Telecommunication Systems (2021) 77:597–623
https://doi.org/10.1007/s11235-021-00787-w

A systematic review of the research framework and evolution of smart homes based on the internet of things

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Accepted: 1 April 2021 / Published online: 15 April 2021

Abstract
The Internet of Things has brought unprecedented technological innovation to smart homes, but the impact of this change on technology and users is limited and dispersed. Based on a systematic literature review, the present research conducted a quantitative analysis of 2874 papers (published in 2008–2020) obtained from the Web of Science to bridge the research gap. The current research identifies the development status and trends, country distribution, and journal categories in this area. Then, based on the main topics covered by smart homes, we proposed a holistic research framework that integrates the infrastructure layer, the communications technology layer, the data analytics layer, and the user service layer. The framework analyzed wireless sensing networks, communication protocols, and security threats, as well as the activity identification process and user services, highlighting the lack of some degree of integration in this area. This study also discussed the evolution of hot spots in the field of smart homes and summarized potential future research directions. Finally, in the discussion section, this paper summarized the research contribution and compared the main proposed technical solutions. We hope this work will provide a solid basis for research and practical guidance for scholars and developers interested in smart homes based on the Internet of Things.

Keywords Smart homes · Systematic literature review · Research framework · Cluster and keywords analysis · User perspective

1 Introduction

The Internet of Things (IoT) as the next big disruptive technology field, was designed to enable communication between intelligent objects [1]. It connects transactions through the aggregating heterogeneous technologies from different applications, seamlessly connecting the digital and physical worlds [2]. As one of the most widely used applications of IoT technology [3], smart homes provide users with more personalized services through sensing devices, hardware and software systems, and computing platforms. The term "smart" is no longer just a household device for automation [4], but an umbrella term for innovative technologies with some degree of artificial intelligence. The constant innovation and convergence of IoT technologies are designed to better interact with residents, which is also a pillar of innovative concepts such as smart homes [5].

The general infrastructure of smart homes includes network connectivity, communication protocols, sensing devices, and applications. In recent years, wireless sensing technology [6] has allowed a large number of devices to spread through the communication network, such as WiFi, ZigBee. Then the devices in the home environment are effectively detected, monitored, or remotely controlled using environmental sensors or wearable sensors, according to the communication protocol standard [3]. But with the development of the Internet of Things, there are more and more smart devices in the home. The rate of data transmission issues is also a great challenge. Optimizing the energy consumption of equipment in the home environment has always been an important task in the development of smart

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homes. Because of the powerful spatial processing power of antenna systems, it is considered a promising way to improve the data rate and capacity of wireless LAN systems [7]. Some authors [8] developed a filter antenna suitable for wearable energy harvesting systems. The antenna system reduces additional losses and improves the overall efficiency of the system. There are scholars [9] who have designed a high-gain and circularly polarized array rectenna system that allows the platform to harvest power from multiple directions, thereby increasing the battery's life. Considering the quality of signal transmission, some studies [10] apply the antenna system to wearable sensors. This application is of great value for smart home healthcare. For example, the authors [10] designed a mobile wireless platform to monitor an individual breathing rate. The platform is a smart T-shirt that can be worn and stretched, and the sensor on the T-shirt consists of a spiral antenna. This antenna shape provides greater sensitivity. Some studies use antenna swings to produce symmetrical keys based on channel interoperability [11]. These studies illustrate the potential of the antenna system in smart homes. In addition to antenna systems, machine-to-machine (M2M) communications have come into being as a new concept [12]. This technology meets the needs of autonomous network communication between sensors, executors, and mobile devices without human intervention. This autonomy is critical to the deployment of smart homes in the IoT environment.

Smart homes are the embodiment of a technology-rich living environment [13], users can integrate service needs with the ubiquitous Internet of Things, as evidenced by numerous academic studies. Smart homes can provide a variety of services, including smart lighting, smart door locks, smart thermostats [14], and so on. For IoT users, smart home management systems meet the security and energy-saving needs and provide personalized healthcare services through wearable smart devices [15]. Although there are many kinds of smart home services, they are mainly focused on comfort, healthcare, security, and energy-saving. In each of the different service requirements, there will be different application status. The essence of user demand is "high-quality service". The service must take software and hardware technology and application scenarios as the carrier, to continuously promote the development of the industry.

But while serving users, it also presents serious challenges to data storage and analysis. For a better interaction experience, these different services must constantly exchange relevant information to effectively coexist. How to handle the big data generated by these devices and access control, the emergence of a highly distributed cloud network architecture is expected to be an effective solution in smart homes [16]. Smart homes can be called smart because they can use the experience to predict future events. To track the activity, the system must mark a large amount of training data and then use a series of algorithms to improve the accuracy of predictive behavior, such as the decision-learning algorithm [17]. Besides, semantic reasoning and classification can be used to further improve the accuracy of predictions [18]. On the other hand, as IoT devices have more and more access to private data in the home, new smart devices are providing users with more convenient services while also causing privacy concerns. As a result, there are many verification methods and policies for privacy protection in this area. Due to data transfer pressure and privacy protection, this data should be processed locally. At the same time, the popularity of the Internet of Things (IoT) has driven Edge computing [19], and the emergence of these new computing paradigms have extended the cloud to the edge of the network.

From the perspective of academic journals and publications, smart homes involve interdisciplinary convergence, with 6 of the top 10 published categories of literature focusing on computer science, of which the engineering electrical electronic category has the largest number. Additional categories include telecommunication, computer science information systems. Firstly, it can be seen that the development of smart homes is inseparable from a large number of academic research on hardware facilities, communication technology [20], and computer applications. However, the current research review is limited to a certain level or a specific application classification of the research content, lack of certain integration. Secondly, although there is a mass of research on technology and its application in smart homes, we can not ignore the factors that influence users' acceptance of the technology. This is because the needs of users are closely related to the development of technology. However, the review of existing technology surveys and literature shows that there is a little view of technological changes in smart homes from the user's perspective. Thirdly, there have been abundant research hotspots in smart homes in recent years, but fewer studies explore the potential research opportunities behind these hotspots. Previous studies have also called for more discussion of technology solutions to gain more practical guidance.

To make up for the above research gaps, this study adopts the systematic literature review method to comprehensively review the research in the field of smart homes. Moreover, the paper combines visualization tools to analyze the situation in different countries, regions, and major research institutions. Most importantly, this paper identifies the research framework and trends in the field of smart homes. Based on this systematic review, we combine the quantitative and objective advantages of bibliometrics to avoid subjective bias in the qualitative review [21]. Specifically, this study attempts to answer the following questions:

- What is the current overall progress of research on smart homes?
- Research on smart homes is too fragmented. Is there an appropriate theoretical framework to provide guidelines and concepts for future providers of solutions for smart homes?
- According to the emerging hot spots of research on smart homes, what research challenges and questions might exist in the future?

The remainder of this article is organized as follows: Sect. 2 overviews the literature background. our method is described in Sect. 3. Section 4 analyzes the three main research questions. Section 5 presents an explicit discussion on future research topics and challenges, Sect. 6 reviews overall research ideas and emerging technologies solutions, hoping our paper will be noticed by society. Section 7 concludes the paper.

2 Literature background

2.1 Definition

The ubiquitous discipline of computing has gained the attention of scholars in recent years by embedding technology into everyday life [6]. In such an intelligent environment, the application of the Internet of Things technology brings a qualitative leap to the development of smart homes. From the perspective of existing academic research, the definition of the existing smart homes is mainly from the technical and services aspects. Lutolf [22] initially defined smart homes as "the integration of different automated services into the home environment, through a public communication system to meet user needs". Balta-Ozkan [23] defined smart homes as "A house with a high-tech network that connects sensors to home devices and appliances for remote monitoring, access, or control." De Silva [24] also defined smart homes by describing the technical elements. Scholars believed that by controlling the smart homes through their infrastructure and a network of sensors that it can effectively predict and respond to the needs of residents. In addition to the technical definition, the different service objectives of the smart homes are also considered within the definition. Put differently, relevant research also defined the smart homes from the perspective of energy management [25] and healthcare services [26]. As can be seen from the above definition, the key content of smart homes services is to better serve users through technology. However, this paper argues that these definitions do not pay equal attention to the interconnection between smart homes technology and users in the context of Iot technology. We must consider the impact of the ubiquitous convergence of Internet of Things technologies on the living environment. Therefore, based on the above definitions, this paper proposes that the smart homes is connected with users by a series of sensing and driving devices through specific communication framework, considering users' satisfaction with interaction rules and styles, advanced edge computing is used to ensure the timeliness and security of user data, so as to realize users' requirements.

2.2 Related work

This subsection will describe the research related to smart homes. To understand the published review papers in this field, the study searches "smart homes" in the Web of Science collection and selects the literature review category. Forty-one relevant literature reviews are selected as the basis for the analysis in this survey. According to the research content and topic, the above manuscripts are divided into three categories: (1) innovative technology; (2) security of privacy; and (3) application in the field (see Fig. 1).

From the review literature dealing with innovative technologies, wireless sensors are identified as the frontier of most technologies in the future [27]. A large number of existing manuscripts have reviewed the progress of research in this field [19, 28, 29]. In addition, Technological innovations such as IoT wearable sensors and devices [30] and Blockchain [31] are also emerging.However, with the ubiquitous collection of data and the sharing of user data by infrastructure devices, a series of breaches of privacy issues have become the focus of particular attention by users in smart homes [32]. To solve the problem, academic research has gradually shifted to the exploration of resolution of privacy issues [29, 33]. Existing literature has extensively reviewed the threats and vulnerabilities of smart homes [34, 35]. They have explored how to provide more secure and reliable services [4] for users, such as intrusion detection [36] and authentication mechanisms [37]. Some scholars have suggested using DDoS Attack Mitigation Approach [38] to deal with threats, and studies have investigated IoT security and blockchain solutions [13].

The development of technology is around improved integration with applications [13]. To a large extent, these related technologies for different applications were dispersed, therefore scholars summarized the literature of innovative technology and application [3, 39, 40]. Existing reviews of applied research emphasized assisted living [41–44], remote monitoring [42, 45, 46], and the management of home energy usage [47–49]. But in these three examples of the practical applications, the human factor was insufficiently incorporated into the decision process. In this process, a terminal interface is a tool that interacts directly with the user, so the user's perception and control of the terminal interface is a problem that researchers must solve.

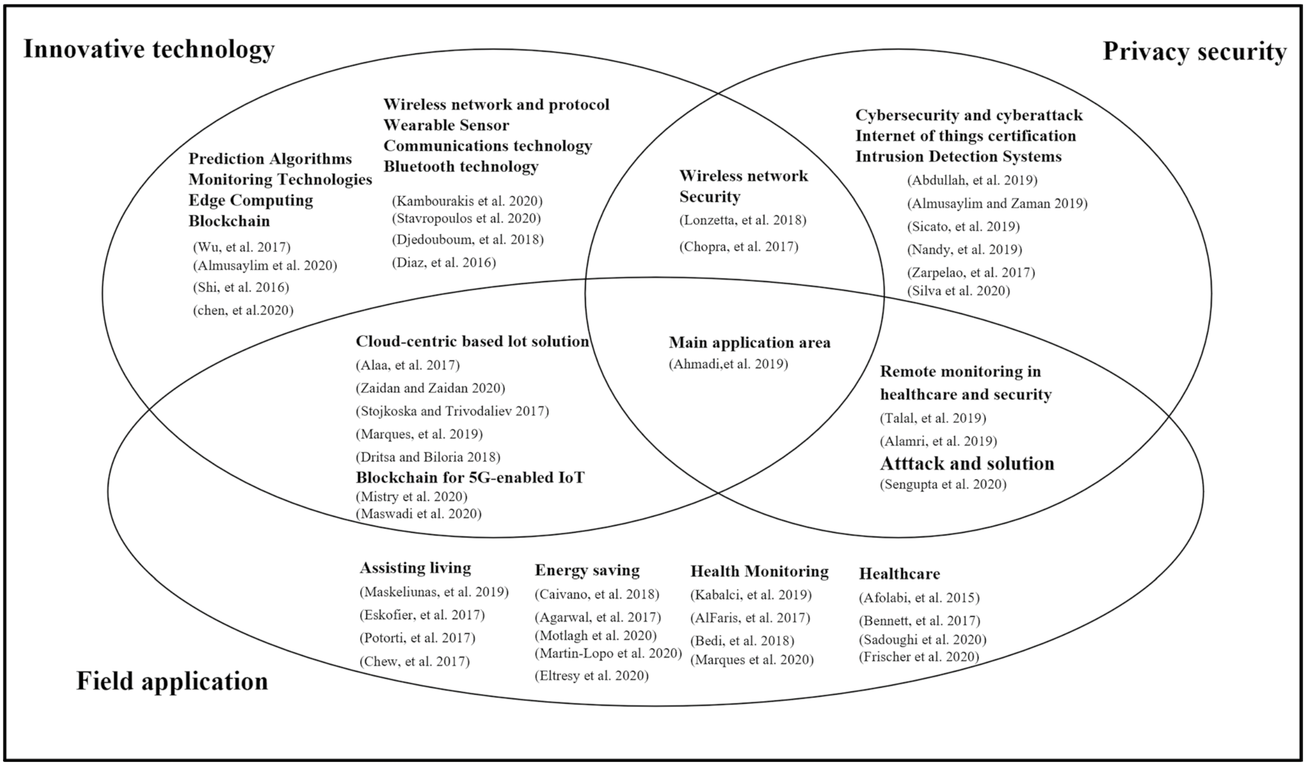

Fig. 1 The core content of the literature review in the field of smart homes

Based on a review of 41 manuscripts, it was suggested that we provide a comprehensive review aimed at addressing these weaknesses highlighted below. Firstly, in the context of the Internet of Things, most research reviews on smart homes are limited to a certain level [50]. There is little analysis of the changes to the overall smart homes brought about by the Internet of Things. Secondly, how to handle large amounts of sensor data remains a serious challenge for smart homes. The content of this aspect is developing rapidly but remains fragmented and requires integration. Therefore, this paper will elaborate on the effective solution for smart homes. Thirdly, only the correct combination of technology and society will provide a more comfortable living environment for residents. However, the existing research does not take into account the changes in users' perception of smart homes with the development of technology and how these factors affect users' adoption. Consequently, this study will be carried out in these aspects.

3 Research method

This study follows the original guidelines of the systematic literature review proposed by Kitchenham [51] (Fig. 2). The method first defines a review protocol and then examines a large body of relevant literature based on a clear search strategy. The research paradigm for identifying, analyzing, and interpreting a particular research problem by searching for predefined policies is fair and repeatable [51].

The advantage of this approach is that it is possible to summarize existing evidence relevant to technology and to identify gaps in existing research to further advance future research. It also helps to further collate existing research. Specifically, the method is divided into three main stages: planning the review, conducting the review, reporting the review. The primary process in Fig. 2 provides an exploration path for finding the inclusive answer to the analytical question (AQ) in the present study [52]. The step of systematic literature review steps taken in this article is shown below [53].

3.1 Planning the review

As a first stage in the study, identification of the need for review, specifying the research questions, developing a search strategy are mainly carried out [51]. First of all, we determine the necessity of this study through the combing of the existing literature review. Then, according to the advantages of this research method, three main research questions are proposed, as shown in Table 1. Concerning the search strategy, the study selects the Web of Science database as the data source, because it is the most

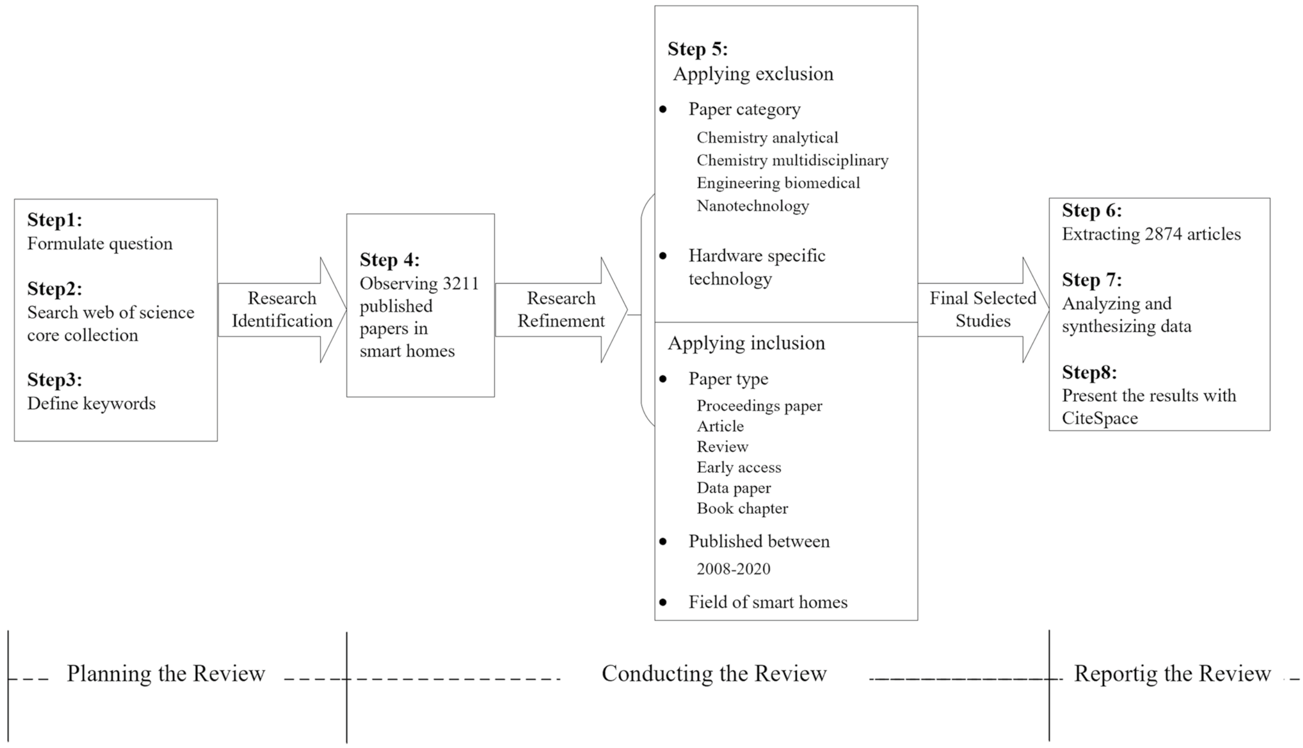

Fig. 2 Process of systematic literature review

Table 1 Research questions of this study

Research questions	Specific questions
Q1. What is the current overall progress of research on smart homes?	Q1.1. What is the trend of this literature quantity?
	Q1.2. What is the literature on different countries and regions and major research institutions?
	Q1.3 What is the distribution of literature types and published journals?
Q2. What are the main research contents of smart homes from 2008 to 2020?	Q2.1. What are the main research contents? Can an appropriate theoretical framework be proposed to cover the research in this field?
Q3. What is the state-of-the-art of research in smart homes?	Q3.1. What are the hot keywords in the smart home field?
	Q3.2 How do these hot keywords evolve?

influential and authoritative citation index with a large amount of cited information sources [54]. "Smart homes" and "Internet of Things" are identified as the most important keywords. Because "smart homes" covers a wide range of research aspects, alternative key elements and synonyms were considered [53]. This lead to the following exploration string being defined and the specific search term is (("smart homes" OR "smart-home" OR "smart house" OR "remote home" OR "remote-home" OR "intelligent home" OR "intelligent house" OR "home automation" OR "automated home" OR "automated house" OR "assisted living" OR "smart homes" OR "smart technology") AND ("Internet of Things" OR "IoT")) [50].

3.2 Conducting the review

This stage focuses on study quality assessment, which involves the development of data extraction and deletion criteria [51]. After providing the research keywords, the inclusion and exclusion criteria for this study are applied to further refine the search content. The purpose of this procedure is to assess the number of potentially relevant studies. To ensure that we are up-to-date on this rapidly changing topic, we limited the literature search to a total of 3,211 articles for the period from January 1, 2008, to December 31, 2020. The Web of Science core collection consists of six online databases: Science Citation Index, Social Sciences Citation

Index, Arts and Humanities Citation Index (A&HCI), Conference Proceedings Citation Index- Science (CPCI-S), Conference Proceedings Citation Index- Social Science and Humanities (CPCI-SSH), Emerging Sources Citation Index (ESCI). These databases contain comprehensive literature and have high academic value, which is suitable for literature analysis [55]. The scope of our research was limited to computer technology, social sciences, business management, the arts and humanities, psychology, and the science of decision making, given the areas in which our research was reviewed. Consequently, chemistry analytical, chemistry multidisciplinary, engineering biomedical, and nanotechnology category were excluded. After completing the systematic literature search and selection process a total of 2874 articles were extracted. The present study downloaded all of these records, including the authors, the titles, the abstracts, the source of the publications, references, and other necessary information. Although smart homes are related to sensor technology, we decided not to research the specific underlying technology in the present study.

3.3 Reporting the review

As the final step in the systematic review, this stage mainly reports the results of the literature analysis. Through the application of inclusion and exclusion criteria, 2874 related pieces of literature were obtained in this study. To more comprehensively review the research, this article combined CiteSpace5.7 R2, a bibliometric tool, to discuss the core content and development trend of this field [56]. CiteSpace is a visual analysis software that uses time series to dynamically map the macrostructure and development trend of the knowledge domain [56]. It can describe the current situation and development trend of the discipline, and realize the analysis and exploration of the evolution mechanism in the field of research. The node type of the software determines the purpose of using CiteSpace analysis and selecting different node buttons can obtain different functions of the network analysis diagram. In the CiteSpace, we selected the node type as "Country" and sliced it for two years. And we extracted the most frequent "Top20" in each time slice. Then we selected "Cosine" as the connection strength, and cluster using the pathfinder, pruning the merged network and pruning the sliced network. The result showed cooperation between different countries (see Fig. 5). CiteSpace also provides the function of co-citation analysis, and then we use the "reference" function node to cluster the literature. Based on the clustering results, keywords timeline evolution analysis can also be conducted to understand the change of research emphasis in each stage. The analysis of the acquired literature is the key content of the present study, and mainly includes the following three research questions (see Table1). The first question is mainly based on the logic from descriptive analysis to cooperative network analysis, including (1) statistics of the number of papers published in the field of smart homes over the years; (2) the status of research of countries/regions and major research organizations; (3) the publisher of articles. The second question includes the cluster analysis of the co-citation network. It summarizes the main research contents and is used to recommend the research framework of the present study. The third question includes timeline trend analysis based on the results of the keywords co-occurrence networks. Through timeline analysis, we can determine the priority research topics that emerge in some periods, which play an important role in sorting out the process by which the research focuses evolved. Then the paper combines RQ2 and RQ3 to explore potential future research opportunities. Finally, the present study summarizes the research contribution and discusses some technical solutions.

4 Results and discussion

This section presents and analyzes the first research question results based on the systematic review objectives.

4.1 RQ1. What is the current overall progress of research on smart homes?

This subsection will answer specific questions in Q1 from three perspectives, including (1) the number of papers published in the smart home field over the years. (2) the country/region and the major research organizations. (3) The distribution of literature types and published journals.

4.2 Annual publishing trends

The statistical analysis of the number of publications provides a measure of the degree of development of credible knowledge in this field. Figure 3 shows the number of manuscripts published from 2008 to 2020. The diagram reveals that between 2008 and 2014 there is little research on the subject. Coinciding with the further development of Internet of Things technology and the expansion of research on the subject, the number of articles in this field increased from 217 in 2015 to 630 in 2019. This shows that research on the field of smart homes is in a rapid growth phase. As of December 2020, there were already 3211 articles related to this field of research. Given the rapid development of the literature in this field, it is necessary to review the papers and summarize the current research emphases and future trends.

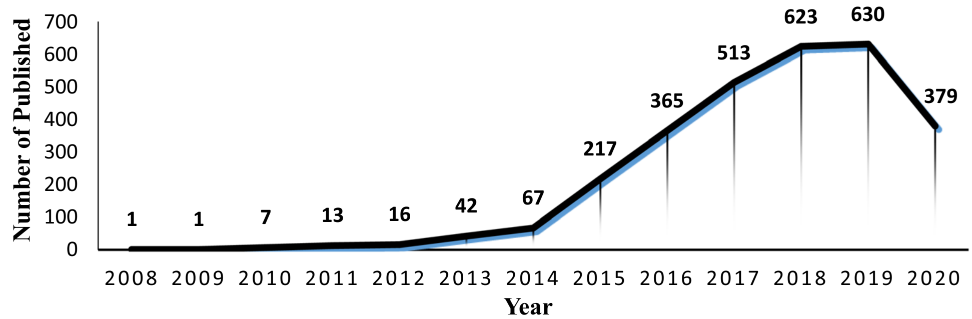

Fig. 3 The number of annual researches of smart homes during 2008–2020

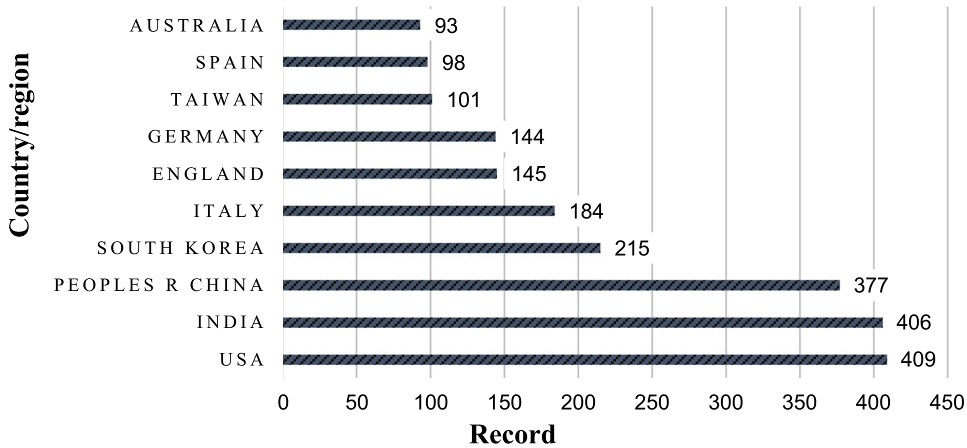

Fig. 4 The top 10 countries or regions by number

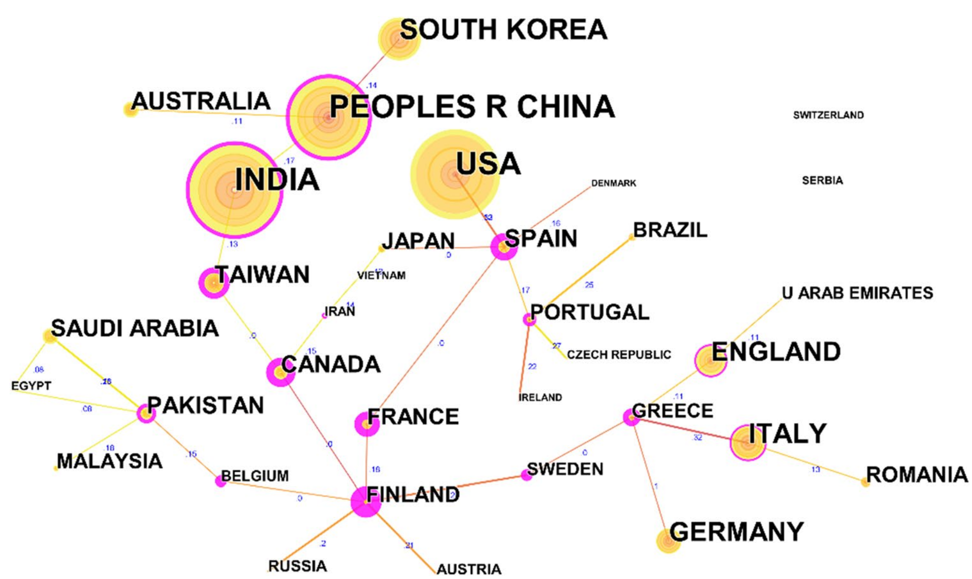

Fig. 5 Principal cooperation network of productive countries or regions during 2008–2020

4.3 Analysis of countries/regions and organizations

The top 10 countries with the most published manuscripts in this field are shown in Fig. 4. The literature published by the United States, India, and China is much higher than those of any other countries or regions. This indicates that these countries are rich in both the development and practical application of this field.

The distribution and cooperation of the countries/regions are analyzed to the academic progress of research in the field from a macro perspective. We used the visualization tool to obtain Fig. 5.The center of the circle is marked with the name of the corresponding country, and the image area is

Table 2 The top 5 organizations with the most publications on the smart homes

Rank	Organization	Country	Publications	Proportion
1	King Saud University	Saudi Arabia	32	1.113
2	National Institute of Standards and Technology	America	24	0.835
3	Beijing University of Posts and Telecommunications	China	21	0.731
4	Kyungpook National University	South Korea	19	0.661
5	Politehnica University of Bucharest	Switzerland	19	0.626

Table 3 The distribution of literature type about smart homes

Rank	literature	Records
1	Proceedings paper	1862
2	Article	975
3	Review	61
4	Early access	48
5	Book chapter	2
6	Data paper	2

positively correlated with the number of publications [57]. The United States has the largest circular area and all the recently published literature is relatively active. The country that cooperates more closely with the United States is Spain. Moreover, there were a large number of manuscripts published in Italy, China, and other countries. International cooperation with China is mainly with South Korea, India, and South Africa. These are all closely connected, indicating close cooperation between these countries. Finally, Saudi Arabia, Pakistan, Jordan, and Portugal have been working closely together.

Important research organizations in this field can be identified through quantitative analysis of the published literature by organizations. According to Table 2, the literature published by King Saud University is much higher than other institutions and is followed by the National Institute of Standards and Technology, and then Beijing University of Posts and Telecommunications. The research papers in this field come from 2632 organizations. Only 45 organizations published ten or more papers, accounting for 32.8% of the total, while the number of papers published by other institutions was highly variable.

4.4 The distribution of literature types and published journals

Table 3 summarizes the types of literature and shows that the conference papers are rich in content, followed by the article. Table 4 describes the top 10 most published journal categories in smart homes. In terms of publication types, given that smart homes are meant to serve the connectivity of the entire system, this field is bound to involve many disciplines, so the periodical categories are also broad. These 10 journals published a combined total of 431 studies related to smart homes, representing ~ 14.9% of all 2874 studies retrieved. Due to the rapid innovation of smart home technology, more literature can be found in IEEE ACCESS and IEEE Internet of Journal. Future Generation Computer Systems has also published a great deal of research literature on this area. Judging from the citations in each article, the Journal of Network and Computer Applications is not the most published, but the literature is frequently cited. This journal belongs to the engineering technology analysis of computer hardware periodicals, can be seen that the communication of smart homes is inseparable from hardware facilities, computer applications.

Table 4 Top 10 Journal with the most publications in smart home studies

Rank	Journal	Publications
1	IEEE ACCESS	106
2	IEEE INTERNET OF THINGS JOURNAL	82
3	LECTURE NOTES IN COMPUTER SCIENCE	65
4	FUTURE GENERATION COMPUTER SYSTEMS THE INTERNATIONAL	41
5	ADVANCES IN INTELLIGENT SYSTEMS AND COMPUTING	34
6	PROCEDIA COMPUTER SCIENCE	25
7	ELECTRONICS	22
8	LECTURE NOTES OF THE INSTITUTE FOR COMPUTER SCIENCES SOCIAL INFORMATICS AND TELECOMMUNICATIONS ENGINEERING	20
9	ENERGIES	18
10	IEEE CONSUMER COMMUNICATIONS AND NETWORKING CONFERENCE	18

4.5 RQ2. what are the main research contents of smart homes?

This section will answer specific questions in Q2 using cluster analysis. The research results describe the framework of smart homes. An analysis of the co-citation network of the literature reveals the content basis of the research topic [59]. To improve the quality of the results of the cluster analysis, we selected the 50 papers with the highest annual citation frequency and adopted the LLR algorithm. The top 10 clusters based on the co-cited networks are listed in Table 5.

Through the citation statistics of references, we can find important frontier articles in the field of smart homes research. Table 6 summarizes the five articles that were cited the most between 2008 and 2020, as well as the key content. The literature with the highest frequency of citations is proposed by Gubbi [60]. This paper presents a holistic vision of the Internet of Things and explores key technologies that drive the development of the Internet of Things. It also calls for more convergence needs for WSN and distributed computing, providing an important direction for research in this field. The authors also discuss Cloud-centric IoT implementations and challenges and pioneer the application of IoT in various fields. Secondly, Al-Fuqaha [1] provides an overview of IoT enabling technologies, protocols, and applications, as well as summarizing the capabilities required for different protocols in real-world applications. They build a bridge for technologies and applications and advance further research in this area. Given that building a common architecture for the Internet of Things requires merging a large number of heterogeneous devices, it is of great practical significance for Zanella [61] to conduct a comprehensive survey of technology solutions by focusing on specific areas, namely, urban IoT systems. Among these key documents, research on the Internet of Things based healthcare technologies by Islam [62] has also received widespread academic attention. This survey discusses the characteristics of Internet security and privacy in a healthcare environment, including the use of various ways to innovate to determine how they can contribute to sustainable economic and social development. But as smart homes are applied to IoT environments, the tasks performed at each level need to be determined. In reference [63], this paper innovatively provides a smart home management model that provides a solid foundation for future exploration in this field.

To further answer the main research topic of smart homes, this study uses the results obtained from the cluster analysis and key literature to formulate a research framework (see Fig. 6). This research framework is composed of infrastructure, communication technology, data analysis, and user services layers. The content of each layer in this research framework will be elaborated in detail in the next part.

Table 5 The top 10 clusters in co-citation network by size

Cluster ID	Size	Silhouette	Label (LLR)	Mean (year)
1	75	0.909	Ledger technologies	2016
2	53	0.816	Smart homes web	2013
3	41	0.837	Present state	2015
4	41	0.805	Enhanced living environment	2016
5	40	0.89	Things technologies	2016
6	37	0.884	Smart home technologies	2015
7	36	0.873	Raspberry pi	2012
8	35	0.926	Data networking	2013
9	32	0.877	Activity recognition	2013
10	30	0.97	Threat-based security analysis	2011

Table 6 The top 5 co-cited references in 2008–2020

References	Key content	Count	Year
[60]	1. Overall IoT vision, definition, Application domains 2. Propose a private and public clouds implementation method 3. Cloud-centric IoT realization and challenges	139	2013
[1]	1. Focus on implementation technologies, protocols, and application 2. Explore the emerging technologies, including big data analytics, cloud and fog computing	116	2015
[61]	1. A comprehensive survey of urban IoT implementation technologies, protocols, and architectures 2. Discuss the technical solutions and practice guidelines adopted by the Padova Smart City project, which was deployed and validated in the city of Dova, Italy	86	2014
[63]	1. Propose a framework for integrating different components of the IoT architecture to effectively integrate smart home objects 2. A smart home management model is defined and the main tasks that should be performed at each level are identified	59	2017
[62]	1. Review the progress of healthcare technology based on the IoT 2. Analyze different security and privacy features of the Internet of Things 3. Propose an intelligent collaborative security model	59	2015

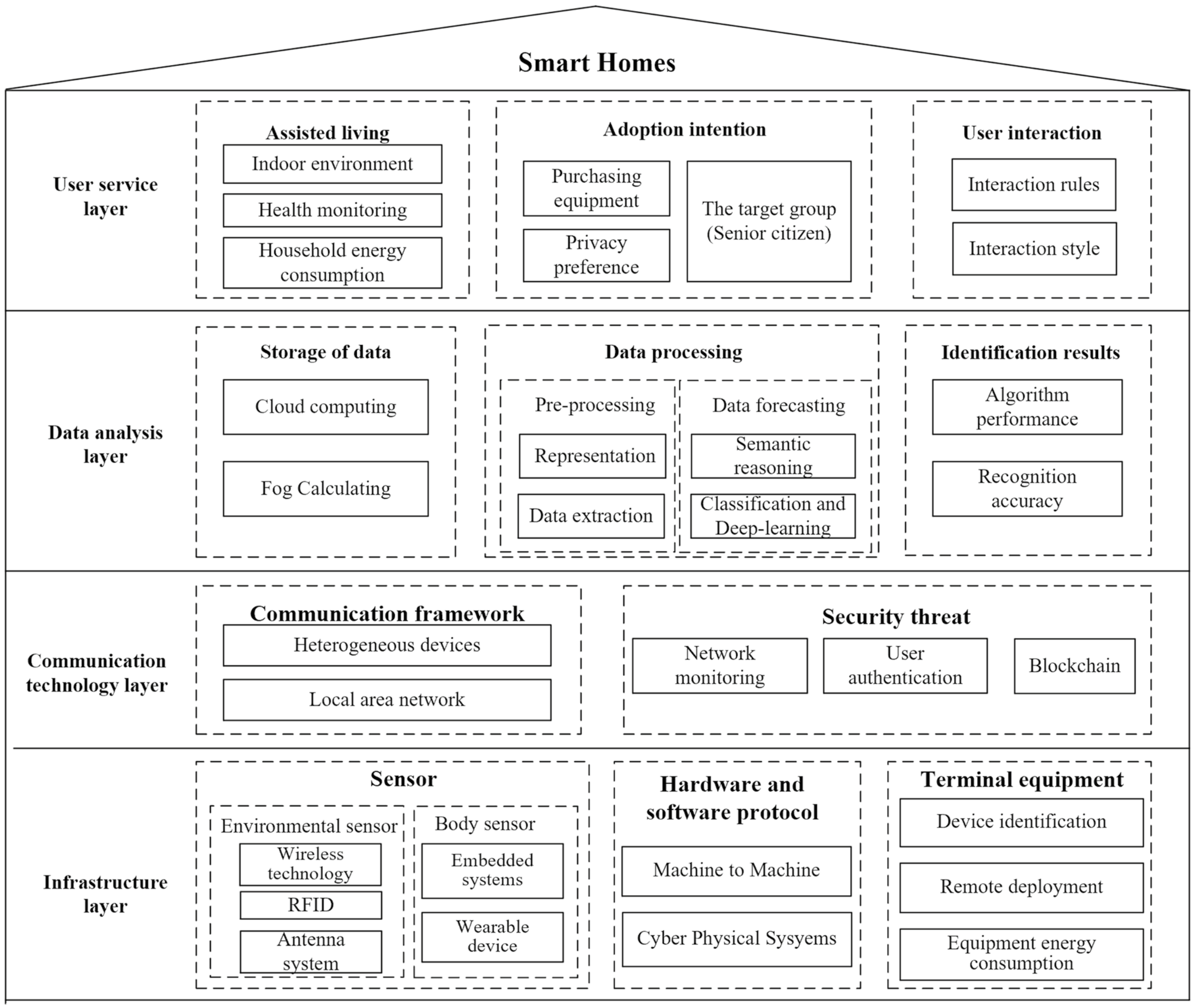

Fig. 6 The research framework of smart homes

4.6 Infrastructure layer

This subsection describes the research content of the infrastructure layer. It is divided into three parts: (1) the sensor; (2) the hardware and software equipment protocol; and (3) the terminal equipment. The sensor is an important component of the infrastructure of smart homes. Depending on the position of the device, the sensor can be divided into environmental and body sensors.

The environmental sensors measure the behavioral information of participants in the environment [64]. In recent years, wireless technology has broad application prospects because it is less intrusive. In this process, IoT technologies and protocols can not only exchange data through the Internet infrastructure but also greatly facilitate communication with adjacent devices [65] [66] [67]. In the IoT network, the realization of sensor mainly depends on the application of wireless technology. Studies have shown that although wireless technology can monitor and drive physical devices, some of its characteristics can also lead to problems such as fading and interference [68]. When all intelligent objects communicate with each other, there is a serious problem of energy consumption. Therefore, wireless techniques with low energy consumption and low latency are needed [69]. The communication features of Bluetooth low energy can make traditional sensor nodes and gateway devices more flexible. This is why low-powered wide area network transmission technologies have become the mainstream [70]. Given that the nature of IoT protocols is still heterogeneous, Kambourakis [65] also provides a detailed overview of five modern Wireless Personal Area Network protocol stacks. With the increase in existing wireless communication systems, spectral parameters need to be further managed and configured. Some scholars [71] believe that cognitive radio is the optimal candidate technology. It is defined as an adaptive intelligent radio technology that can automatically detect the available channels in the radio frequency spectrum, thus facilitating more communication. Radio frequency identification (RFID) is also widely used in this environment for the interconnection of home devices. RFID technology can read the information on the labels in smart devices, In Reference [72], Householder can use handheld mobile RFID to control the device. The MRFID reader can be carried by the user to different rooms and then read the information of the RFID tag under coverage [72]. The Antenna system is also a key application in wireless technology. It has strong spatial processing power and low energy consumption, which contributes to meet power challenges. The author [7] designed a switched-beam antenna system for the 2.4 GHz band's in-home networking. The system has a regular nine-prism structure, which can guarantee the consistency of each beam, and has good advantages in shape. Because traditional networks and filters take up a lot of space, the author [8] proposes a broadband filter antenna modeling and design method to realize complex input impedance, which has the advantages of broadband operation, harmonic suppression, and low cost.

The body sensors can be divided into wearable medical devices [46] and implanted medical devices. By tracking the activities of the wearer it provides convenience to the user [73]. As sensors are increasingly implanted into family members in need (e.g. elderly care groups), studies in related fields of wearable and assistive robotics are becoming more abundant. Robots in these families can provide useful services or act as partners to lighten the burden on society.

However, since an increasing number of sensor input devices are dynamically generated in the Internet of Things environment, effective network device communication protocols are needed to conduct necessary coordination and control the various system components. Current studies have provided evidence that machine-to-machine communication systems and the cyber-physical system are newly-rising solutions in this field. Machine-to-machine (M2M) communication systems can be applied to support autonomous communication between heterogeneous devices without manual intervention [74]. Scholars propose that algorithms for the assignment of M2M architecture nodes [75] could be used to determine the priority of the tasks undertaken by the equipment. In addition to the assignment of communication protocols by the node, both the data obtained from the sensors and access to the Internet of Things infrastructure require appropriate software and business logic to accomplish tasks more effectively. Therefore, Cyber Physical System (CPS), a new research field is growing rapidly. It is controlled by the software system with physical entities and strict real-time constraints [76]. The software in CPS is real-time embedded software, which requires the hardware to make responses to the occurrence of things at short intervals [77].

In addition to sensors and hardware and software protocols, the application of terminal devices in smart homes is also critical. For existing designs. For existing smart home design solutions, it is necessary to continuously improve the terminal equipment's identification and control ability, deployment ability, and energy consumption to provide a solid foundation for the real-time operation of smart homes. First, identification equipment is an important aspect of terminal equipment, because an increasing number of intelligent sensors can be used to perform monitoring tasks. Consequently, different types of devices need more effective equipment for identification technology. Second, to effectively improve the efficiency of the equipment deployed for family services, the related research design is required to ensure the suitability of the remotely deployed distributed intelligent family and invoke the distributed service-oriented architecture (D—SOA) [78]. Finally, the energy consumption of the device (e.g. the battery capacity of the device) is also a challenging issue. This is because data transmission in the Iot is usually very energy-intensive. In this case, to extend the life of the application device, the existing solution can determine whether the device is enabled or not based on the distances between nodes [79].

4.7 Communication technology layer

An assessment of the existing literature was used to elaborate on the communication technology layer in the smart home architecture. This is based on the following two parts: (1) the communication framework proposed by the existing research; and (2) the security threats encountered in the communication process as well as the corresponding solution.

Regarding the first part, the communication framework is crucial to the distributed architecture of smart homes. This is because it determines the communication specifications of the different devices and services as well as the way they connect. The co-existence of communication technologies is a great challenge for the new paradigm of the Internet of Things. Hence, it is necessary to define standardized frameworks for communication that can identify communication problems between devices. Table 7 summarizes solutions to communication between heterogeneous devices, and the gateway and software aspects.

In recent years, the weaknesses of the Internet of Things in communication have often been attacked by malicious users. For example, when a home appliance is connected to a network, allowing users to control it remotely, this creates a vulnerability that can be used to attack entire networks. These situations continue to drive research on

Table 7 Communication framework of smart home based on Internet of Things

References	Communication framework		Application
	Heterogeneous devices	Gateway	
[80]	Simple Object Access Protocol (SOAP) technology	–	Home devices
[81]	Communicate in a collaborative manner in which device requests are sent to a centralized database to verify the authenticity of the device	–	Health monitoring
[82]	–	Integrating several X10, Insteon, ZigBee, and Universal Plug-and-Play protocols	Home devices
[83]	Patient identification through RFID	Wireless transmission through 6LoWPAN and YOAPY protocol	Mobile Health
[84]	Remotely control the end-devices over Bluetooth	Based on an IPv6 personal area network protocol—the 6LoWPAN	Home automation system
[85]	A Representational State Transfer (REST/RESTful) framework	Raspberry PI based gateway	Access smart home appliances
[86]	Based on the long-range and low-power technology LoRa	–	Reduce power consumption

network security and mitigation technologies [87]. Especially wearable devices are becoming increasingly popular. These devices can collect more sensitive information from users by observing their daily activities [88]. Therefore, to maintain the privacy security of all users, effective identification of threats to the security of the network from applications and corresponding strategies to address them are required.

The countermeasures against security threats mentioned in literature can be roughly divided into the following three categories: (1) network monitoring, (2) authentication of user, and (3) blockchain (see Table 8 for details of the first two categories). In terms of network monitoring, intrusion detection systems have been an important tool to protect networks and information systems [36]. To prevent the intrusion of malicious activities, the scheme outlined in Table 5 provides network-level detection for smart devices. To effectively enhance network security architecture, some scholars also diagnose security threats in smart homes by extracting the correlation between network traffic characteristics [89, 90] and the detection of traffic anomalies [91]. Under traditional communication specifications, encryption, and proprietary protocols used by devices limit the value of traditional network monitoring. There is literature proposing the deployment of HomeSnitch [92] to enhance the control of network-level services by classifying internet of Things device communications. A growing body of literature shows that there are limitations to using encryption alone as a defending strategy. we can consider starting with an intrusion detection system, intrusion prevention system, and intrusion response system. These policies enhance the ability to protect privacy.

In addition to the monitoring of network security, the user authentication mechanism can also effectively protect data and communication security. In the environment of smart homes, all components must undergo an authentication process [37] before establishing communication. For example, accessing IoT data in a home healthcare environment requires user data security. Simultaneously, user authentication mechanisms should also be able to prevent physical capture and misuse [97]. Furthermore, most of the above research on authentication can only realize coarse-grained access control [99]. Namely, once the device has passed authentication, the user can access all devices, which can easily lead to excessive access behavior. To solve this sort of problem, a function-based access control scheme in the internet of things is proposed to prevent unauthorized access [99]. Previous solutions for security and privacy protection have been based on a centralized architecture, but from the advice of [13], blockchain can provide applications with fine-grained, decentralized access control. Blockchain-based IoT deployments are characterized by centralization so that transactions of different actors in the environment can be stored in an immutable way. Also, the blockchain consists of a chain of encrypted blocks with timestamps, which greatly increases the level of security of the solution [100]. The solution is widely used in smart home scenarios. Han [101] proposed a smart home door locking system based on blockchain. Because of the immutable nature of blockchain, intruders can neither attempt to bypass the authentication of the locking system nor make changes to transactions that have already been performed [13]. However, the computational overheads of blockchains are very high with limited scalability. Moreover, it uses much bandwidth and causes

Table 8 Smart homes solutions to security threats

Classification	References	Measures	The specific methods	Purpose
Network monitoring	[89]	Secure network architecture (SH-SecNet)	Multivariate Correlation Analysis (MCA) technique	Diagnosis of security threats
	[93]	Three-layer intrusion detection system (IDS)	classify each IoT device type; identify malicious packets; classify the type of attack	Detect cyber-attacks
	[94]	Intrusion detection and mitigation framework, called IoT-IDM	Modular design of IoT-IDM; OpenFlow communication protocol	Provide network-level protection for smart devices
	[95]	NETRA a novel lightweight docker-based architecture	Network function virtualization (NFV)	Deploy security functions at the network edge
	[90]	IoT-app privacy inspector	Random forest classifier	Maintain users privacy
User authentication	[96]	Three-factor authentication	real-or-random (ROR) model; Burrows–Abadi–Needham (BAN) logic; automated validation of Internet security protocols and applications (AVISPAs) software simulation tool	Design a secure user authentication mechanism
	[97]	A lightweight anonymous user authentication protocol	Real-Or-Random (ROR) model, automated validation of internet security protocols and applications (AVISPA)	Satisfy user anonymity and untraceability requirements, and resist device misuses
	[98]	Anonymous secure framework (ASF)	Efficient authentication and key agreement	Enable devices anonymity and unlinkability
	[72]	A Trust-based RFID Authentication Scheme (TRAS)	Adding trust-based parameters to authentication	Address two typical attacks, jamming and cloning attacks

delays, which is not suitable for most Internet of Things applications. In this regard, some researchers have proposed authentication methods for privacy disclosure, which are often lightweight. Dorri [102]proposed a lightweight blockchain smart homes structure. To reduce the associated overhead, the structure introduces a special node of the home miner. The node is prepared to treat the received transactions as a separate chunk, and can also perform the transaction process by creating the corresponding account for the device or deleting it. When managed by blockchain smart contracts, lightweight agents of multiple devices in the smart homes collaborate to detect distributed denial of service (DDoS) attacks [103], providing security services for households [104].

4.8 Data analysis layer

This subsection expands on and describes how to store and process the obtained data, and identify the final activities in the home, based on the data analysis layer in the framework.

Regarding data storage, the popularity of the Internet of Things has promoted the development of edge computing [19, 105, 106], cloud computing [107], and fog computing [108]. Due to resource constraints, terminal devices cannot meet the increasingly high demand for intelligent applications (such as augmented reality and face recognition). Coupled with the large amount of data being accessed in the Internet of Things environment, the emergence of highly distributed cloud network architectures is expected to be a solution supporting data-driven services [16, 109, 110]. Traditional centralized computing cannot meet users' needs in real-time because it is far from the terminal, resulting in delays and poor experience. Given the pressures of data transfer and privacy protection, this data should be processed locally. Edge computing provides security features extending the cloud to the edge of the network, which is useful for critical applications that require high reliability, real-time processing, and context awareness.

Regarding data processing, it includes both preprocessing and making predictions based on the data. After obtaining data from various sensors there are some preprocessing processes. This process includes data representation and feature extraction. Preprocessing involves the deletion and representation of the original sensor data, which is needed to extract higher-level information from the original data obtained by heterogeneous devices and then express it in a form that can be understood by the machines. It also needs much information processing technologies, such as the introduction of software toolkits [111] to realize the extraction of information from the sensor data. Subsequently, the extracted features are further simplified to the most discriminative features in the recognition task by the feature selection method. Only then can the daily activities of the occupants be identified by applying different machine learning algorithms [112, 113].

After the data preprocessing is completed, the data needs to be used for making predictions. The predictions from the data made by existing studies focused on three types of exploration paths: semantic reasoning, classification and deep-learning(see Table 9). The smart home is called intelligent because it can use past experiences to predict future events [17, 114, 115]. Semantic reasoning [116] mainly applies knowledge-driven methods based on sensors to further improve the accuracy of prediction [18]. Classification mining is also an effective method for data prediction. Some scholars have applied the classification to extend activity recognition to a large number of activity classes and for training data sets [81, 117]. Based on the classification, data mining algorithms can be used to effectively determine the activity sequence characteristics in the intelligent family [118] to promote the decision process of identifying user behavior.

From the results of activity recognition, existing studies mainly focus on the performance of algorithms and the accuracy of the final results of the recognition of behavior [122]. Existing studies have shown that the accuracy of activity identification can be improved through continuous optimization and deep learning techniques [123]. Simultaneously, the accuracy of the recognition results must consider three different situations, namely task time, activity order, and multiple users, leading to greater differences in the accuracy of activity recognition. For the performance of these algorithms to be feasible and scalable, semantic information about sensor data and relationships, as well as observed activity information [124], must be analyzed further.

4.9 User service layer

As the key layer of smart homes, the user service layer needs to further summarize the current research progress. The paper concludes that environmentally assisted living, service interaction, perception, and adoption are the core contents of the user service layer. This subsection will specifically focus on these three aspects.

Environmentally assisted living is an important application field in smart homes [125, 126]. By combing the existing literature on specific applications, we find that research in this field mainly focused on comfort, health, and saving energy. Since the essence of applications is to better assist users, the paper will analyze the different applications of three service types. Firstly, smart homes need to provide users with more comfortable services. Indoor air quality monitoring is crucial for improving living environments, and its application mainly focuses on the results of research of iAir, AirPlus, and iAirBot [91–93]. The intelligent kitchen [127] and other concepts have gradually entered people's lives, providing users with an efficient environment. (see Table 10 Panel A for details). Secondly, the application of intelligent technology can provide users with health and safety services. On the one hand, it can help the elderly live independently at home through remote monitoring of their health and assist them in obtaining medical guidance. As the proportion of the elderly increases, smart homes have gradually become an extension of traditional medical services. Besides, these environments are often equipped with non-invasive sensor devices that enable hospitals or health care professionals to effectively provide medical assistance through remote monitoring and communication with users. On the other hand, it can monitor the security of household appliances. (see Table 10 Panel B for details). Thirdly, considering the inefficiency of household energy utilization, the combination of the smart homes and energy management system [128] not only effectively promotes the further development of household energy management systems, but also maximizes energy efficiency on the premise of satisfying users' comfort [129]. Since users rarely spend time analyzing their home electricity consumption, wise advice is needed to help them plan savings measures.

Table 9 Smart homes prediction algorithm

Prediction algorithm	References	Description
Semantic reasoning	[116]	Proposes a knowledge-based multi-agent (MA) collaboration approach to automatically acquire semantic knowledge
	[17]	The algorithm is based on hierarchical model to learn the control strategy of intelligent environment
Classification	[108]	The classification of different activity types and sensors in smart home scenarios for the elderly living independently
	[81]	Activity recognition is extended to large training datasets by taxonomy
Deep-learning	[118]	Frequent sequential pattern mining algorithm suitable for real life smart home event data
	[119]	A new framework for 3D body detection, tracking and recognition of deep video sequences based on spatiotemporal features and hidden Markov model
	[120]	A Microwave Multiple Input Multiple Output (MIMO) array is used to identify different people
	[121]	Propose an management algorithm based on deep deterministic policy gradients

Table 10 Different categories of smart home applications

Type of service	References	Main point
Panel A: air quality monitoring	[131]	An indoor air quality system is named iAQ. The system uses Arduino, ESP8266, and XBee technologies for data processing and transmission
	[132]	An Internet of Things system for real-time indoor air quality monitoring is named iAir, which includes an ESP8266 unit and a MICS-6814 sensor
	[133]	A real-time indoor environmental quality monitoring system named AirPlus
	[134]	An auxiliary robot for indoor air quality monitoring based on the Internet of things named iAirBot
	[127]	An integrated smart spoon device is used at the front end of the catering assistance system
Panel B: Health monitoring	[135]	Application of new home sensing technology (remote monitoring) in cancer care
	[46]	Assist in the delivery of health services by extending the home network sensor capabilities
	[136]	An intelligent intrusion and surveillance system based on smart foot mat, which realizes the function of home security through Adaptive Neuro-Fuzzy Inference System
	[83]	Personalized health monitoring is realized through a mobile health interconnection framework based on the Internet of things
Panel C: Power control	[137]	Developed the ZigBee network intelligent energy control system based on the coordinator. Optimize the running time of household appliances by controlling unnecessary energy consumption
	[138]	Presented a hierarchical intelligent home control system to control household appliances. The system consists of a supervisory controller, a secondary controller, and some smart plugs
	[139]	Designed an intelligent energy management (SEM) system based on NodeMCU and Android, which can not only monitor household energy consumption in real-time but also record the running time and energy consumption information of each device
	[140]	Explored the implementation and technical selection of smart meters in Italy. The concept of smart meters is to allow information to be linked to customers, enabling smarter solutions rather than uniform pricing
	[2]	Designed a smart home energy management system based on IoT

By implementing information processing capabilities, such as big data technology and machine learning [130], smart homes provide a meaningful perspective for users to participate in the process of energy conservation. (see Table 10 Panel C for details).

As a large number of interactive devices and intelligent objects are applied in smart homes [141], research shows that application versions suitable for different users need to be dynamically created and executed. Since services interact with people, it is necessary to design a user satisfied interaction style. Consumers can use visual language communication and interaction with smart home accessories [142]. The visual language sets an object with rules for intelligent control, such as a graphical user interface. Existing studies have shown that this approach can improve user satisfaction when using smart objects that rules can be used when using smart objects [143]. Some scholars [144] compared two common user-created rule systems in the Internet of Things and intelligent scenarios and pointed out which interaction style was more suitable for rule design. However, there has been limited research in this field, and it needs further exploration in the future.

Although the current application extends the experience of the user interaction, the acceptance by residents is still far less than expected. Existing literature on exploring the factors influencing users adopting new equipment can be summarized into three categories [145]. the first category is mainly functional factors, such as perceived usefulness and perceived ease of use [146]. The second category is mainly emotional, such as user awareness, perceived enjoyment. The third category is mainly about network security, such as perceived risk and trust. Smart homes technology is aimed at assisting the elderly with being more comfortable, secure, and happy. However, it will have the opposite effect on the elderly that are wary of emerging technologies and have insufficient skills to use electronic devices and computer systems effectively. It is necessary to explore the key factors affecting the elderly and their acceptance of smart home services and devices. Pal as an important research scholar in this field, proposed that performance expectation, effort expectation, and perceived trust have a positive impact on elderly intention. Whereas, technical anxiety and perceived cost are negatively correlated, with convenience and social influence having no impact on behavioral intention [147]. On this basis, to quantify the extent to which the elderly are willing to accept smart home technology, the scholars extended the original technology acceptance model and combined motivation with a technology acceptance model for the analysis.

4.10 RQ3. What is the state-of-the-art of research in smart homes?

In this section, we will analyze the hot keywords and phase evolution of smart homes based on the results of bibliometric analysis. In the background of the deepening of the Internet of Things technology, smart homes involve the communication and integration of various physical devices and virtual things, especially the wireless sensor network. These contents are closely related to “communication protocol”, “wireless sensor network” and other keywords. To reduce the delay of the awareness of the location, keywords such as “cloud computing” and “fog computing” are integrated into the smart homes. In terms of the application of smart homes, such as the “smart city”, “environmentally assisted living”, “healthcare”, “optimization” and other keywords appear frequently, which indicates that an increasing amount of promising technologies are being applied in the healthcare industry [148].

To further understand the evolution of these smart home frontier fields of research, the present study generates a viewable keywords timeline evolution diagram (see Fig. 7). Against the background of the gradual rise of the concept of the Internet of Things, much research on smart homes has emerged. In this study, the period from 2008 to 2014 is named the embryonic stage. Since many intelligent things depend on the networks of wireless sensors, scholars began to study the important role of networks. Therefore, "Internet of Things", "wireless sensor network" and other keywords began to appear in the literature. This set the stage for increased research of smart homes. In the beginning, smart homes mainly provided different forms of automated services (including alarm services, intelligent monitoring, and communication, etc.), while the literature mainly focused on the corresponding management systems and configuration of the infrastructure.

With the continuous improvement of hardware and software technology, smart home technology can be applied to more scenarios. As the period of rapid change and development in the field, the keywords in 2014–2017 were very extensive. Keywords in this period can be divided into two categories: (1) “Bluetooth low energy consumption”, “Edge computing”, “Activity identification”, “Home automation” and “Technical challenges”; (2) application scenarios such as "environment assisted living", "smart grid" and so on. The continuous enrichment of application scenarios requires corresponding technical support and data integration. Since each device in smart homes

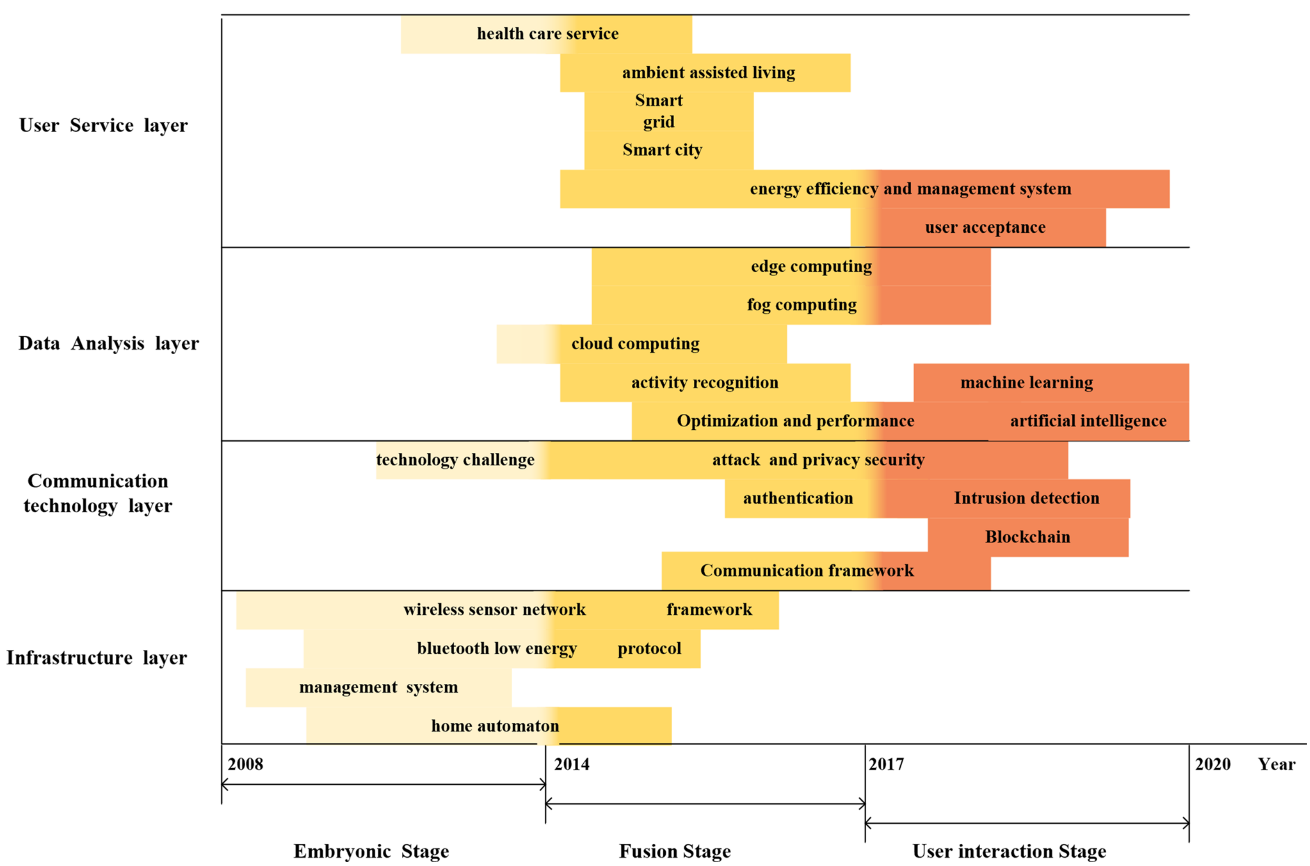

Fig. 7 Keywords timeline evolution diagram of smart homes based on the internet of things

is separate, how to effectively integrate the data generated by each system becomes particularly critical. Besides, the acquisition of intelligent interactive behaviors cannot be separated from a series of algorithms, which indicates that this stage of development focuses more on the performance of the algorithms and applications in smart homes.

When smart home applications become more popular among users, the research starts to analyze smart home infrastructure and communication technology from the perspective of the end-users. The period from 2017 to 2020 can be summarized as the user interaction stage. This is because the usability and adoption by users of smart homes were gradually explored, such as “user acceptance” and “communication performance”. In this phase, many researchers focused on solving the problems of privacy security through various methods, such as keyword "classification", "authentication" and "intrusion detection". With the huge amount of data generated by the smart home, future systems will need to study privacy and network security issues in depth. Also, the sudden emergence of “blockchain” as a keyword means that blockchain became a hot topic of research in 2018. The existence of other keywords from the previous stage, such as “fog computing”, “edge computing” and “energy management”, indicates that the research in this field is deepening constantly.

5 Future research topics

Based on the research framework proposed above, this section further analyzes research gaps and frontier topics in this field. It discusses future research directions, as shown in Table 11, which may provide useful insights for researchers and practitioners.

In recent years, a range of smart devices, such as wearables, have penetrated the vast market for smart homes. However, existing research is limited to the technical implementation of wearable devices, with little consideration given to users’ use of wearable devices and information sharing between data. Some scholars [73] have explored the use of IoT-based wearable health trackers, and then used Delphi to evaluate existing research and theories, but this aspect of the exploration is still insufficient. Consider that wearables are in close contact with our lives, but users know less about how wearables are acquired, stored, and transmitted. As a result, users may experience privacy concerns that further affect their continued use of such products. Future research could further take the human factor into account in the design of wearables, thereby further developing the huge potential of such products. As the use of smart healthcare continues to expand, some scholars are improving the user experience by combining IoT devices with home health services

Table 11 Future research questions for smart homes

Research streams	Future research questions
Infrastructure layer	What are the factors influencing the adoption of wearable devices by users? Is it related to the invasiveness of the device?
	With the continuous application of decentralized medicine, what technological innovations are needed to form a comprehensive platform?
Communication technology layer	Can the smart home provide user privacy configuration? Can users define acceptable privacy metrics for the smart home?
	Is there a compensating role between privacy configuration and service convenience in the smart home?
	Does fine-grained user authentication access reduce user willingness to use while improving security?
	How can blockchain technology and smart home applications be combined in the future to effectively improve communication efficiency and network security?
Data analysis layer	Can design different user preference service recommendation algorithms according to the user’s intention and demand?
	In the big data environment, what factors will affect the accuracy of smart home activity identification? Can different learning prediction models be designed for different sample users?
	What is the index system for evaluating the performance of algorithms in the process of comparing algorithms such as machine learning to predict user activity?
User service layer	Can we further explore the interaction styles that affect different user perceptions based on the underlying technology?
	With the development of 5G technology, what types of smart home activities can increase user satisfaction and technology adoption?
	Consider exploring user acceptance factors for different service purposes?
	In terms of home energy applications, how will device interface Settings affect users’ changing consumption habits?
	The existing researches all start from functional perception to study the influence of users. Can we start from emotional perception?
	How can smart home manufacturers integrate user experience into their technology development strategies to provide better service quality?
	How to integrate virtual reality and immersive environments into the role of smart homes and reduce the user’s psychological perception distance?
	How will changes in the level of home intelligence affect users’ perceived satisfaction? Whether there are spillover effects?

such as smart medicine cabinets [149]. The integration of smart healthcare and smart homes also assists groups in need to a great extent. For example, smart homes can further reduce the overload of medical resources by capturing data on the physical condition of users with asthma behavior through environmental sensors. However, there is still a gap between smart homes and seamless health monitoring systems. At present, academic research is still in the stage of technology exploration, has not been able to solve the problems faced by elderly people at home or special groups for different needs scenarios, so the exploration of this aspect will make up for the lack of resource integration process.

Existing research architectures lack solutions to provide information protection for different levels of data [150]. From the literature analysis, it can be seen that through various sensors, human behavior is gradually integrated into the control process of smart homes. Different types of services require different key technologies, especially for health monitoring services, and research should focus on addressing privacy issues in real-time. The details of the data collected by the sensor should be concisely defined, thus increasing the user's trust. The study suggests that personal privacy can be configured in two ways: enhanced privacy (from residential home systems to cloud platforms) and the user-driven way [151]. Privacy enhancement technology can solve the problem of multi-layered privacy data analysis, including controlling access during data collection, management, and so on. At the same time, the architecture may consider adding a privacy module that should configure personal privacy in a user-driven manner [151]. In the communication process, smart homes need to ensure the security of user privacy, but different users of privacy disclosure of different degrees of recognition. To address such issues, future studies can explore the implementation path of integration of privacy features into the architecture. Considering the immutability of the blockchain, whether the correct combination of this technology and smart homes can improve the degree of network security is also worth exploring. This paper holds that the premise of protecting privacy is to satisfy the data communication between different sensors and that privacy disclosure within the user's acceptable range is the best trade-off. Therefore, this paper suggests that there may be a compensatory effect between the privacy configuration and service convenience of smart homes, how does it affect the change of user perception? If smart home providers use fine-grained user authentication access to protect privacy, will it reduce willingness to use it because of the cumbersome authentication process? Future explorations of these issues are undoubtedly interesting. Besides, there are some gaps in the scope of academic research regarding the criteria for determining the implementation of privacy protection measures. Future researchers can further explore user-acceptable privacy agreement standards.

This study found that due to the combination of big data and smart homes, user activity recognition has changed significantly. In general, activity recognition methods can be divided into two categories. The first category is about visual/camera detection of changes in environment or behavior, which is likely to lead to privacy breaches. At present, the academic research content is relatively rich, such as pixel-based human morphological characteristics detection method, calculating the area ratio of each partition of the human body as a data source for fall detection, the second type is the use of emerging sensor network technology (wearable/implantable monitoring system and auxiliary robot). The researchers use data mining and machine learning techniques [152] to build a variety of activity identification models. We think there are three reasons why this kind of method has great potential in future research: (1) the choice of sensor and data processing methods in different scenarios has a great influence on the prediction of activity behavior. The first is that task time variances are difficult to predict, the second is that the sequence of activities is different and even interrupted, and finally when multi-user situations are involved, these factors can make activity identification challenging. Future scholars can further establish indicators to evaluate the performance of algorithms to better compare various types of algorithms. (2) Because of the differences between individuals, samples need to collect and tag data for each person before they can reliably use the learning model to track individual activity, but the process is cumbersome. Future research needs to consider what factors affect the accuracy of smart home activity recognition in a big data environment. Can we design different learning prediction models for different sample users? (3) Even for the same user, their behavior also varies in different environments. In the process of activity prediction, it is difficult to guarantee the accuracy of activity identification if the system assumes that they have completed activities with consistent preset criteria. Therefore, future research can design the preferred service recommendation algorithm according to the user's demand, thus promoting the decision-making judgment to identify the user's behavior. The research on this content can make the application of smart homes constantly refined, with high commercial value.

From an application service perspective, different users have different perceptions of the same service. Existing research often focuses on the accuracy of application services, but ignores the social and cultural impact between different groups, which is critical for smart homes users. This new mode of interaction brings rich sensory changes to the user, from the continuous iteration of the interactive logic of speech to space control. This process of change also brings potential research value. Future research can explore the impact of different interaction patterns on user perception, thus further solving the bottlenecks encountered by smart homes in interactive scenarios. At the same time, we can consider how smart home providers integrate the user experience into their technology development strategy to provide better service quality. Smart homes have also penetrated every detail of a user's life. Future research can integrate virtual reality and immersive environments into smart homes to reduce the user's psychological perception of distance, and also provide the basis for enterprise development and marketing activities. In the future, the stackability between users and smart homes will be stronger, and the exploration of this aspect is of theoretical and practical value.

6 Discussions

In this section, we review the general ideas of the above. Then we discuss the problems and emerging technologies solutions. The discussion provides insights for technicians, smart home providers, and governments to understand the industry development.

6.1 Discussion of general ideas

First of all, considering that few pieces of literature systematically review the research in the field of smart homes based on the Internet of Things from both a horizontal and a longitudinal point of view, this paper analyzes 41 review studies. The results show that there are three important studies in this field, namely (1) innovative technology, (2) privacy security, and (3) practical application. This article also identifies influential countries in this area and their partnerships, among which the United States, India, and China are the larger countries in smart homes and play a more important role in regional cooperation. Therefore, the first important contribution of this paper is to fill the research gap of using the systematic literature review to review the overall framework of smart homes.

Secondly, this paper points out the key development context in the field of smart homes. Technology development requires different protocols to complete the response function, but because of the large number of heterogeneous devices in the IoT environment, practical applications need to integrate seamlessly with the environment around us. Therefore, RFID tags, embedded sensors and executor nodes, and other wireless technologies, driven by more applications. Then based on 41 summary literature analyses, the subject framework of smarts home research is divided according to the granular size of the research content, namely, infrastructure layer, communication technology layer, data analysis layer, and system layer. Therefore, the second contribution of this paper summarizes the main framework of existing research in smart homes, which is designed to provide valuable insights into the entire technology environment and to support researchers working in this field.

Thirdly, based on the network clustering in the previous, this study further explores the evolution of hot keywords. Through timeline analysis, This survey is divided into three stages, namely, embryonic stage, fusion evolution stage, user interaction stage. The study found that in the early stage, the development of wireless sensor networks has generated research related to home automation services. In the fusion evolution stage, the changing technology and application scenarios have had a revolutionary impact on smart homes, as well as the "cloud computing" and other keywords on the development of technology. In the user interaction stage, the research objects are mainly environmental-assisted living applications, user adoption, and human–computer interaction experience. The third contribution of this paper is to reveal the development of smart homes based on the Internet of Things and to explore the current research hot spots and future research directions.

6.2 Discussion of emerging technologies solutions

This section compares and discusses the main technical solutions proposed. Figure 8 outlines the main solutions based on emerging challenges. The Internet of Things (IoT) is expected to be the new driver of the connected world through the connectivity of smart devices, network communications, and services. We believe that IoT devices can

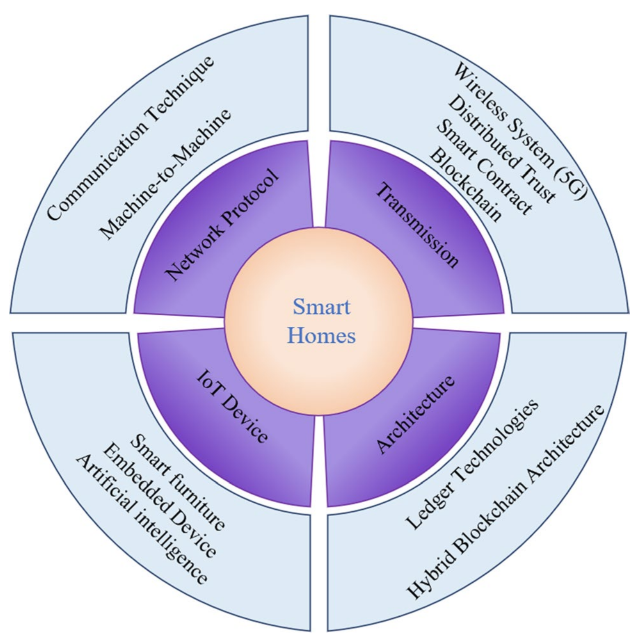

Fig. 8 Emerging technologies solutions for smart homes

be widely used in intelligent solutions. Existing IoT devices typically have built-in sensors and executors, but rarely apply user information to the real world. In the case of smart mirrors, for example, while they can provide makeup guidance, they do not provide efficient assistance to users with different emotions and needs. Therefore, we suggest that different levels of activity recognition algorithms can be used to solve data analysis problems, and when combined with machine learning to continuously improve accuracy. Also consider embedding the smart home packet into the furniture of the home, which allows any device to be connected. When the packet is embedded in smart cooking, the smart mirror can be based on the user's face data, and then give today's dietary advice. Finally, we can combine artificial intelligence technology to add voice interaction and gesture interaction to the device mode, reduce the perceived distance of the user operating the terminal device, and maximize the degree of device utilization.

The management of these IoT devices complicates technology implementation due to the heterogeneity of the system and limited resources. Fragmented data is scattered across different institutions, and smart homes need to get the most out of it. From the above analysis, many devices of the Internet of Things rely on IoT protocols for connectivity. However, the main problem at present is that the communication between different device providers is difficult to be compatible with. Among the communication technologies of IoT components established at present, this paper holds that wireless personal area network (WPAN) is suitable for small scale, relying mainly on technologies such as 6LoWPAN, and wireless local area network is suitable for larger networks, relying mainly on technology such as Wi-Fi [153]. Table 12 summarizes the characteristics of each communication technology. Because the implementation of the Internet of Things requires the negotiation and development of communication standards between various smart home providers, the process is costly. The Internet of Things (IoT) starts with radio frequency identification technology and is standardized through a range of operations, from low frequency to high frequency, ultra-high frequency. In most cases, these technologies are used to design wireless sensor networks (WSNs). Machine-to-machine (M2M) communication technology also plays an important role in the exchange of data between IoT devices and gateways. Existing markets are also actively advocating standardized M2M technology solutions. M2M communication technologies are critical to the deployment of the Internet of Things [74]. Most of the existing market for M2M technology is specific to fixed categories, and there are specific requirements for performance, frequency of use, and support network topology [74]. In terms of healthcare solutions, the reliability of communications and low latency are important indicators. Scalability, on the other hand, depends on the size of the monitoring range and can be installed between a room in the home (small range) and remote patient monitoring (large range). In terms of home automation solutions, infrastructure compatibility and cost are more popular with users. M2M communication technologies include *Message Queue Telemetry Transport (MQTT), Constrained Application Protocol (CoAP), Extensible Messaging, and Presence Protocol (XMPP), Session Initiation Protocol (SIP)* [154]. Terminal devices that use the MQTT protocol are habitually asleep and therefore do not apply to devices with limited power. CoAP is a lightweight application protocol, so there is no significant overhead during communication. XMPP can efficiently perform tasks that are easy to accomplish in a client–server system, such as a sharing state. SIP is also widely used in telecommunications infrastructure, and its head contains key attributes, which improves the security of the protocol. These solutions can be considered effective protocols for the Internet of Things, but both SIP and CoAP are better able to reach the potential of the Internet of Things. Because this protocol provides response and communication, these features are required in the network architecture.

Access control [31] is a challenging issue for smart homes because their homes are connected to IoT devices, leaving them in an open environment for information sharing. Most of the authentication mechanisms for RFID are sensitive to severe DoS jamming attacks and cloning attacks [72]. Verification methods are usually based

Table 12 Comparison between IoT technologies

	6LowPAN	BLE	Z-Wave	ZigBee	EnOcean	LoRaWAN	Wi-Fi
Frequency	Global 2.4-Ghz band	2.4 GHz	800–900 MHz	2.4 GHz	928 MHz	Regional sub-Ghz bands	Global bands: 2.4 Ghz, 5.8 Ghz
Coverage	100 m	50–800 m	100 m	10–100 m	30–100	10 km	100 m—several km
Rate	0–250 kbps	125 kbps to 2 Mbps	9.6–100 kbps	20–250 kbps	125 kbit/s	0.3–50 kbps	10–100 + Mbps
Power	Low	Lower	Low	Low	Ultra-low	Low	Medium
purpose	Low power consumption	Conserving energy	Authenticated encryption	Interoperability	Point-to-point	Protect bidirectional communication	Low-power

on historical transaction trust between the label and the reader [155]. Blockchain, on the other, reaches consensus on ledgers through all nodes to prevent block modifications [31]. Existing scholars believe that the application of blockchain in access control can be divided into two categories, one is not only to act as a distributed ledger, but also to provide authentication, authorization, etc., and the other is only used to store access and authentication rules. To protect the privacy of user data, IoT access should also be controlled at a granular level because of differences in the characteristics of the object's target requirements. Novo [156] has proposed using smart contracts to act as a central management entity, and other scholars [157] have proposed similar access control delegate frameworks that provide fine-grained access by defining the actions required for a single resource. Blockchain smart contracts are therefore also an effective access strategy. Also, access control mechanisms should be developed in a lightweight manner so that they can be applied to a variety of environments.

The delay caused by sensor transmission is also an important problem in the development of technology. IoT devices need to be transmitted efficiently at very high bandwidths, and scholars have conducted corresponding studies on device configuration changes, such as improving data rates [158]. We believe that fifth-generation wireless systems (5G) help with the network capabilities of huge amounts of equipment, supporting very high frequencies from 30 to 300 ghz. This high-performance connectivity technology is a stepping stone to the development of IoT technology. This approach solves the barriers to the IoT implementation process by providing a more efficient rate. Dorri [159] introduced distributed trust to address transaction latency in smart homes, arguing that overlaying the network can reduce processing time. Compared with traditional networks, this mechanism is an enhancement of traditional models. But the limitation of this model is that it is difficult to guarantee fault tolerance and network security. Smart home environments must be managed efficiently with information about sensor data and observed activity, but even so, their behavior varies from the environment and is prone to activity identification errors. However, distributed is difficult to roll back the database in the event of an error [31], and requires a relatively large throughput, so consider whether activity identification requires supervised learning and the requirements for results to maximize the configuration transfer rate. As mentioned above, one of the important goals of smart homes is to provide users with a convenient life. We should also consider the need for transmission rates in the scenario. 5G technology provides timely access to relevant information about user activity, especially in remote health monitoring environment, which allows residents to ensure maximum independence. In the future, with the continuous development of 5G and AI technology, intelligent products will provide more development opportunities.

Finally, the existing IoT architecture relies mainly on centralized management, and how to design a more adaptable architecture in the future is challenging. With the rapid rise of smart devices, existing smart home design solutions still need to solve many problems. It can be seen that the throughput and latency of the blockchain consumes a lot of resources. The user's privacy disclosure is also a huge challenge. However, from a data security perspective, a centralized solution may not be suitable for data security storage. Because the implementation of smart homes requires mobilizing a wide range of data to perform different functions, the integrity of the data is likely to be subject to malicious attacks, such as DOS attacks. Using blockchain is considered a viable way to secure data. At the same time, blockchain as a ledger technology, user access to object transactions is inevitably recorded in the chain. There are also scholars [102] who propose a hybrid blockchain architecture in which the cloud is responsible for data storage and can also provide a ledger for each user, the equivalent of using blockchain as an infrastructure layer for the Internet of Things. Therefore, this article suggests that the appropriate architecture can be constructed more according to the level of data privacy needs and infrastructure environment. For example, we propose that hybrid architectures can be used in scenarios where data volumes are large and security requirements are high.

7 Conclusions

This study reviews the academic research results in the field of smart homes in recent years. The paper uses the method of systematic literature review to make a macro-analysis of smart homes based on the Internet of Things. Then we combined with the literature analysis tool CiteSpace to further elaborate the research content obtained and formed a research framework. The research framework is designed to provide a summarization of current state-of-the-art knowledge and to support researchers in this field. Besides, we have explored potential future research opportunities based on hot keywords and the evolution of different stages. This paper also summarizes the research ideas and puts forward three main contributions. Then we specifically discussed solutions based on the emerging technologies of smart homes, intending to provide practical value to smart homes providers. Through the above analysis, this paper draws the corresponding conclusions and contributes to both theoretical research and practice.

Funding This study was supported by grants from the National Natural Science Foundation of China (NSFC) (71802126), and a grant from the Shanghai Pujiang Program (18PJC060).

Declarations

Conflicts of interest Not applicable.

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