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DEVELOPMENT TRENDS IN INTELLIGENT HOMES

I-Chen Chen
Department of Electrical Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C., D97530008@mail.ntou.edu.tw

Jia-Shing Sheu
Department of Computer Science, National Taipei University of Education, Taipei, Taiwan, R.O.C

Husan-Wei Huang
Department of Electrical Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.

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DEVELOPMENT TRENDS IN INTELLIGENT HOMES

I-Chen Chen[1], Jia-Shing Sheu[2], and Husan-Wei Huang[1]

Key words: intelligent house, citation network analysis, cluster development, data technology analysis.

ABSTRACT

Since the U.S. National Science and Technology Council began implementing its plans for the development of intelligent structures in 2004, the Taiwan Communications Industry Alliance has been committed to applying communication and monitoring technologies in the construction industry to develop a market for intelligent houses. Accordingly, in this paper, relevant studies from January 2000 to December 2016 were collected from the Web of Science database. A key-route main path analysis of the text and data as well as a growth analysis of the research clusters in this field were performed to determine the main research topics and development trajectories.

The development track for intelligent houses involves seven topics, namely general care, application of recognition sensors, energy management, medicine, application of the Internet of things, activity recognition systems, and monitoring technology. This paper offers a valuable literature review and analysis of this field and may acquaint scholars with related industrial development trends and academic progress.

I. INTRODUCTION

The ongoing work of enterprises, research institutes, and universities has led to the rapid development of intelligent houses in recent years. Many products related to intelligent houses have been released, and investment into research on relevant technologies has increased. Gartner, a prominent American research and advisory firm, forecasted that house automation and security would be ranked first for investments from 2014 to 2020 because of the compound annual growth rate of home Internet equipment. Gartner, an American research and advisory firm, also predicted that energy-efficiency management would be ranked second. Recently, the Taiwan Communications Industry Alliance mentioned that the intelligent houses are based on house control networks. With a house automation system as the core, an intelligent house controls all home apparatuses to meet users' needs for a convenient and comfortable environment, energy efficiency, environmental protection, safety, monitoring, health care, and audiovisual entertainment. Thus, automation systems play an indispensable role in intelligent houses.

Cloud technology has gradually advanced with the development of information technology. Thus, large volumes of data can now be collected. Over recent decades, most studies have adopted similar perspectives to investigate the development of intelligent houses. Therefore, the present study collected numerous academic papers on intelligent houses to conduct a complete literature review and adopted innovative methods to investigate the future development track of intelligent houses.

In this study, a main path analysis of the critical path (Liu and Lu, 2012), was adopted to define the overall development direction of studies on intelligent houses. For a more rigorous evaluation and analysis of the consistency between corresponding clusters, keywords were used to identify specific development titles. Moreover, technical analysis of text and data was combined with growth analysis. Finally, a key-route main path analysis of the critical path was applied to analyze the connection between the development tracks and the clusters in order to derive a more insightful literature review and analysis.

II. LITERATURE REVIEW

To obtain information on the contents and achievements of studies in various fields, this paper discusses the analytical tools used in academic papers on intelligent houses, such as citation analysis and main path analysis.

1. Citation Analysis

Bibliographic coupling identifies two papers that both cite a third document, and co-citation analysis identifies two papers that are both cited in a third paper. These analysis techniques examine the relationships between papers from a single perspective (Garfield, 1955). However, innovations and breakthroughs in a subject are mainly achieved by building on the experiences and ideas of predecessors. Thus, knowledge can be expanded

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[1] Department of Electrical Engineering, National Taiwan Ocean University, Keelung, Taiwan, R.O.C.
[2] Department of Computer Science, National Taipei University of Education, Taipei, Taiwan, R.O.C.

and insights in different fields can be connected. Citation of academic papers plays a vital role in academic evolution. The distinctive feature of citation analysis is that academic papers are unitized and widely applied to various quantitative statistics, mathematical algorithms, and other comparative, analytic, and inductive methods for analysis and research. By analyzing cited academic papers, researchers can become acquainted with the current development trends of a subject, the features of academic paper use, the relevance of academic papers, and possible directions for future studies. In addition, many scholars specialize in citation analysis (Peritz, 1992). Before citation frequency can be used as a criterion for assessing academic quality, the hypothesis that multiple academic papers are cited in one article must be tested. The assumptions for this hypothesis include the following:

1. Cited papers are those that have been used in a particular academic paper.
2. Cited papers are valuable and influential.
3. A connection exists between a citation and why is cited.

2. Main Path Analysis

In research on main path analysis, Garfield et al. (1964) were the first to use the temporal sequence of academic citations to establish a time-sequence network map of studies into DNA and thus illustrate the development of this field of research. Subsequently, Hummon and Doreian (1989) extended these achievements by introducing the triple-weight calculation method and applying the priority-first search algorithm to determine the main path. These researchers were the pioneers of main path analysis.

Hummon and Doreain (1989) subsequently applied this analysis method to identify the major development trajectory in DNA research. In main path analysis, the citations of academic papers are used to track the development of the mainstream thought pertaining to a given subject in order to predict development trends (De et al., 2005). For example, if a node represents a single paper, then two nodes are considered to be connected if one of these papers cites the other. Hence, after collecting academic papers from a certain field, researchers can establish a citation network by identifying mutual citations. In the citation network, the source point is a node that is cited but does not cite other papers, and can thus be considered as the knowledge source. Conversely, the convergence point is the node that cites other papers but is not cited, and can thus be considered an endpoint of knowledge communication (Verspagen, 2007). Main path analysis integrates bibliometrics with social network analysis. Key-route main path analysis is the most effective integrated approach (Liu and Lu, 2012). Top significant links are ones with the highest traversal weight in the citation network. Key-route main path identifies a top significant link and searches forward from the head node of this link and backward from the tail node of the same link. The three advantages of adopting the key-route main path method to analyze a citation network are as follows: (1) it transforms the complex citation network into a few representative nodes and connecting lines, (2) it highlights the main developments in the technological field and serves as a guide for new entrants, and (3) it reveals key turning points in the development of the field. The global key route determines the paths with connecting lines of the highest weights between two nodes in the whole network. Searching forward and backward from the two ends of the connecting lines reveals the locations of paths with the highest total weights. These paths can then be plotted as the main paths. For instance, in Fig. 1, global main path includes the top three paths with the highest weights between nodes in the network. The overall main paths that run across these nodes can then be determined. In Fig. 1, both CF and BD have a weight of 4. The paths that run across CF and have the highest total weight are A-C-F-G and A-C-F-J, whereas the paths that run across BD and have the highest total weight are B-D-H-I and B-D-H-G. Therefore, the main paths of global key route 1 are A-C-F-G, A-C-F-J, B-D-H-I, B-D-H-K, and B-D-H-G.

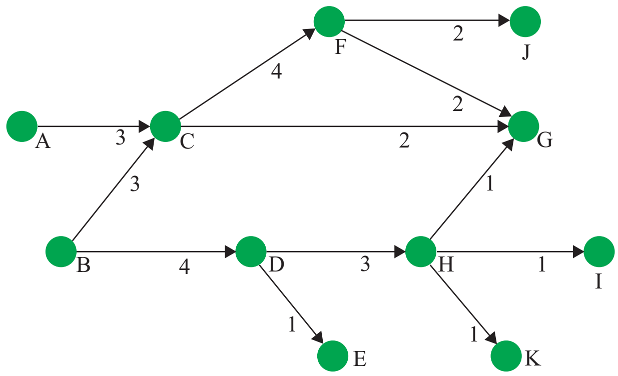


Fig. 1. Global main path example.

III. RESEARCH METHOD

1. Data Collection and Keyword Retrieval

The academic papers and citations in this study were collected from the Web of Science database, which includes the Science Citation Index Expanded and the Social Science Citation Index.

Keyword searching plays a vital role in citation network analysis because it influences which data are selected. Therefore, the accuracy and completeness of keywords are crucial for this type of analysis. To determine which keywords to select for the search, this study reviewed several prominent articles on intelligent houses (Tang and Venables, 2000; Cook and Schmitter-Edgecombe, 2009; Reeder et al., 2013; Cimperman et al., 2016).

The study was conducted at the time of data collection. The keywords used for data collection were “smart home,” “smart live,” “smart life,” and “smart living.” Any article whose title, abstract, author, or keywords were related to these phrases was included in the study. After data collection, the retrieved studies were sorted, and they removed if they failed to pass an anonymous review, were beyond the research scope of the present study, or lacked complete data.

Table 1. Top 20 influential journals on intelligent houses.

Ranking	Journal	g-index	h-index	Publishing years	Total papers	Papers after 2000
1	IEEE transactions on consumer electronics	26	16	2004-2016	48	48
2	IEEE transactions on smart grid	19	10	2010-2016	19	19
3	Pervasive and mobile computing	17	8	2009-2016	20	20
4	Personal and ubiquitous computing	14	7	2004-2015	24	24
5	Methods of information in medicine	13	8	2007-2015	13	13
6	Journal of ambient intelligence and smart environments	12	8	2009-2016	36	36
7	Energy and buildings	11	7	2012-2016	12	12
8	IEEE transactions on automation science and engineering	10	4	2008-2016	11	11
9	IEEE transactions on information technology in biomedicine	10	9	2005-2012	10	10
10	Journal of ambient intelligence and humanized computing	10	5	2010-2016	16	16
11	Sensors	10	7	2010-2016	39	39
12	IEEE communications magazine	9	5	2002-2016	9	9
13	IEEE sensors journal	9	3	2012-2016	9	9
14	Computer journal	8	4	2009-2011	8	8
15	Designing smart homes: role of artificial intelligence	8	6	2006-2006	9	9
16	Indoor and built environment	8	5	2011-2015	11	11
17	Energy	7	5	2012-2015	7	7
18	Engineering applications of artificial intelligence	7	4	2012-2015	7	7
19	IEEE transactions on systems man and cybernetics part c-applications and reviews	7	7	2007-2012	7	7
20	IEEE wireless communications	7	5	2002-2015	7	7

Note: Journals listed in order according to their g-index, h-index, and total number of articles.

2. H-Index and G-Index

In this study, the h-index (Hirsch, 2005; 2007; 2010) and g-index (Egghe, 2006) were adopted to measure the influence of authors and journals in the field of intelligent houses. If the h-index is applied as an indicator of scientific influence in the h-index field, then it could be described as having a nonsignificant influence on journals, articles, and other data, as determined through the analysis of the citation relationship. This index indicates that h out of n articles in a journal cited more than h times, the citation frequency and influence of an author. It also shows that a research institute in different research areas reflects the influence of these articles on later studies and reveals the quantity and quality of their papers. However, the h-index has a notable problem. The most influential paper is not included in the evaluation criteria. The g-index can be used to overcome this problem. It is obtained by ranking (in descending order) the number of times that an author's research is cited in a set of articles. The g-index is higher than the h-index because the top g articles must have received at least g^2 citations (Egghe, 2006). For example, if the g-index of Scholar A is 5, then the five highest-ranked articles in the article set cite Scholar A at least 25 times. The h-index and the g-index are complementary indices for rating an author's impact.

IV. RESEARCH RESULTS

1. Journal Statistics

The present study found that some journals have published many articles on intelligent houses. Table 1 reveals that three journals have each published more than 30 papers on intelligent houses over the past decade. The h-index and g-index were adopted to rank the journals. Journals with the same g-index were ranked according to their corresponding h-index values. Of the top 20 journals, the highest scorer was *IEEE Transactions on Consumer Electronics*, followed by *IEEE Transactions on Smart Grid*, *Pervasive and Mobile Computing*, *Personal and Ubiquitous Computing*, and *Methods of Information in Medicine.* The *Journal of Ambient Intelligence and Smart Environments*, which was ranked sixth, included 36 articles. *Sensors*, which was ranked eleventh, included 39 articles. This indicated that these journals occupy a prominent position in research on and the application of intelligent houses.

2. About Statistics

To reveal the influence and contribution of scholars in studies on the application of intelligent houses, the present study summarized data concerning authors who published articles on intelligent houses from 2000 to 2016. Higher g- and h-indexes indicate authors with greater influence in the field.

On the basis of the g- and h-indexes of academic papers on intelligent houses, the 20 most influential authors were identified and ranked according to the number of papers they have published on intelligent houses. As shown in Table 2, 11 authors have published at least 10 papers on intelligent houses. The top six

Table 2. Top 20 influential authors on intelligent houses.

Ranking	Author	g-index	h-index	1st authors	publishing years	Total papers
1	Cook, DJ	28	15	8	2002-2016	28
2	Demiris, G	13	8	4	2004-2016	13
3	Noury, N	11	9	2	2002-2013	11
4	Lee, S	10	5	2	2006-2013	11
5	Mukhopadhyay, SC	10	5	1	2012-2016	10
6	Schmitter-edgecombe, M	10	5	0	2009-2016	10
7	Chen, LM	9	6	3	2010-2014	9
8	Nugent,C	9	5	0	2008-2015	9
9	Shin, D	9	4	1	2004-2009	18
10	Wang, H	9	6	0	2008-2014	9
11	Fu, LC	8	6	0	2007-2014	8
12	Kim, JT	8	5	0	2011-2015	10
13	Zhang, DQ	8	5	0	2005-2013	8
14	Campo, E	7	4	2	2003-2013	7
15	Choi, J	7	3	6	2005-2014	12
16	Kim, TS	7	5	0	2011-2015	7
17	Nugent, CD	7	5	0	2006-2013	7
18	Park, S	7	4	0	2006-2014	7
19	Bouchard, B	6	3	2	2006-2015	12
20	Bouzouane, A	6	3	0	2006-2015	12

Note: Journals listed in order according to their g-index, h-index, and total number of articles.

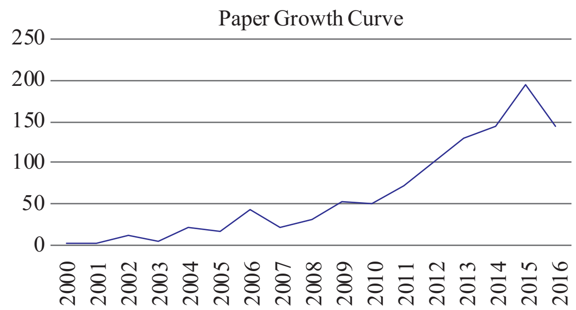


Fig. 2. Trends in academic papers on intelligent houses.

authors who published articles on intelligent houses were Cook (28 papers), Demiris (13 papers), Noury (11 papers), Lee (11 papers), Mukhopadhyay (10 papers) and Schmitter-Edgecombe (10 papers) and played the prominent roles in the field.

3. Growth Curve Analysis

According to the summary of the data obtained through the keyword search, 1,044 academic papers on intelligent houses were published within the study period. This study revealed a constant increase in the number of published academic papers on intelligent houses since 2002, which was particularly noticeable in recent years. In addition, these studies have expanded to various disciplines. To date, the field includes 374 journals, and 194 studies into intelligent houses have been published since 2015 (Fig. 2). In recent years, the Internet of things has been an emerging trend in the information and communications industries, and intelligent houses have become an essential development direction and objective for the Internet of things. Because of this trend, the number of papers being published in this field is increasing. Table 3 shows the number of journals covering the field in recent years.

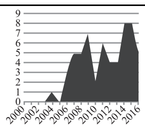
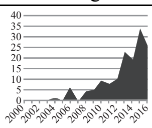
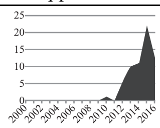
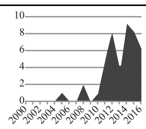
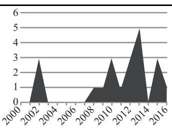
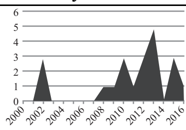
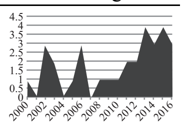
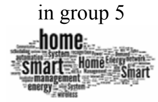
4. Technical Analysis of Text and Data As Well As Cluster Development Track

In this study, the overall development direction of studies on intelligent houses was determined through main path analysis of the critical path (Liu and Lu, 2012). To guarantee consistency between the cluster and development direction and to evaluate and analyze the consistency between a cluster and its corresponding cluster, a technical analysis of text and data as well as a key-route main path analysis of the critical path were used to divide the citation network into various clusters. The keywords in the clusters were used to determine the main topics and research trends. The search involved articles published before 2016. The analysis indicated that papers on intelligent houses can be divided into seven clusters. Subsequently, a technical analysis of the text and data was performed to identify the main topics. Table 3 shows the identified clusters and growth trends. Keyword frequency is ranked in descending order of frequency.

5. Development Tracks of Intelligent Houses and Clusters

First, this study analyzed the development path for the field of intelligent houses. Academic development generally occurs along

Table 3. Keyword text cloud and growth trends of the clusters (Groups 1–7).

Rank	Group 1 (58 articles)	Group 2 (144 articles)	Group 3 (62 articles)	Group 4 (44 articles)	Group 5 (27 articles)	Group 6 (22 articles)	Group 7 (32 articles)
Focus	Care in intelligent houses	Application of recognition sensors to intelligent houses	Energy management of intelligent houses	Medical care in intelligent houses	Application of Internet of things to intelligent houses	AR systems of intelligent houses	Monitoring technology of intelligent houses
1	health	activity	energy	technologies	energy	human	health
2	technology	recognition	management	environment	management	control	elderly
3	older	data	demand	services	control	activities	monitoring
4	care	approach	load	health	wireless	features	data
5	adults	sensor	scheduling	user	power	depth	people
6	data	using	appliances	devices	networks	systems	technologies
Growth Trends							
Technical analysis of text and data	Key topic in group 1 	Key topic in group 2 	Key topic in group 3 	Key topic in group 4 	Key topic in group 5 	Key topic in group 6 	Key topic in group 7 

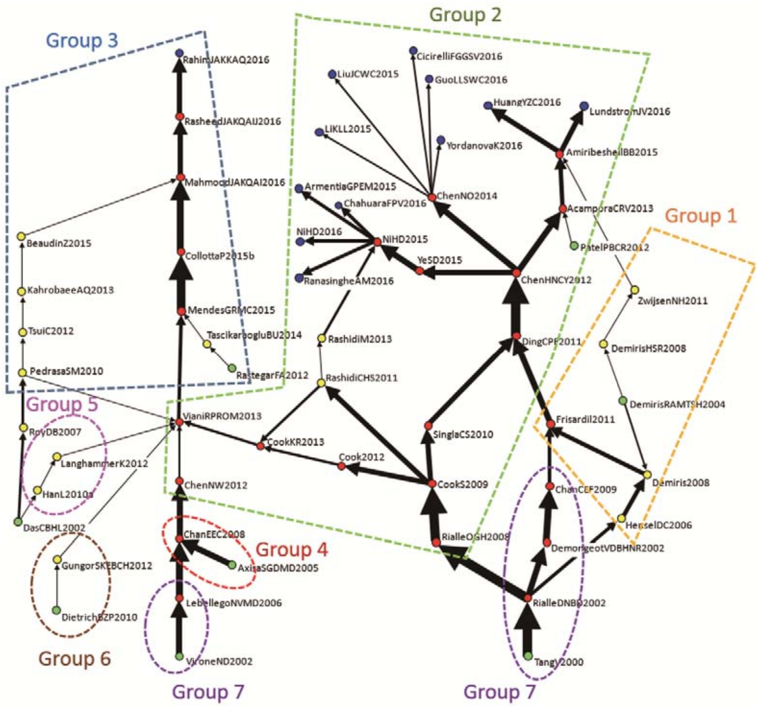


Fig. 3. Cluster development of academic papers on intelligent houses.

multiple channels. According to the paths developed through the key-route main path analysis of the critical path, two main papers were source points leading to two branches (Fig. 3). The first branch, which included the two slashes on the left, contained 33 studies of intelligent houses or health monitoring (Demongeot et al., 2002). The three slashes on the right were included in the second branch, which contained 35 studies of long-distance care services and intelligent house technology (Tang and Venables, 2000) that combined information and communications technologies. Subsequently, key-route main path analyses of the critical paths of the clusters were performed. In the main path of a critical path, each node represents a study, and connecting lines

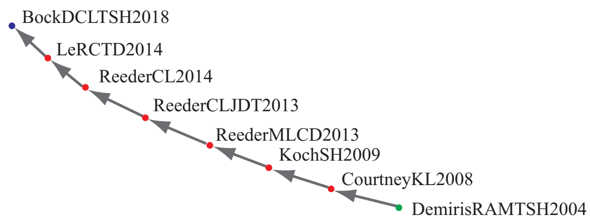


Fig. 4. Main path of critical extension in cluster 1.

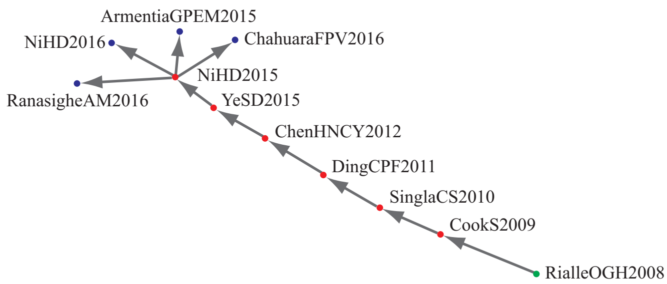


Fig. 5. Main path of critical extension in cluster 2.

represent citation relationships between studies. The studies were ranked by publication date, with those published earlier ranked lower. Arrows were used to indicate the directions of knowledge movement, and the weights were represented by the thicknesses of the connecting lines. A thicker connecting line implies that the citation path is more crucial.

The results show the cluster developments of academic papers on intelligent houses and the connections among the seven research clusters. The development of recognition sensors, monitoring technology, medical care, and energy management were placed in the middle of the clusters. While the other three clusters were placed on either side. The development tracks of the clusters are introduced in the following sections.

Cluster 1: Care in Intelligent Houses

The main path for exploring studies on care in intelligent houses is that of the critical path in Cluster 1 (Fig. 4). These studies have focused on enabling intelligent houses to provide home-based care for elderly people. In recent years, aging populations in certain countries have increased the demand for healthcare services, such as domestic care for elderly people. Meeting the demand for this vital type of care, providing integrated healthcare for elderly people, and alleviating the burden on hospitals through intelligent house technology are crucial topics for future development. Demiris et al. (2004) emphasized the installation and operation of domestic care equipment in conjunction with intelligent house technology to monitor the health of elderly people. Courtney (2008) emphasized the importance of information technology in intelligent houses and equipment improvement for hospital care.

Koch and Hagglund (2009) proposed the integration of health information systems and public health systems into family environments as a viable solution for addressing medical care concerns. Similarly, Reeder et al. (2013) proposed health smart homes and home-based consumer health technologies. Moreover, graphic user interfaces have been designed to control older adults' home sensors, on the basis of interviews with older adults, to ensure that the interfaces met their needs (Le et al., 2014; Reeder et al., 2014). More recently, Bock et al. (2016) demonstrated the application of intelligent house system to open and extendable platforms and the development of applications that provide real-time visual data.

Cluster 2: Application of Recognition Sensors to Intelligent Houses

The main path for exploring studies of the application of recognition sensors to intelligent houses is that of the critical path in Cluster 2 (Fig. 5). To apply sensor technology to intelligent houses and promote technologies for human-machine interaction and situation perception, authors and research institutions have developed applications for recognition sensors. Rialle et al. (2008) discussed establishing and applying recognition and tracking in intelligent houses. Cook and Schmitter-Edgecombe (2009) and Singla and Cood (2010) have adopted a recognition algorithm for recognizing and evaluating the daily health monitoring and support technologies used in intelligent houses. Ding et al. (2011) argued that the sensor technology of intelligent houses should be applied to remote environmental sensors and sensors used in basic equipment. Chen et al. (2012) discussed the status and development of sensor monitoring activities. Ye et al. (2015) proposed a new method for solving the problem of correspondence between sensor events and activity recognition, and Ni et al. (2015) combined activity classification and reasoning to design an auxiliary home sensor for older adults. Noting that multiple sensors are used in a home on a daily basis, Chahuara et al. (2016) proposed an automatic identification method for automated equipment coexistence. Armentia et al. (2015) established a domestic care application for optimizing medical resources. Ni et al. (2016) proposed a three-layered contextual perception system for monitoring daily activities in intelligent houses. Ranasinghe et al. (2016) integrated medical care monitoring applications, monitoring systems, and indoor and outdoor augmented reality (AR) systems.

Cluster 3: Energy Management of Intelligent Houses

The main path for exploring studies into the energy management of intelligent houses is that of the critical path in Cluster 3 (Fig. 6). Optimizing energy management can reduce carbon emissions by lowering communications costs and electricity consumption. Pedrasa et al. (2010) proposed using particle swarm optimization to optimize decentralized energy resources and energy service delivery. Tsui and Chan (2012) established a smart grid to reduce the energy burden on intelligent houses. Kahrobaee et al. (2013) maximized the use of distributed power-generation systems, such as wind turbines and batteries, in the framework of a smart grid. Beaudin and Zareipour (2015) explored how to reduce residential energy consumption and production. Mahmood et al. (2016) proposed a realistic scheduling

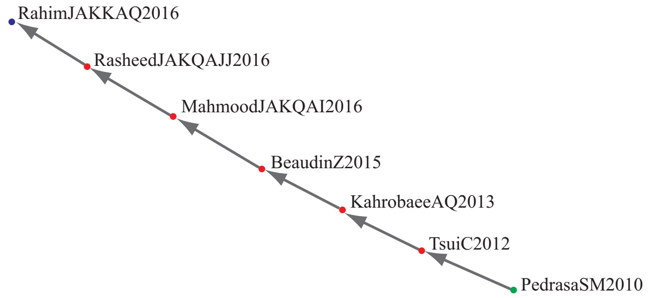


Fig. 6. Main path of the critical path in cluster 3.

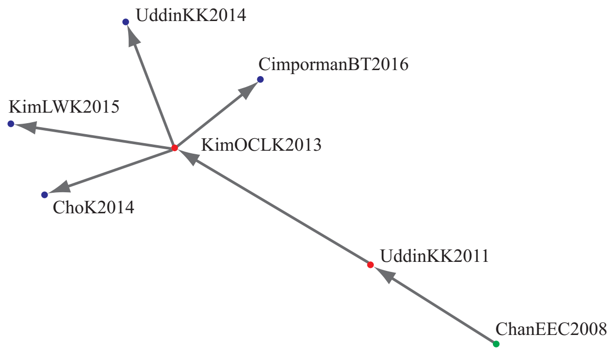


Fig. 7. Main path of critical extension in cluster 4.

mechanism to improve energy management. Rasheed et al. (2016) proposed a real-time information energy management algorithm for reducing the energy consumption of intelligent houses. Rahim et al. (2016) proposed a heuristic algorithm that was also designed to effectively reduce the energy consumption of intelligent houses.

Cluster 4: Medical Care in Intelligent Houses

The main path for exploring studies of medical care in intelligent houses is that of the critical path in Cluster 4 (Fig. 7). The authors of these studies have established an evaluation and application system for medical care in intelligent houses. Moreover, to conduct remote diagnoses using medical equipment, they have equipped intelligent houses with technologies such as sensor-embedded monitoring systems, imaging technology, and remote monitoring technology. Chan et al. (2008) adopted a sensor-embedded monitoring system and support-robot technologies to monitor the health of elderly people and people with disabilities. Uddin et al. (2011) used imaging technology to develop an AR method for monitoring the activities of domestic care users. From the perspective of user experience and cognition, Kim et al. (2013) suggested relevant strategies for the service and technical satisfaction of intelligent medical system users. Cimperman et al. (2016) established a factor model for empirically testing and predicting the remote medical care service needs of elderly users. Uddin et al. (2014) developed a step-recognition-based smart system to protect the health of elderly people residing in intelligent houses. Kim et al. (2015) explored the environmental factors influencing health and wisdom family

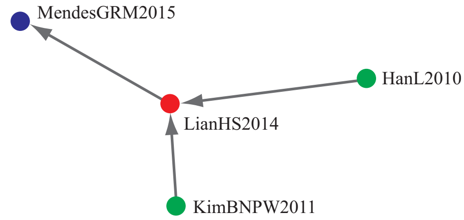


Fig. 8. Main path of critical extension in cluster 5.

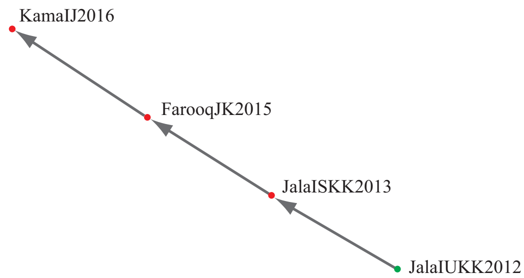


Fig. 9. Main path of critical extension in cluster 6.

service. Cho and Kim (2014) discussed users' care experiences in intelligent houses and developed related smart services and technologies.

Cluster 5: Application of the Internet of Things to Intelligent Houses

The main path for exploring studies on the application of the Internet of things to intelligent houses is that of the critical path in Cluster 5 (Fig. 8). The Internet of things is a topic that has emerged during the past decade and involves the connection, through wireless sensor networks, of appliances that fulfill daily needs. One method for applying the Internet of things is to combine Internet-based remote control with intelligent houses. Chen et al. (2014) utilized the Internet of things to explore methods for applying embedded processors, sensors, and actuators to fixed and mobile platforms. Emphasizing health care, energy management, and entertainment, they investigated service quality, energy efficiency, and security. Han and Lim (2010) adopted the Internet of things for the seamless integration of intelligent houses into daily life. Moreover, they integrated innovative systems into various apparatuses, smart sensors, and energy technologies. Kim et al. (2011) described methods of designing simple and secure access control policies that enable visitors to use home devices. Additionally, Lian et al. (2014) used handwriting recognition technology to identify users and manage access control. Mendes et al. (2015) integrated the Internet of things into a domestic communication interface and machine–machine communication gate.

Cluster 6: AR Systems of Intelligent Houses

The main path for exploring studies on AR systems in intelligent houses is that of the critical path in Cluster 6 (Fig. 9). Authors have explored how to promote AR through innovative

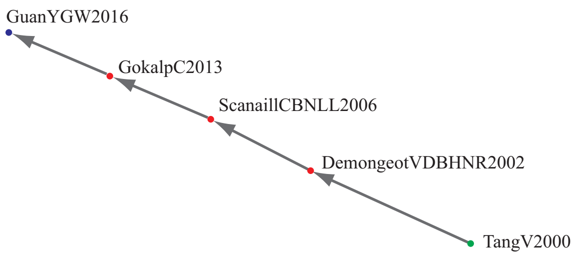


Fig. 10. Main path of critical extension in cluster 7.

methods and systems and offered suggestions for medical care services. Jalal et al. (2012, 2013) have discussed human AR systems and how to offer necessary assistance to elderly people and people with disabilities, specifically those receiving medical care services through intelligent houses. Moreover, they established an image database with synthesized silhouettes and corresponding body parts. Farooq et al. (2015) adopted a functional structural framework and 3D technology to test the tracking and recognition of human activities in an RGBD video sequence. Kamal and Jalal (2016) presented spatiotemporal hybrid features, human tracking, and activity recognition in a single framework from video sequences captured using an RGB-D sensor.

Cluster 7: Monitoring Technology of Intelligent Houses

The main path for exploring studies on the development of monitoring technologies for intelligent houses is that of the critical path in Cluster 7 (Fig. 10). Tang and Venables (2000) combined information and communication technologies to develop remote care services and intelligent house technologies such as domestic alarms, smart monitoring sensors, and interactive phone use. Demongeot et al. (2002) argued that smart homes can reduce hospitalizations and enable hospital staff to quickly diagnose acute diseases. They established a framework for a health information system for intelligent houses and developed an automatic measurement system to ensure medical security and quality. Scanaill et al. (2006) and Gokalp and Clarke (2013) have suggested that a remote electrocardiography monitoring system may facilitate early diagnosis and management, slow the deterioration of patients with chronic diseases, reduce the number of hospital visits, and enable clinical physicians to remotely evaluate patients. More recently, Guan et al. (2016) proposed a remote-sensing module that monitors changes in infrared radiation to recognize and facilitate regular activities of daily living.

V. CONCLUSIONS

The present study determined the influential articles, authors, and journals related to the main research topics and the development directions of the field of intelligent houses. Moreover, a citation analysis and a key-route main path analysis of critical papers were conducted to identify the core research in studies of intelligent houses. The growth trajectory of academic papers was described to provide a deeper understanding of the development trends of research into intelligent houses.

A technical analysis of text and data was conducted to identify articles and derive clusters. Key-route main path analyses of the critical paths were performed to analyze the research topics emphasized in the clusters. The overall development track and the connections between clusters were explored through seven topics, namely general care, the application of recognition sensors, energy management, medicine, the application of the Internet of things, AR systems, and monitoring technology.

The present study adopted the key-route main cluster path analysis in 1,044 highly relevant papers of intelligent houses to identify the paths of clusters and to develop their overall trajectories. This review can help motivate and inform studies in this field. Moreover, the results of the present study can help future researchers to define their research directions and understand the development directions of the field.

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