

The search in IEEE Xplore, ScienceDirect and Web of Science was conducted in December 2017. To determine the related studies on IoT, such as 'Internet of Things', a set of keywords was utilised, including 'smart home', 'smart-home', 'smart-house', 'remote house', 'remote-home', 'intelligent home', 'intelligent house', 'home automation system', 'house automation system', 'automated home' and 'automated house' in various combinations and combined with the 'OR' and 'AND' operators, followed by 'Internet of Things' or 'IoT'. Figure 1 shows the query text. The advanced search options in the database search engines were utilised to exclude book chapters, correspondence, letters and short communication. The recent scientific research related to the article on the tremendous trend in IoT application utilisation in smart homes was also accessed.

2.4 Eligibility criteria

The articles that satisfied our criteria (Fig. 1) were included in our work. An initial goal was established to determine the research space on the intelligent process for IoT-based smart home applications in a coarse-grained and generic taxonomy of four classes. These classes were derived from a pre-survey of the literature without constraint. After the first round, including three screening and filtering iterations, the ineligible articles based on the required criteria were excluded. The criteria of exemption included (a) non-IoT-based smart homes, (b) articles on smart grids and smart cities and (c) non-English articles. Hence, the articles were excluded if they did not fulfil the intelligent process criteria.

2.5 Data collection process

For the simplification of the filtering process, all included articles were read, analysed and summarised based on their initial categories and were saved as Microsoft Word and Excel files. The authors performed full-text reading on all articles. Numerous highlights and notes on the surveyed articles and a running classification of all the articles enabled us to create the proposed taxonomy. Furthermore, taxonomy was utilised to classify the articles with numerous comments and highlight collections. The comments were recorded as hard or soft copy versions based on each author's style. This process was followed by another process of characterisation, description, tabulation and conclusion of the essential findings. These findings were provided in the supplementary materials as a complete reference for the results, which will be described in the subsequent section.

3 Article results and statistical information

The results of the initial query search of 1798 articles are as follows: 268 articles from ScienceDirect, 1425 articles from IEEE Xplore and 105 articles from WoS. The articles were filtered twice according to the sequence adopted in this research. In the first round,

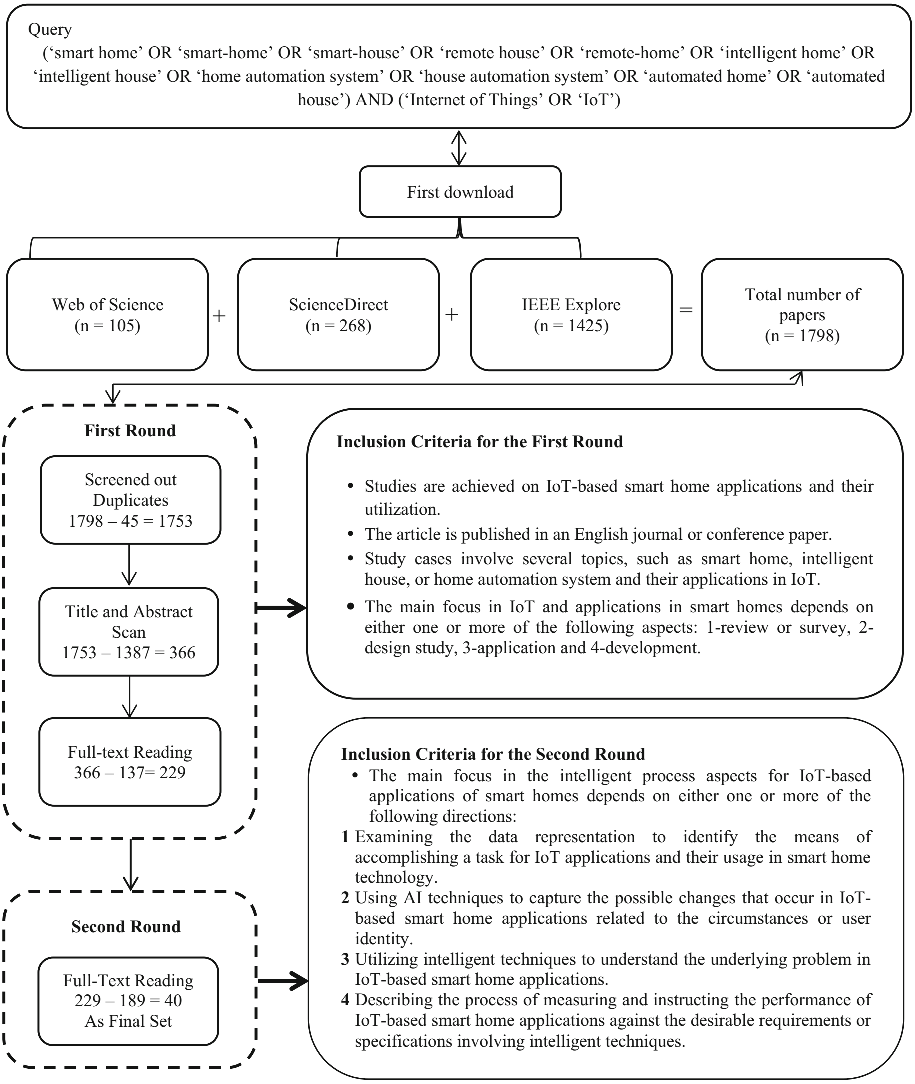

Fig. 1 Flowchart of study selection, including search query and inclusion criteria

three screening and filtering iterations were performed to determine the studies related to IoT-based smart home applications. A total of 45 articles out of 1798 articles were duplicates and thus removed, leaving 1753 articles. After reviewing the titles with abstracts, 1387 articles were excluded, leaving 366 articles. The full-text review excluded 137 articles, leaving 229 articles related with IoT-based smart home applications. In the second round, the final full-text review excluded 189 of the 229 articles, leaving 40 articles for the final set. The remaining articles were related to the intelligent process for IoT-based smart home technology through different topics. Figure 2 presents the taxonomy utilised to review the research articles, which concentrate on intelligent process characteristics and their general utilisation in the IoT-based smart home approach. This taxonomy expressed the complete development

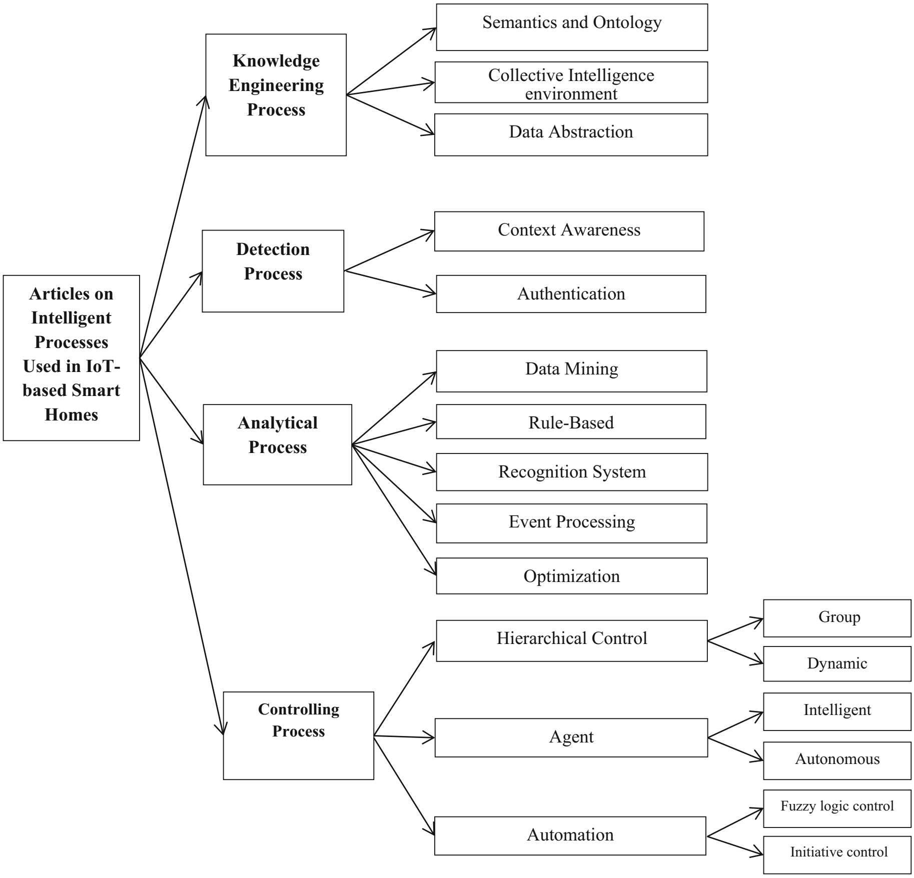

Fig. 2 Taxonomy of literature on intelligent process for IoT-based smart home applications

of different studies and applications. The classification proposes four major classes. The first class includes the knowledge engineering process that examines data representation to identify ways of accomplishing a task for the IoT applications and their usage in smart home technology (10/40 papers). The second class includes papers on the detection process that attempts to use AI techniques to capture possible changes in IoT-based smart home applications, which are related to circumstances or user identity (7/40 papers). The third class comprises the analytical process based on intelligent techniques to understand the underlying problem in IoT-based smart home applications, infer new knowledge and suggest a solution to the problem (12/40 papers). The final class includes studies on the controlling process, which describes the process of measuring and instructing the performance of IoT-based smart home applications against the requirements or specifications of intelligent techniques (11/40 articles). The following sections present the categories for statistical analysis.

3.1 Knowledge engineering process

This category describes and focuses on the engineering process in IoT-based smart home applications, which examines data representation to identify ways of accomplishing a task for the IoT applications and their usage in the smart home approach. This section includes 10/40 articles that are grouped into three sub-categories, namely, semantics and ontology, collective intelligent environment and data abstraction.

Semantics and ontology includes 6/10 articles, covering the smart home semantic knowledge representation and the semantic web essentials (Web 3.0). The researchers derived a semantic layer within the highest level of the AI platform that enables systems to utilize a knowledge-based environment representation completely (Miori and Russo 2012). They ensured information interoperability among virtual objects (VOs), reusability and extensibility (Kibria and Chong 2014; Shamszaman et al. 2014). Particularly, they developed an ontology service that includes VOs to represent the actual world in a virtualised manner, which is defined by the object's attributes, features and resources. The objects are then connected to one another in a semantic ontological manner. Semantic ontology-based service synchronisation offers a consolidated extracted object service by utilising the IoT service by ontologically extracting the related object for the user (Kim et al. 2014). It covers the links used to represent semantic associations (Sun et al. 2014) by introducing ideas, forming model and querying of event-linked networks and exploring the practical sensing scenario of smart homes. The reasoning ability enables the event-linked model to discover potential useful semantic links between events and useful patterns. Finally, the researchers Huynh et al. (2014) proposed a localised solution for lost objects within the home range, with a fine description of possible system implementations. The proposed solution utilises a passive radio-frequency identification technique for localisation services and saves information in the form of ontology. This information allows the application of reasoning to the search and simplifies the entire smart home system integration. Furthermore, it guarantees adaptability with the emerging semantic web.

Collective intelligent environment and a group of individuals acting collectively are presented by 2/10 articles that cover the dynamic injection of automation rules based on semantic web technologies (Kasnesis et al. 2015). The researchers proposed a platform where the users can create semantic rules based on their own requirements of a smart home system. In network monitoring Sanchez et al. (2014), the researchers explored information leakage, such as applying pattern matching and machine learning techniques, to determine the encrypted traffic and the critical impact on the privacy of citizens in the smart home context.

Data abstraction is presented in 2/10 articles that present the challenges and the management flow of information abstraction. Raw data were derived and provided valuable and comprehensible information (Ganz et al. 2015). In this study, two granularity levels of abstraction, namely, low-level data abstraction and high-level semantic abstraction were introduced. Low-level abstraction represents atomic and static information, which can be acquired through data gathering from the stream of a local sensor and merging the data with local sensor metadata, such as range, capability and type. Meanwhile, high-level abstraction may be concluded through observing multiple low-level abstraction sources to gain the global picture about current activities and multivariate events.

In the management flow for the abstraction of real-world objects (RWOs) and the virtual composition of those objects to provide IoT services Sasidharan et al. (2014), the researchers also enhanced the IoT architectural framework with cognitive technologies to abstract the heterogeneity of RWOs by creating a semantically enriched virtual representation of the objects known as VOs. Moreover, this work implemented the framework for a smart home use-case and improved it with additional learning and a semantic reasoner to utilize the advantages offered by both the cognitive methodologies to make meaningful decisions.

3.2 Detection process

This category uses the AI method to identify changes in IoT-based smart home environments. This category has 7/40 articles, which can be further divided into two sub-categories according to detection (i.e., context awareness and authentication). Context awareness sub-category consists of 6/7 articles. This sub-category refers to the use of AI to detect, interpret and use circumstances in the setting of smart home environments with humans who realise that their behaviours are affected by the circumstances. The circumstances are related to ambient improvement for comfort (Li et al. 2012), lifestyle improvement for wellness (Ghayvat et al. 2015), lifestyle improvement for energy saving (Wright et al. 2015; Wang et al. 2012; Lima et al. 2015) and emotional virtual human-based management system for comfortable interaction with actual users (Du and Wang 2012). Authentication involves the recognition of user identity through AI methods. Only 1/7 article belongs to this sub-category, which proposes the use of face recognition for user identification; thus, the correct user profile can be extracted to provide personal services based on user preferences (Hu et al. 2013).

3.3 Analytical process

The analytical process uses AI techniques in analysing the data obtained from systems to gain knowledge about the data, infer new insights and suggest appropriate solutions based on the data. A total of 12/40 articles belongs to this category, which can be further divided into data mining, rule-based recognition and recommendation system, optimisation and event processing.

Data mining uses AI to identify patterns in a large data set to infer new knowledge. This category consists of 4/12 articles on analysing appliance usage patterns based on data from smart devices (Ye et al. 2012; Kim et al. 2015a), predicting the best possible solutions when device malfunctions occur (Bhide and Wagh 2015) and learning the relationship between events in a smart home with uncertain reasoning (Xiao et al. 2015). Rule-based algorithms refer to AI techniques that identify, learn and adapt the sets of rules that collectively represent the knowledge extracted from a smart home system. The application of rules allows humans to interpret the knowledge easily. A total of 2/12 articles belongs to these sub-categories, which focuses on the use of the reasoning rule to extract relationships between events in large data (Biswas et al. 2011) and FL to perform top–down hierarchical analysis on home situations to avoid rule-increased problems (Dovydaitis et al. 2017).

The recognition and recommendation system can identify an object or event of interest and suggest appropriate solutions for the object or event. This sub-category has 3/12 articles that are related to identifying and suggesting solutions to problems in privacy, smart home and energy management. In smart home management, the system is utilised to predict the states of appliances and recommend their settings at a given time by learning the usage patterns of the appliances (Bhole et al. 2015). Instead of appliances, the system is used to learn consumer behaviours of smart homes and recommend solutions for energy saving to the consumers (Schweizer et al. 2015). The system is used in privacy management to identify the leakage of confidential information, preserve privacy for the smart meter data and alert the user in case of a privacy breach (Ukil et al. 2015).

Event processing is a method of tracking and analysing (processing) the collected data about events from different sensors and deriving a conclusion from them. This sub-category has 2/12 articles. Events are matched based on real-time smart home data (Li et al. 2013), and a hierarchical model is designed for smart home services, which supports real-time data awareness, data processing, event processing and service mapping. CEP uses an intelligent mechanism to analyse information from various resources, justify sensing events and trigger appropriate actions in a system. The mechanism focuses on implementing CEP to ensure ambient conditions for building and satisfying the specifications, detecting failure in the system and triggering malfunction alarms when necessary (Chen et al. 2014).

Meanwhile, optimisation is about finding possible solutions to maximising the desirable characteristics of a system (e.g., smart home system) while minimising the undesirable characteristics with the aid of AI techniques. Only a single article (1/12) falls under this sub-category, and it is related to finding the co-locations of IoT services on devices to save communication and computation energy (Huang et al. 2014).

3.4 Controlling process

The controlling process focuses on IoT-based smart home environments to cater to the special needs of and orchestration among devices. A total of 11/40 articles belongs to this category and are grouped into three sub-categories, namely, hierarchical control, agent control and automation.

Hierarchical control focuses on the Web of Objects (WoO) ranking, as shown in the following topic group, and the dynamic hierarchical control of appliances in a home environment, which was reported in 3/11 articles. The hierarchical control group has 2/11 articles. The hierarchical control group in Yin et al. (2017) categorises household electricity loads based on their importance. It also expresses a rule of reduction when the limitation in the total load is exceeded. This method maintains the total power or the summation of active loads, which is lesser than the home capacity, by grouping the household facilities under a single premise into Groups I, II and III. The system then cuts the load based on the rules created hierarchically. The correctness of the rules in the hierarchical control group method is validated by simulating numerous states of appliances. Load cutting is random to ensure that a certain group works all the time. Thus, it can efficiently prevent the optimum load state from overloading and maintain the advantage of the power system. Another hierarchical control group was demonstrated in Zhao et al. (2017), which involved the adaptation of rules. Most ambient intelligence contexts in processing infrastructure are completely transformational rather than reactive data processing systems. The infrastructure should not only be able to capture all sequential constraints and potential side effects that may result from physical sensing and actuation effects but should react to them as well. Therefore, a self-configurable data mediation (SCDM) infrastructure that can mediate and adapt a generic rule through finite-state-machine models is proposed for smart homes. The dynamic control creates personalised speech recognition by effectively controlling dynamic hierarchical language models (Mehrabani et al. 2015); this method concentrates on a set of natural language understanding and speech recognition for smart home applications with configurable devices. Speech recognition systems utilise several acoustic and language models for translating a spoken command to text. Dynamic hierarchical language models operate in personalised speech recognition creation and are evaluated in terms of semantic accuracy and word accuracy.

Agent control focuses on the ability to manage the appliances of heterogeneous IoT-based smart homes and was reported in 5/11 articles. Agent control is categorised into two sub-categories. The first sub-category is intelligent agent, including resource name services (RNSs) (Yang et al. 2014). This method presents a smart home architecture based on RNS, which defines the contributing counterparts of smart homes and designs the required process of smart home services to attain interoperability among multiple vendors. In addition, a security (Kim et al. 2015b) method was used to develop a scheme with dynamic- and energy-aware authentication for the IoT (DAoT). DAoT uses a feedback control scheme to select an energy-efficient authentication policy dynamically. With DAoT, loT devices with limited resources can be safely interconnected because DAoT finds and adopts the best cost-effective authentication mechanism (Kim et al. 2015b). Moreover, the autonomous cooperation method (Perešíni and Krajčovič 2017) attempts to provide highly flexible services through an intelligent home security system (IHSS). The second sub-category is an autonomous agent, which includes autonomous intelligent modules (Peng et al. 2015); this method proposes a modern intelligent house solution for actuator realisation. The house is relatively inexpensive, robust and secure against intrusion and automated forensics edge management system (FEMS) (Oriwoh and Sant 2013). This method also proposes a system capable of integrating a home–IoT network in conducting initial forensic investigation and providing basic security services to improve the orchestration further and use network-enabled devices, such as IoT devices. FEMS includes the fallibility of tools and components, the chain of custody management (which affects evidence acceptability), steganography, cryptography and gradually holding hybridised networks.

Automation introduces automatic equipment, devices and appliances in IoT-based smart home environments and was discussed in 3/11 articles. Automation is divided into two sub-categories. The first sub-category is FL controller (FLC), which includes the sleeping time of field devices in an automated home environment based on Bluetooth low energy (BLE) (Collotta and Pau 2017). This method presents an automated home-based BLE that determines the sleeping time of field devices. The proposed FLC determines the sleeping time of field devices according to the battery level and the ratio of throughput to workload. An energy dispatch strategy (Yao et al. 2015) also satisfies the energy consumption requirement by affording the least paid amount of electricity bill. The FLC-based energy dispatch strategy ensures that (a) less grid powers are bought through the peak of price epochs and that (b) high grid powers are bought at the off-peak price epochs. The second sub-category is intuitive control, which includes point-and-press remote controllers (Lee et al. 2016). This method addresses a point-and-press directionality feature, which allows intuitive control through pointing to the targeted device to display the interface of the target's control on the remote controller screen for home automation. This provides convenience and easy utilisation in a smart home environment.

4 Distribution results

The distribution of articles in various categories is presented according to the authors' nationality and publication journals. Figure 3 indicates that the three databases store numerous research articles. The articles were grouped into four categories, namely, knowledge engineering, detection, analytical and controlling processes.

Five of the selected articles were published in ScienceDirect, consisting of 0 articles for knowledge engineering process, 2 for detection process, 2 for analytical process and 1 for controlling process. The number of articles selected from Web of Science was 4, including 1 article for knowledge engineering process, 1 for detection process, 1 for analytical process and 1 for controlling process. The number of selected works from IEEE Explore was 31, comprising of 9 articles for knowledge engineering process, 4 for detection process, 9 for analytical process and 9 for controlling process. Meanwhile, the distribution according to the authors' nationality in Fig. 4 shows that the articles on the intelligent process aspect of

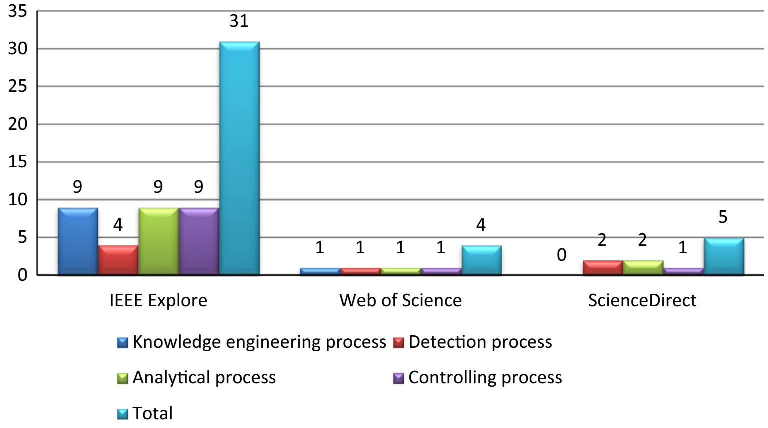

Fig. 3 Number of involved papers in various categories based on publication journals

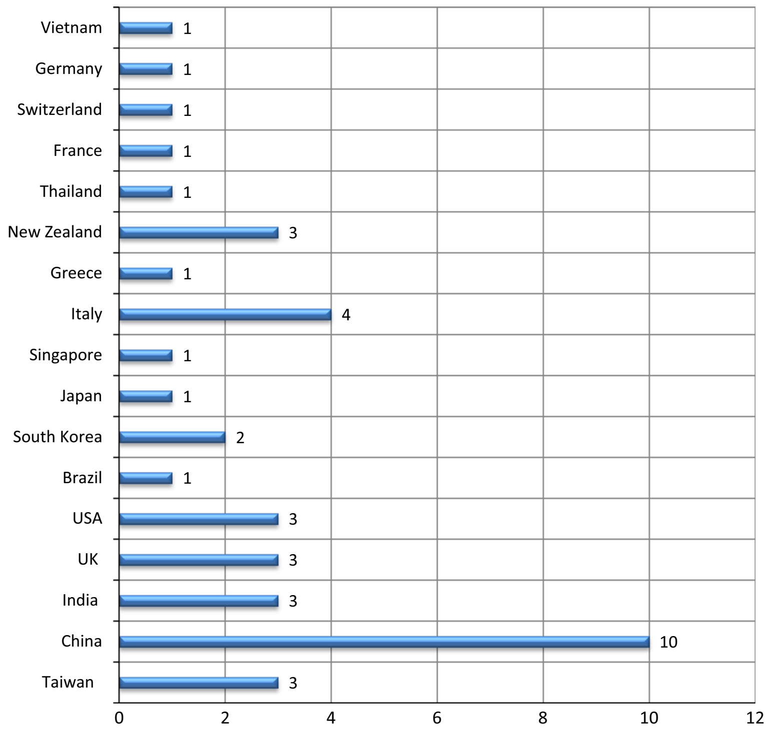

Fig. 4 Distributions by authors' nationality

IoT-based smart home applications in this review were written by authors from 17 countries. These articles typically included case studies in 17 countries.

At n = 40, the geographical distribution of intelligent process for IoT-based smart home applications in terms of numbers and percentages shows that the most creative authors are from China, with 10 case studies, followed by Italy with 4 case studies, USA, UK, New

Zealand, Taiwan and India with 3 case studies each, South Korea with 2 and Brazil, Japan, Singapore, Greece, Thailand, France, Switzerland, Germany and Vietnam with 1 case study each.

5 Discussion

This survey presents the most relevant studies on the intelligent process aspects of IoT-based smart home applications. This work aims to emphasise the research trends in this area. This survey differs from previous reviews because it is current and focuses on the literature on intelligent process for IoT-based smart home applications rather than IoT-based smart home applications themselves. A taxonomy of the related literature is proposed. Developing a taxonomy of the literature in a research area, particularly an emerging one, can provide several benefits. A taxonomy of published works organises various publications. New researchers who study the intelligent process aspects of IoT-based smart home applications may be overwhelmed by the overlapping of papers about intelligent process concepts and the absence of any type of structure. Thus, they may fail to obtain an overview of this area. Various articles address the topic from an intelligent process perspective, whereas other works examine the data representation to identify ways of reaching the conclusion of IoT application tasks and their utilisation in smart home technology. Some studies attempt to employ AI techniques to capture the possible changes in IoT-based smart home applications related to circumstances or user identity. Other studies aim to understand the underlying problem in IoT-based smart home applications through intelligent techniques. However, other studies describe the process of measuring and instructing the performance of IoT-based smart home applications against the desirable requirements or specifications using intelligent techniques. A taxonomy of the related literature helps arrange these different works and activities into a meaningful, manageable and coherent layout. Meanwhile, the structure introduced by the taxonomy provides researchers with important insights into the subject in several ways. First, it outlines the potential research directions in the field. Second, taxonomy can reveal research gaps. Grouping the literature on intelligent process for IoT-based smart home applications into distinct categories emphasises weak and strong features in terms of research coverage. The statistical data on the individual categories of taxonomy identify the sectors involved in the intelligent process aspects for IoT-based smart home applications to cope with new trends and strengthen inactive areas. Similar to taxonomies in other fields, the proposed taxonomy in this survey employs a common language for researchers to communicate and discuss emerging works, such as research on knowledge engineering, detection, analytical and controlling processes in IoT-based smart home applications. The conducted survey reveals three aspects of the literature content, that is, the motivations behind developing intelligent process for IoT-based smart home applications, the challenges to the successful utilisation of such technologies and the recommendations for alleviating these difficulties.

5.1 Motivations

The benefits of using intelligent process for IoT-based smart home applications are evident and compelling. This section presents several advantages reported in the literature, which are grouped into categories depending on similar benefits, as shown in Fig. 5. Corresponding references are cited for further discussion.

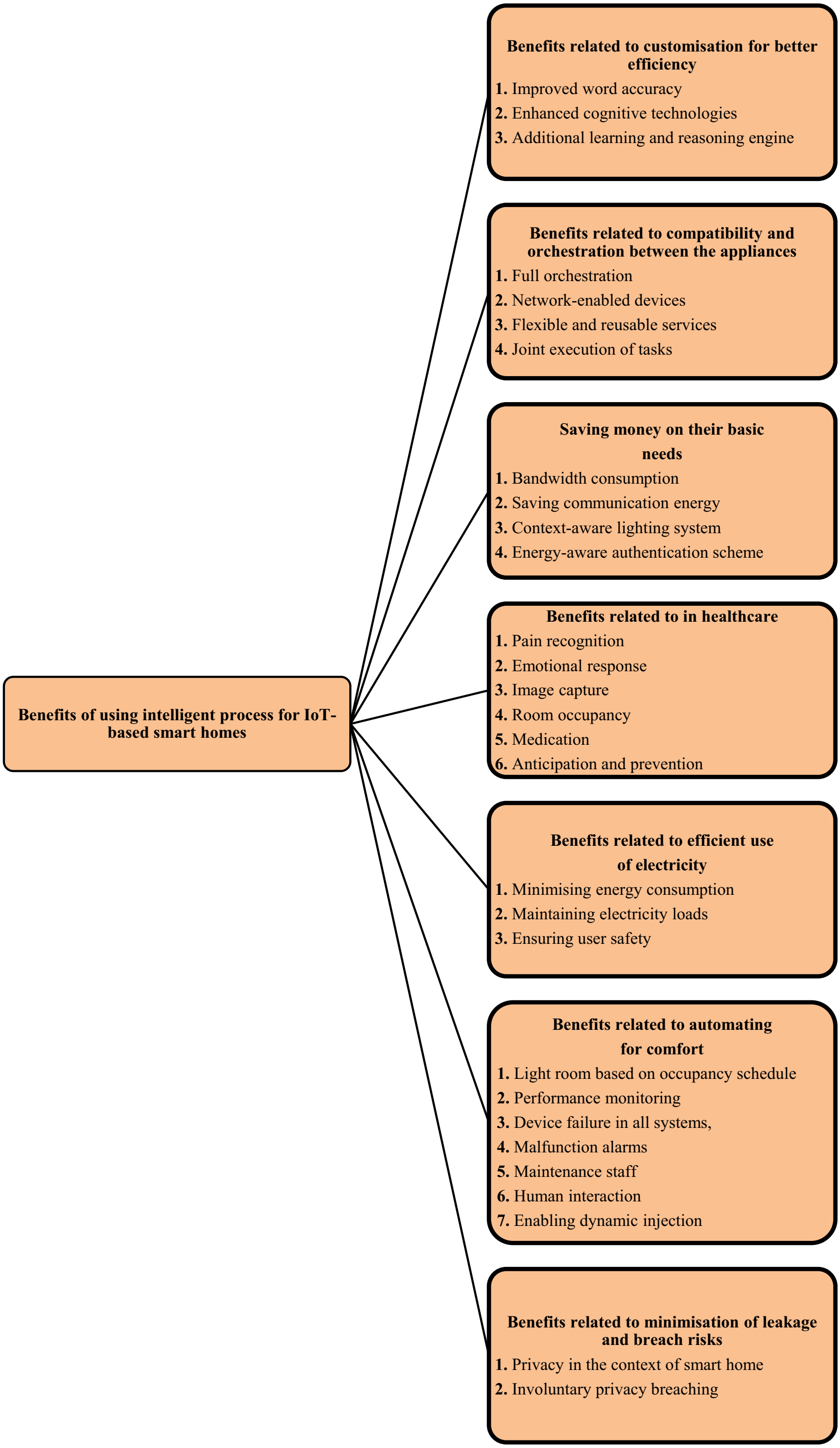

Fig. 5 Categories of benefits of using the intelligent process for IoT-based smart home applications

5.1.1 Benefits related to minimising leakage and breach risks based on intelligent process

One of the problems in smart home technologies is the vulnerable security and privacy aspects (Ghayvat et al. 2015). The main potential impacts on the privacy of citizens in the smart home context are information leakage and involuntary privacy breach (Sanchez et al. 2014; Ukil et al. 2015). Intelligent processes, which involve AI methods, are applied to minimise leakage and breach risks. To decrease the leakage of information essential to these technologies, a demonstration of how a smart device can visit websites can be conducted through machine learning. The utilisation of pattern-matching techniques can determine encrypted traffic (Sanchez et al. 2014). We propose the dynamic privacy analyser scheme, which was developed based on essential principles, such as robust statistics and information theory, to overcome the involuntary privacy issue in rupturing risk minimisation in smart energy management systems (EMSs) (Ukil et al. 2015). Forensic investigations within the IoT require solutions, techniques and tools that consider the IoT as a dynamic pervasive network model composed of disparate technologies for any utilisation. Accordingly, digital forensics solutions for examining attacks on the home must be adaptable, intelligent and suitable for the requirements and lifestyles of home owners.

5.1.2 Benefits related to automating the intelligent process for comfort

Smart home application lacks the built-in support for low potency processing of uncertainty (Xiao et al. 2015). Thus, smart home residents embed intelligent processes into their devices to automate the process for comfort. Enabling automation rules the dynamic injection utilising semantic web technologies; in cooperative intelligence, environment is a recommended method to process automation (Kasnesis et al. 2015). An expressive interaction with humans can be established by utilising the semantic connection layer, which can simplify the goal-oriented collaboration between devices (Kasnesis et al. 2015). Moreover, training algorithms based on FL and the top–down hierarchical analysis of home situations are utilised to overcome the increasing number of rules (Dovydaitis et al. 2017; Collotta and Pau 2017). In environments with FL-based algorithms for corresponding subset development and processing of rules, a successful combination of crisp algorithms for the identification of the presence/absence of users decreases the number of necessary rules significantly (Dovydaitis et al. 2017). Moreover, the core functionality of a building automation system continuously builds an environment within a specific range, light rooms based on an occupancy schedule monitor device performance and failures in all systems and delivers failure alarms to building engineering contractors and the maintenance staff (Chen et al. 2014). Developing techniques that enable smart human–device interfaces and an appliance usage-prediction engine can also aid home automation systems (Bhole et al. 2015).

5.1.3 Benefits related to intelligent process for IoT-based smart home applications in the efficient use of electricity

Domestic appliances with features to minimise energy consumption have gained increasing attention because they can utilise energy efficiently. Maintaining the entire electricity loads under restriction might guarantee the safety of users in terms of electricity consumption (Yin et al. 2017). One motivation is to develop a method that can recognise user activities based on the relation between activity and appliance (Wright et al. 2015; Lima et al. 2015).

Data mining classification algorithms can be applied to increase the recognition accuracy of various activities. The energy consumption of electrical appliances is related to human activities and is dependent on the actual needs of users (Lima et al. 2015). A system for improving the lifestyle and modifying customer behaviour can save energy, as well as machine learning and AI techniques (Miori and Russo 2012; Wright et al. 2015; Schweizer et al. 2015). To support energy efficiency management, the home environment should be able to monitor, control and optimise energy usage for the households (Kibria and Chong 2014). Activity–appliance–energy consumption (AAEC), personalization model and WoO-based EMS (WEMS) are some of the methods used to provide efficient power management by gathering and analysing real-time data and situation information (Shamszaman et al. 2014; Lima et al. 2015; Du and Wang 2012).

5.1.4 Benefits related to the intelligent process for IoT-based health smart home (HSH)

The intelligent process for IoT-based smart homes non-evasively enhances home care for the elderly and disabled. Most of the devices for an HSH are unable to identify discomfort or any emotional response, which is a vital parameter for home treatment. Therefore, a healthcare solution is necessary because it can help capture images or facial expressions for monitoring patients or elderly people who have special needs at home. Most smart-home-based monitoring and assistive systems for activated recognition are overwhelming for an elderly who lives alone, and allow prompt coarse-grained information, such as room occupancy, or supply specific reminders for medication times (Biswas et al. 2011). These monitoring and assistive systems are key factors in implementing an e-health system that can anticipate and prevent possible health hazards before emergency situations (especially for the sick and elderly) (Miori and Russo 2012). To improve the standard of living, the home environmental condition should be changed according to the mood of the habitants without any interruption. In some cases, persons with physical disabilities cannot move from one place to another; thus, accessing regular domestic appliances is difficult for them. Developing a system that requires less human interaction is essential to persons with disabilities (Bhide and Wagh 2015).

5.1.5 Benefits related to intelligent compatibility and orchestration between IoT-based smart home appliances

Several restrictions are set in orchestrating and using network-enabled devices, such as IoT devices, to provide flexible and reusable services because of the lack of interoperability and compatibility between smart home appliances (Sasidharan et al. 2014; Yang et al. 2014; Perešíni and Krajčovič 2017; Peng et al. 2015). Heterogeneous services and devices require interoperability with one another to execute tasks jointly (Yang et al. 2014). In creating orchestration from multiple objects that can provide user-centred services in the IoT architecture platform, we provided various user-centred IoT services using the objectification method and the semantic ontology-based service orchestration mechanism in the WoO platform (Kim et al. 2014). An innovative home-based IoT network concept was developed, in which home-networked devices could communicate with others in a networked method for agent service integration and the design of the IoT middleware architecture (Hu et al. 2013). In addition, a shared ambient intelligence and the IoT infrastructure should built upon a systemic, environment-specific yet environment-wide perspective, encompassing and capturing all the temporal constraints and potential side effects that may result from physical sensing and the actuation effects interwoven with network relationships (Zhao et al. 2017).

5.1.6 Saving money on basic needs in the intelligent process for IoT-based smart homes

Cost-saving mechanism is vital to the design and development of smart homes (Ghayvat et al. 2015; Kim et al. 2015b). Given that perpetually running and managing IoT services on distributed located devices account for the main energy cost, one way to save on energy cost is to co-locate several services on a device and reduce the bandwidth consumption to save computing and communication energy (Huang et al. 2014; Lee et al. 2016). A system that automatically learns useful parameters from users, such as a lighting control system based on the context-aware approach for smart meeting rooms, can also save money through the low electric bill (Li et al. 2012; Ye et al. 2012). Moreover, the DAoT can determine and adopt the best cost-effective authentication mechanism (Kim et al. 2015b). A strategy was utilised to satisfy the household energy demand by affording the least paid amount of the electricity bill, that is, (1) only a minimum amount of grid powers is purchased during the maximum price periods and (2) a high amount of grid powers is bought at the off-peak price periods based on the FLC (Yao et al. 2015).

5.1.7 Benefits related to intelligent customisation for improved efficiency in IoT-based smart homes

Some intelligent customisation should be performed on all smart home devices to improve the efficiency in smart homes (Huynh et al. 2014). For example, a combination of speech recognition and natural language understanding for smart home applications with customisable devices can improve word accuracy and semantic accuracy (Mehrabani et al. 2015). Inefficient methods for extracting, abstracting and analysing real-time, heterogeneous, raw and complex data, such as sensory data and usage information, can be a critical issue (Sun et al. 2014; Ganz et al. 2015; Li et al. 2013; Kim et al. 2015a). An IoT architectural framework enhanced with cognitive technologies can be used to abstract the heterogeneity of RWOs. An engine for further learning and reasoning (cognitive methodologies) can also aid in decision making (DM) (Sasidharan et al. 2014).

5.2 Challenges

The intelligent process for IoT-based smart home applications has numerous benefits; however, these technologies are not perfect solutions to communication network delivery. The survey indicated that researchers were concerned about the challenges associated with the intelligent process in IoT-based smart home applications and their usage. The main challenges in the adoption of the intelligent process for IoT-based smart home applications are shown in Fig. 6, with references for further discussion. The challenges are classified according to their nature.

5.2.1 Concern about security issue

The security issue covers cyber attack (Sanchez et al. 2014; Oriwoh and Sant 2013) and privacy (Ukil et al. 2015; Kim et al. 2015b). Protection is not applied to all transmitted information even when encryption is utilised because the source and destination of media access control (MAC) addresses still travel in clear air. Consequently, an attacker can remotely collect the MAC addresses of devices to identify the active ones operating in the smart home

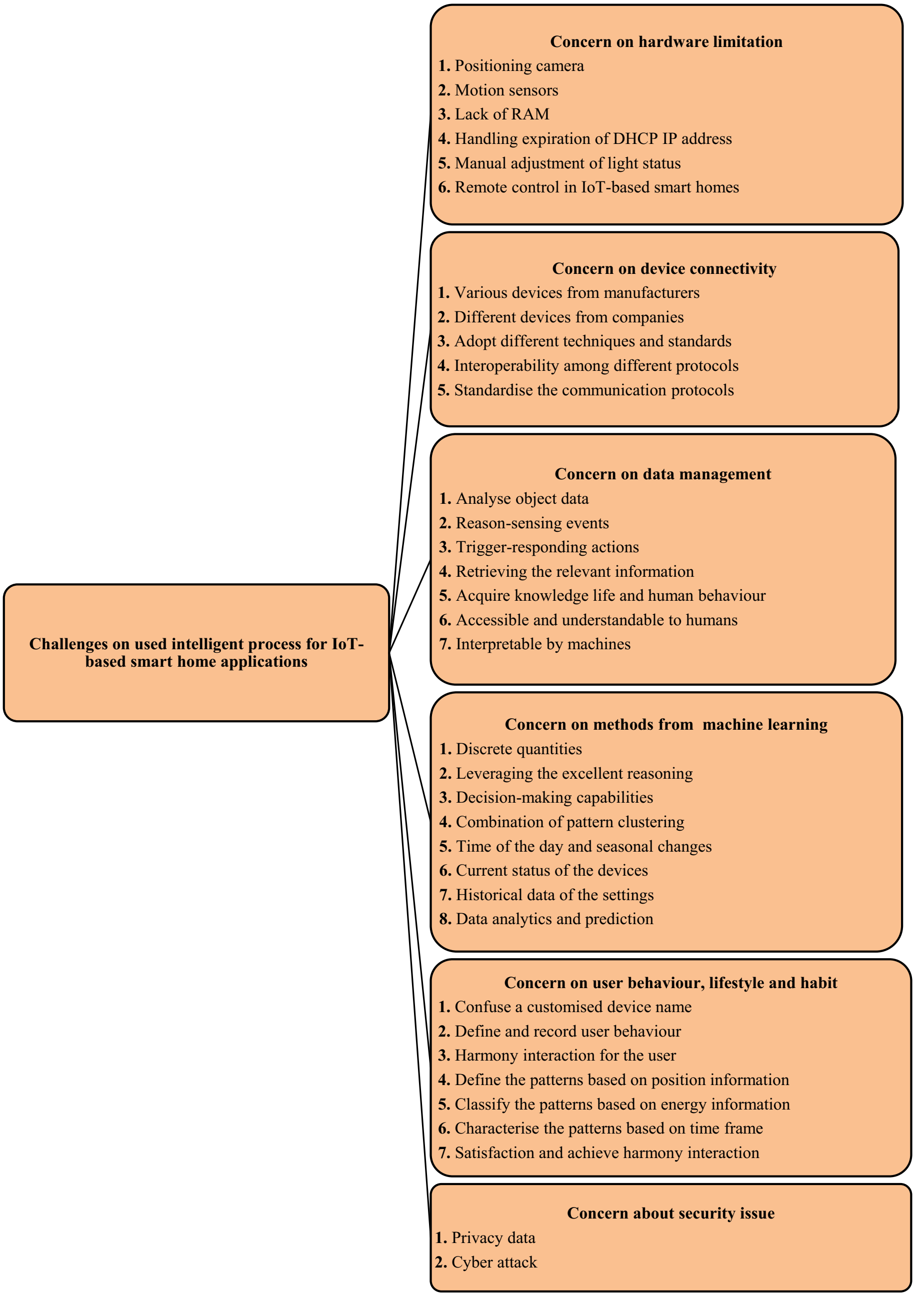

Fig. 6 Categories of challenges of used intelligent process for smart-home-applications based-IoT

and can launch a cyber attack (Sanchez et al. 2014; Kim et al. 2015b; Oriwoh and Sant 2013), such as providing opportunities for malicious parties to execute attacks that can directly affect home occupants and owners and the leakage of privacy data, such as life patterns (Ukil et al. 2015; Kim et al. 2015b).

5.2.2 Concern on data management

Data management covers data from different sensors (Sun et al. 2014; Biswas et al. 2011; Chen et al. 2014) and extracts significant information (Miori and Russo 2012; Ganz et al. 2015; Wang et al. 2012) and various standardised instruments (Kim et al. 2014) in smart home applications. The researchers (Chen et al. 2014) were concerned with three parts, that is, (1) an efficient mechanism for object data analysis, (2) determining events and (3) activating corresponding actions for IoT. The researchers Sun et al. (2014), Wang et al. (2012) and Chen et al. (2014) also focused on the organisation of the dataset and the accuracy in retrieving relevant information from the users as part of the concern in the area of data management. Moreover, the intelligent process for IoT-based smart home applications can acquire knowledge and information about daily life and human behaviour. Furthermore, the researchers Ganz et al. (2015) and Biswas et al. (2011) emphasised that how sensor data were transferred from their raw form into higher abstraction representations and how they were made accessible and understandable for humans or interpretable by machines and DM system remain unclear.

5.2.3 Concern on device connectivity

Device connectivity covers the communication problem that occurs among various devices from manufacturers or companies that adopt different techniques and standards (Kim et al. 2015a; Yang et al. 2014; Collotta and Pau 2017). For example, most existing solutions are still unable to attain interoperability within different protocols (Kim et al. 2015a; Yang et al. 2014) and standardise the communication protocols (Collotta and Pau 2017). The interoperability among multiple appliances or protocols in the home environment is one of the main challenges in designing smart home applications. In addition, the integration of multiple electrical devices in the household is critical and considered an open challenge due to the lack of standardised and inexpensive communication.

5.2.4 Concern on hardware limitation

The hardware limitation covers the IoT devices, such as the positioning camera (Wang et al. 2012), lack of random access memory (RAM) (Perešíni and Krajčovič 2017) and control mechanism, for handling dynamic host control protocol (DHCP) internet protocol (IP) address expiration (Perešíni and Krajčovič 2017), the manual adjustment of light status (Li et al. 2012) and the design of the remote control in an IoT-based smart home (Lee et al. 2016). The main concern is the effect of the positions of the camera and motion sensors on system accuracy (Wang et al. 2012). RAM also forced the researchers to optimise the code and libraries to fit the entire functionality into the available memory capacity of approximately 1800 bytes and the digital temperature sensor, which had a delayed processing of 1 s and caused data retransmission because of the opposite node's presumed loss of function (Perešíni and Krajčovič 2017). Furthermore, the lack of a control mechanism for handling the expiration of the DHCP IP address would result in the inefficiency of the application (Perešíni and Krajčovič 2017). Manual adjustment is another concern that required considerable research for finding a feasible solution (Li et al. 2012). Meanwhile, the remote control in IoT-based smart homes should be intuitive and user friendly (Lee et al. 2016).

5.2.5 Concern on methods from machine learning

The methods from the machine learning cover rule are based on (Kasnesis et al. 2015; Xiao et al. 2015; Schweizer et al. 2015) FL (Dovydaitis et al. 2017), neural network (NN) and pattern clustering, as well as data analytics and prediction (Bhole et al. 2015). The main challenge in rule-based leaning is the possibility of conflict between two rules (Kasnesis et al. 2015) and uncertainty (Xiao et al. 2015). Thus, discrete quantities cannot be avoided, and limited information collected can cause serious information loss. The recommendation system should be provided with the stream of an event from the smart home and the previous patterns that replicate the inhabitants' behaviour. The main challenge in FL can be addressed by leveraging excellent reasoning and DM capabilities. Moreover, the researchers explored the best combination of a pattern clustering method and an activity decision algorithm, because most of the related works focused on only one of the two steps. Finally, the researchers (Bhole et al. 2015) faced several challenges, including (1) time of the day and seasonal changes, (2) the duration of device use by the user, (3) the status of the devices, (4) historical data of the settings at a specific time and (5) the difference between the preferences of a child and adult user during the data analytics and prediction.

5.2.6 Concern on user behaviour, lifestyle and habit

User behaviour, lifestyle and habit cover the human behaviour (Ghayvat et al. 2015; Wright et al. 2015; Ye et al. 2012; Mehrabani et al. 2015), which also includes virtual humans (Du and Wang 2012). Speech recognition systems use acoustic and language models to translate a spoken command to text. Accurately recognising the device name is important when an end-user uses a personalised label to issue a command to a device. However, generic language models that are trained with large amounts of data based on an intelligent process might confuse a customised device name with a common phrase in a specific language. Describing and recording the behaviour of a user (Miori and Russo 2012; Ghayvat et al. 2015; Xiao et al. 2015; Bhole et al. 2015; Schweizer et al. 2015) and lifestyle pattern, such as defining the patterns based on energy and position information and time frame, are critical. However, smart home applications should improve comfort and satisfaction and achieve harmonious interaction of users in the digital home environment.

5.3 Recommendations

The implementation of intelligent process for IoT-based smart homes has gained extensive attention from researchers in various domains. However, the implementation faces challenges related to large data and software and hardware technologies. To overcome the challenges, the researchers have recommended potential future works. The recommendations can be grouped into four main categories, as shown in Fig. 7.

5.3.1 Recommendations related to benefiting users

One of the common recommendations in implementing smart home technologies is the enhancement of privacy and security protection (Sanchez et al. 2014; Yang et al. 2014). Several countermeasure solutions were suggested in Sanchez et al. (2014) to mitigate the risk of privacy leaks. Improving the security protocols increases the resilience against adversarial attacks, thus minimising the risk of privacy leaks (Sanchez et al. 2014; Oriwoh and

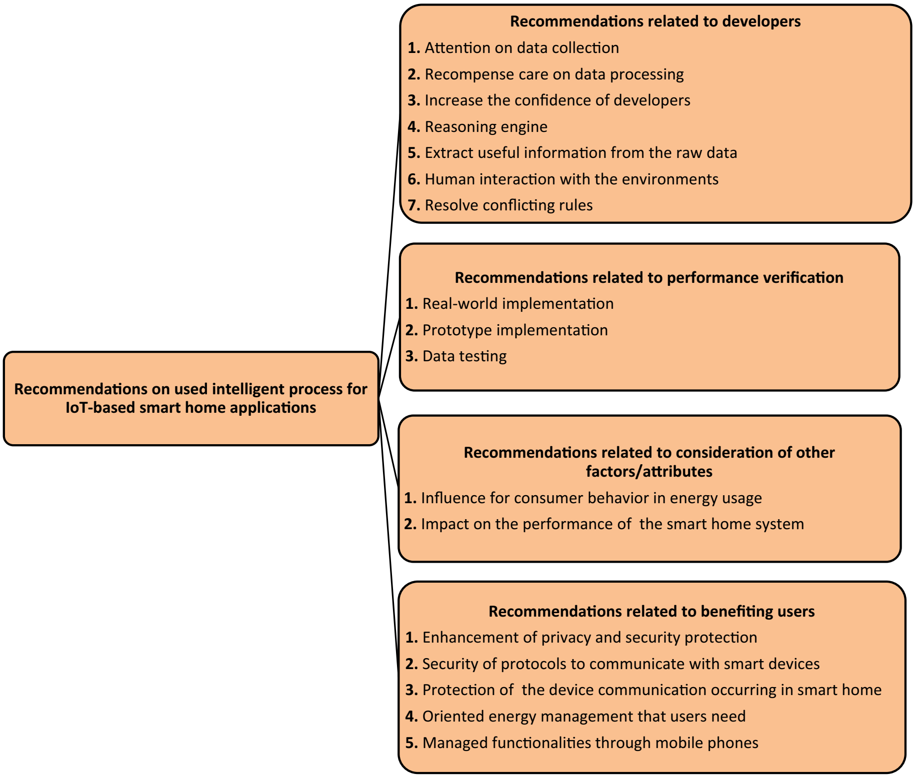

Fig. 7 Categories of recommendations for smart homes via IoT

Sant 2013). Therefore, FEMS was recommended in Oriwoh and Sant (2013) to use secured protocols in communicating with smart devices in smart homes. Another potential solution to reduce the vulnerability of smart home against privacy leaks is to protect the device communication in smart homes. This solution can be done by injecting noisy data into the communication between the smart devices and adding encryption in the higher communication layers (Sanchez et al. 2014). Researchers in Bhide and Wagh (2015) and Perešíni and Krajčovič (2017) also recommended considering human user needs and experiences. Smart homes should be oriented with security features and energy management, in which user needs are considered into the smart home system, such as voice alert, motion detection and energy monitoring (Bhide and Wagh 2015). The functionalities or features of smart homes can be managed through mobile phones. Different mobile phone platforms may affect user experience in using the household management system, which should be further investigated (Perešíni and Krajčovič 2017).

5.3.2 Recommendations related to developers

The activities of users should be recognised and predicted to improve the efficiency and energy management of smart home applications. Therefore, in Perešíni and Krajčovič (2017), a combination of AI methods consisting of the K-pattern clustering algorithm and NN to perform the task was proposed. However, the prediction accuracy may be affected by the sensitivity of sensors in collecting data from smart environments and the existence of redundant or irrelevant attributes in the data (Perešíni and Krajčovič 2017). Developers should also focus on data collection and data processing to ensure the prediction accuracy of AI methods. Improving the accuracy of AI algorithms is important for an intelligent ecosystem based on AI techniques to recognise the user needs correctly and adapt itself to the specific setting (Miori and Russo 2012). Consequently, the system can anticipate the user needs with minimum intervention. Meanwhile, considering the usage of an evolutionary mechanism to improve the accuracies of AI techniques should be further investigated. In terms of classification and prediction, the promising results demonstrated by the ensemble model of random forest and gradient boosting methods in Bhole et al. (2015) should increase the confidence of developers in expanding the potential use of AI, such as in optimisation and recommendation systems.

A middleware has been used to facilitate the development of IoT applications and provide useful abstraction for developers. In a middleware architecture, a reasoning engine enables the switch of local or remote services. In future works, the use of a reasoning engine to support complex service queries for smart objects in the IoT applications should be investigated. In addition, a reasoning engine can be used to enable the switch of available services based on different criteria.

Another challenge is making the raw data highly useful by extracting information in IoT applications to be further understood by users. The challenge depends on how to query, organise and analyse large data. To address the challenge, developers can focus on the solutions for addressing storage schemes, the index mechanism and the query and analysis of large data (Sun et al. 2014; Ganz et al. 2015). In managing large and multimodal data, data processing and abstraction techniques should be able to handle the changes in data automatically and adaptively without the need for domain knowledge from users (Ganz et al. 2015). In Kim et al. (2015a), the results of data analysis were stored in a knowledge base to infer new knowledge in the future. Advanced AI techniques not only can help understand the needs, preferences and habits of IoT users but also predict their future trend.

Human inhabitants of smart homes have different needs, routines and habits. Therefore, a home automation system design that considers the human interaction with the environment is important. A platform known as smart home user interface (Sem-SHUI) has been proposed to allow the dynamic injection of semantic rules by human users (Kasnesis et al. 2015). Unlike Sem-SHUI, an SCDM infrastructure has been proposed for smart homes, where it mediates and adapts a generic rule through finite-state machine models. Regardless of the approaches suggested in Zhao et al. (2017), conflicting rules may exist and a user must decide. The process becomes time and labour consuming when the operation rules for a system depends on the state dependencies of appliances in a system that still depends on humans (Chen et al. 2014; Lee et al. 2016). Therefore, an autonomous mechanism is required for the system to learn rules automatically and resolve conflicting rules with minimum human intervention (Zhao et al. 2017). Such intelligent and autonomous mechanism consists of a toddler algorithm, and a correlation algorithm was used in Ye et al. (2012) to learn and adapt the operation rules of smart homes according to user preference. However, the mechanism requires extensive time for learning the rules. Therefore, developers should consider AI techniques that not only exhibit learning and adaptive abilities but are also an efficient autonomous mechanism. The autonomous mechanism is also preferable in the control system for smart home appliances.

5.3.3 Recommendations related to performance verification

Insufficient real-world implementation, prototype implementation and data testing are the main obstacles in verifying the performance and potential of AI in IoT applications, such as security system, human behaviour-aware system and EMS. The work in Peng et al. (2015) proposed an IHSS that used agent-based IoT devices and could provide security services through monitoring sensors and autonomously controlling actuators. However, the work lacked details of a real scenario setting and a comprehensive evaluation for ensuring its real-world implementation. No prototype and data are available for human behaviour-based IoT applications, such as context-aware control system (Sasidharan et al. 2014; Li et al. 2012), location-aware lifestyle improvement system (Wang et al. 2012), personalised speech recognition system (Mehrabani et al. 2015) and emotional virtual human-based management system (Du and Wang 2012). The applications operate through the recognition and consideration of the needs, preferences and habits of human users.

The performance verification of AI is commonly recommended in home energy management (Shamszaman et al. 2014; Ghayvat et al. 2015; Lima et al. 2015; Hu et al. 2013; Yin et al. 2017; Kim et al. 2015b; Collotta and Pau 2017; Yao et al. 2015). A DAoT has been developed to secure the interconnection between limited resources, and its implementation in real-world smart home appliances is recommended (Kim et al. 2015b). In a home EMS, AI methods, such as FLC, are used to approximate the amount of electricity to be purchased from the utility due to its resemblance to human reasoning and DM and its ability to capture uncertainties and ambiguities in human languages (Yao et al. 2015). Therefore, FLC should be tested in other real-world problems that exhibit complexity and uncertainty. FL is also used as a mechanism for enhancing the device lifetime in an automated home wireless network (Collotta and Pau 2017). However, the approach has been applied in simulations rather than real-world implementations (Collotta and Pau 2017). Hence, its real-world applications and simulations should be compared to verify its energy efficiency (Collotta and Pau 2017).

In IoT environments, heterogeneous devices/objects are connected and communicate to provide services. An architecture of the WoO platform has been proposed as a solution to enable the interaction of heterogeneous objects that can provide user-centred services (Kim et al. 2014). However, quality of service/experience should be analysed to verify the service stability and service integration. The potential WoO platform has also been applied in energy management. We proposed the WEMS- (Lima et al. 2015) and AAEC-based management system (Shamszaman et al. 2014) to increase energy efficiency. Both systems were developed to manage energy consumption by recognising the need of human inhabitants (Shamszaman et al. 2014; Lima et al. 2015). The comparison between the normal system and WEMS based on energy efficiency should be verified through real-world applications. The feasibility of using AI methods in a real-world energy management demonstrates the potential of AI as a green technology in the future.

Actual demonstration is crucial in identifying the weaknesses of proposed solutions that handle the placement of objects, household equipment and communication devices in different locations inside smart home environments (Ghayvat et al. 2015; Hu et al. 2013). In Ghayvat et al. (2015), the misplacement of sensor nodes was recommended to be further investigated in an actual setting that has different objects and household equipment in smart home environments because it could obstruct wireless communication. Furthermore, the design of media content-sharing devices that are placed in different locations should also be tested in real household environments to confirm its effectiveness (Hu et al. 2013).

5.3.4 Recommendations related to the consideration of other factors/attributes

For potential work related to the IoT application, the inclusion of other factors or attributes that may affect the research outcome are recommended in the research on consumer behaviour modification and the improvement of smart home systems. The factors that influence consumer behaviours in energy usage, such as social, cultural and behavioural factors, should be expanded (Wright et al. 2015). Other factors that affect the performance of smart home systems, such as data preparation and types of machine learning algorithms, should be considered, as reported in Xiao et al. (2015), Dovydaitis et al. (2017) and Schweizer et al. (2015).

6 Conclusions

Recently, a significant emergence occurred in utilising the intelligent process for the IoT applications in the smart home technology. Although the research is continuous, associated descriptions and restrictions remain ambiguous. The present study aims to present a taxonomized survey of related works that will contribute such visions. Certain patterns can be derived from various works on intelligent process aspects for smart home applications, including semantics and ontology, collective intelligence environment (location- and situation-based), data abstraction, training algorithm, query based, context awareness and prediction. In addition, some intelligent processes involve behavioural detection, authentication, data mining, ruled-based analytical process, recognition and recommendation system, optimisation solutions and CEP. Other intelligent processes are also considered in this study, including the introduction of an autonomous and intelligent agent, hierarchical control and the use of FL and intuitive control. The works are classified as follows: knowledge engineering, detection, analytical and controlling processes. A detailed analysis of the articles that recognise and define the issues, limitations, advantages and recommendations related to the intelligent process aspects for IoT applications in smart homes was conducted. The available application types are in the current market together with the issues and gaps in the intelligent process utilisation in IoT-based smart home applications. We identified the issues and provided recommendations that would benefit users and developers and conducted performance verification. We also provided recommendations related to the consideration of other factors/attributes that could help solve the issues and potential challenges in utilising the intelligent process for IoT-based smart home applications and new opportunities for research in this approach. These issues are associated with security, data management, device connectivity, hardware limitation and methods from machine learning (user behaviour, lifestyle and habit). The insights were recognised in the current view, and the published studies on the intelligent process of IoT applications in smart homes were presented. This study is significant for future research. The research community will continue to work and focus on this approach; hence, researchers should explore the evolving trends and intelligent developments for IoT in smart home applications.

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