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Review Article

Smart Home System: A Comprehensive Review

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Smart home is a habitation that has been outfitted with technological solutions that are intended to provide people with services that are suited to their needs. The purpose of this article is to perform a systematic assessment of the latest smart home literature and to conduct a survey of research and development conducted in this field. In addition to presenting a complete picture of the current smart home system's (SHS) development and characteristics, this paper provides a deep insight into latest hardware and trends. The research then moves on to a detailed discussion of some of the important services provided by the SHS and its advantages. The paper also statistically discusses the current and future research trends in the SHS, followed by a detailed portrayal of the difficulties and roadblocks in implementing them. The comprehensive overview of the SHS presented in this paper will help designers, researchers, funding agencies, and policymakers have a bird's-eye view of the overall concept, attributes, technological aspects, and features of modern SHSs.

1. Introduction

In recent years, the term smart has become synonymous with any technology that boasts some level of artificial intelligence. The ability to gather information from its surroundings and react accordingly is the essential characteristic of smart technology [1]. With the main objective set as to the welfare of humanity, smart technology has become the main driving force for pioneering ideas such as the smart home system (SHS). Due to the development of smart products and services, the world has witnessed the rise of device interconnectivity and information sharing, which has influenced the rapid development of smart home technology globally [2]. Fueled by the advantages provided by smart technology and a possible large global market, interest in smart home technology has skyrocketed among researchers.

In the field of home automation and management, the smart home has become a very promising sector. The term "smart home" is not strictly limited to human abodes. It rather has a wider range of technological implications which include smart or intelligent habitation/living [3]. The inclusion of computer-regulated technology such as smart cities, smart manufacturing, and smart societies broadens the notion of the smart home beyond the human residence.

Smart home systems (SHSs) comprise a division of ecumenical computing that encompasses integrating smart technology into homes to achieve comfort, safety, security, healthcare, convenience, and energy conservation [4–6]. By offering automated and remote home appliance control and services, smart homes provide a higher quality of life. One of the main services provided by SHSs is a remote monitoring system that uses telecommunication and the Internet to offer remote home control and elderly care. An SHS user can control home appliances remotely from anywhere and can perform tasks before arriving home. Smart sensors can monitor home temperature and humidity and maintain an optimal atmosphere as per the user's preference. With the help of a smart object detection system, enhanced security systems for smart homes can provide better safety.

The rapid growth of automation technology has led it to domestic service, which introduced the term "smart home." Due to the high demand and success in the market, constant upgrading in this sector is noticeable. To get a better understanding of the ongoing demand as well as the future of this industry, predictions and analyses carried out by the World Economic Forum (WEF) suggest that the value of this industry will likely hit 13 trillion USD within 2030 [7]. According to Statista, for the year of 2021, the smart home market was likely to hit 99.41 billion USD globally [8]. All the predictions and studies target the greater growth of smart home technology. As it grows, expectations are likely to be increased as well. The smart home was considered a convenience product at the preliminary stage, but as the technology grew, it turned out to be a solution of efficiency, preference, and security as well. Studies have shown that smart homes can reduce the total electricity cost, which can greatly affect efficiency [9, 10]. Even though a single unit of a smart home saves very little using this technology, collectively, the impact is greater than what it was before. Smart homes can also play a great role in the security system of the house, which is another field with great potential. A security system can utilize various sensors within the smart home to ensure a safer environment [11, 12]. The smart home can also play a great role in the ambient luxury of the home, which is its biggest market. However, if implemented correctly, smart home technology can be properly utilized for the handicapped, elders, and patients as well [13]. Application-specific systems such as motion and image recognition systems can provide an assistive technology that can be utilized by patients with limitations due to age or certain conditions [14]. Virtual reality systems are also coming into play in similar cases as well [15].

A revolution in technological development caused a mass advancement in the Internet, information, and communication technology, which led to the development of better quality SHSs at a relatively lower cost. Interest in SHS research is at its all-time highest. Research interest in SHSs has been high throughout the last decade. However, there is a lack of collective information assortment and demonstration of the previous works related to this field for future research reference. Several recent review papers [16–18] provided short descriptions of the recent advancements in the field of SHSs and presented the advantages and disadvantages of the solutions discussed by researchers. However, these works failed to provide a categorical analysis of the different approaches followed by researchers or microprocessors and sensors used in the development of recent SHSs or services provided by SHSs. For these reasons, it has become necessary to review SHSs based on technological approaches, microprocessors, sensors, networking methods, computational techniques, and services. In this review, an overview of the current works on technological development in smart homes, based on the aforementioned subjects, is presented. This paper also analyses the data obtained from the works of several researchers to provide an accurate description of the specific areas and methods followed by scholars in SHSs. This work fills up the gap left by the previous reviews as mentioned previously by illustrating as follows:

(i) Various technological approaches used by different SHSs and their suitability

(ii) Microprocessors and microcontrollers used in the development of SHSs

(iii) The various types of sensors used in the development of SHSs

(iv) A comprehensive review and classification of SHSs based on numerous characteristics such as networking technologies, computational approaches, user interfaces, and services provided

(v) A thorough analysis of the data collected from the literature

The main aim of this review is to provide a collection of the most recent research advancements made in the field of SHSs. This extensive review will help researchers, engineers, designers, and other people involved in the development of SHSs offering a systematic and comprehensive evaluation of SHSs, along with a general idea of recent trends.

Figure 1 presents the overall structure of this paper. An introduction and motivation for this paper are presented in Section 1. The process through which the research materials are selected is described in Section 2. This process is divided into 3 segments: planning, review, and result. Section 3 presents a literature review of a few selected research articles. Sections 4–6 describe the technological approaches, microcontrollers, and sensors used in the development of SHSs by various researchers. Later sections analyze the networking technologies, user interfaces, computational methods, and services provided in SHSs. A comprehensive analysis based on the reviewed factors in the previous sections is provided in the discussion section. Finally, concluding observations have been provided in the conclusion section.

2. Methodology

The process of assessing and elucidating all available research pertinent to a certain topic, question, subject matter, or occurrence in a particularly faultless way is termed "systematic literature review" (SLR). The objective of such a review is to present an impartial evaluation of a research topic with the help of a reliable, rigorous, and inspectable methodology [19]. The SLR provides future researchers with a short and informative guide of the previous works carried out by other researchers on a particular field or topic. Fundamentally, there are two common reasons for performing an SLR:

(i) Summarization and evaluation of the most recent developments available for a specific technology or research

(ii) Creating a path for potential future research on a topic by identifying gaps in the present literature

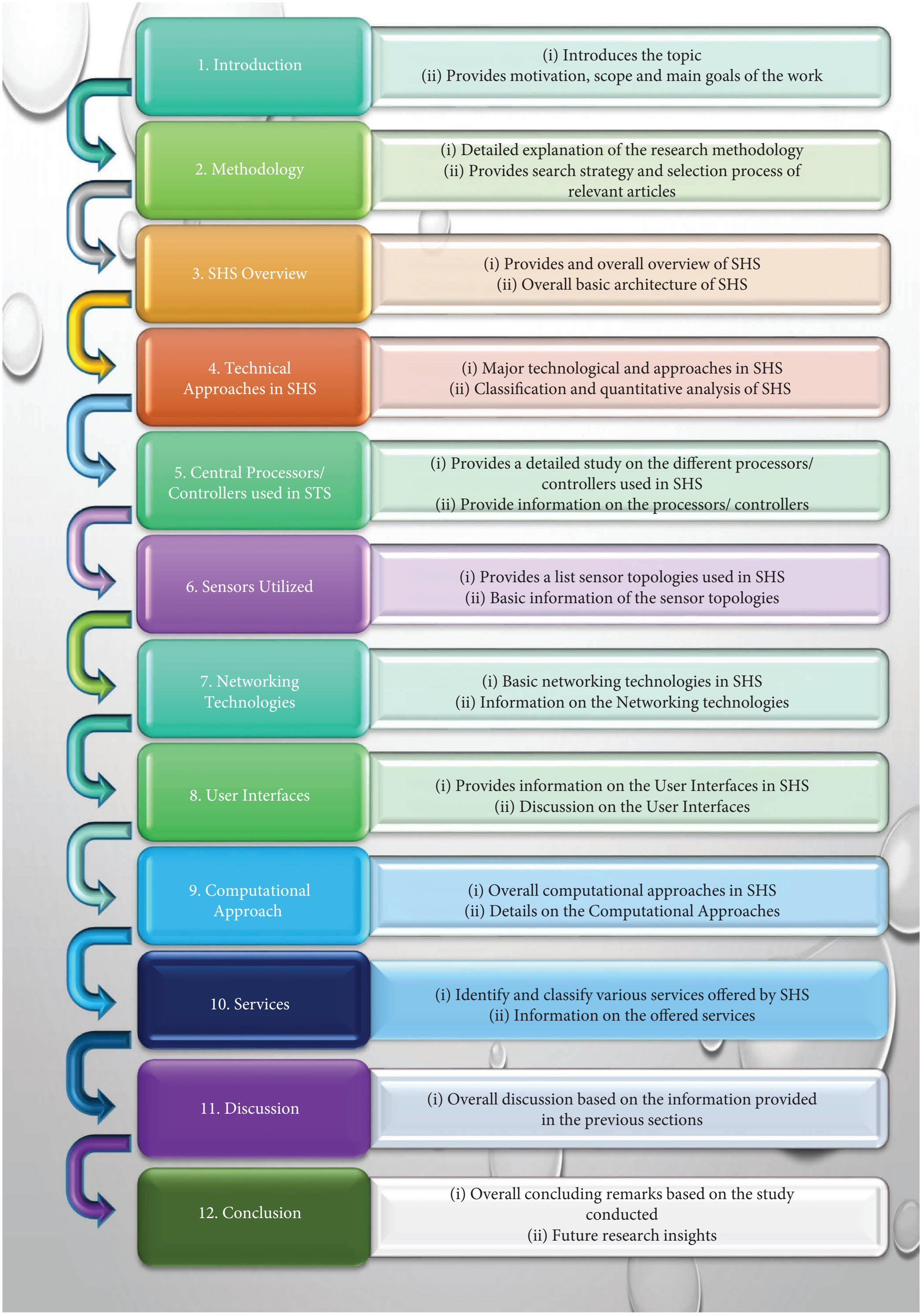

Figure 1: Structure of this paper.

This segment describes the methodologies implemented in this research work to review the currently available works and build up a panoramic analysis of the SHS concept. This review evaluated and synthesized the existing works on SHSs based on various aspects such as communication mediums, energy management, sensors, and comfort. To procure information from current publications on SHSs, reputed publishers such as IEEE Xplore, SpringerLink, ACM Digital Library, ScienceDirect, and MDPI were utilized. The research procedure portrayed in [20] was adopted for this work, which categorized the reviewing procedure of this paper into three major stages. The stages are termed the planning stage, the review stage, and the result stage.

A guideline to search for different reviews of the literature and materials is defined in the planning stage. The review stage concentrates on strict instructions for developing keywords and search strings to find precise data to review from various sources. Collection of preliminary results, extraction of relevant research materials, and categorization of the candidate papers are also carried out in this stage. Finally, a comprehensive evaluation of the chosen materials is conducted in the result stage.

The overall process of the search and selection of the research paper are illustrated in Figure 2.

2.1. Planning Stage. Identification of the objectives of the study and development of the review protocols comprised the planning stage of the review. After a preliminary search of the available research material, the necessity for further study of the smart home system was identified. Following the establishment of the field of study, specific protocols were developed for the study, which included the search criteria, database selection, inclusion and exclusion criteria, and the process of searching.

2.1.1. Formulation of the Research Questions. At an early point of the planning stage, a list of questions that specify the key objectives of the research is created. The Goal-Question-Metrics approach proposed by Van Solingen [21] was used to construct the most relevant research questions for this study. Following this approach, four main coordinates were obtained as follows:

(i) Purpose: investigate, evaluate, and assess
(ii) Issue: complete analysis of the smart home system
(iii) Object: smart home system
(iv) Viewpoint: a researcher's point of view

Based on these points, four major research questions were formulated as follows:

(i) What are the tactics or methods for constructing a smart home system?
(ii) What types of sensors were utilized in the development of the smart home system?
(iii) What kinds of communication protocols and networking tools were implemented?
(iv) What types of security measures were considered for smart home systems?

The main objective of this research work is to review the existing research work on smart home systems and discover the approaches adapted, the hardware and networking technologies utilized, and the security systems considered. The four previously mentioned questions are linked to these objectives. Apart from that, the formulated research questions were also used to detect keywords such as "smart," "home," "system," "solution," "sensors," "communication," "networking," and "security." Based on these keywords, initial search strings were established to detect the literary works.

2.2. Search and Review Stage. The second stage consists of a systematic search in preselected databases, which are shown in Table 1, based on search terms found in the planning stage and filtering through the search results for the most relevant research papers.

The most important term here is "smart home," and all the keywords are selected based on it. As the goal is to cover the entire zone of the smart home system, the technologies utilized inside the house and beyond, and the overall features and comfort provided by the system, the application of the term "smart home" is validated.

The keywords formulated in the planning stage were used as the primary search string, and several types of literature reviews were obtained from the search. To keep the review most up-to-date, only the papers published in the last ten years were analyzed, where priority was given to the papers from the last six years.

Following the primary search, papers were inspected and sorted manually by reviewing the title, abstract, and conclusion. In this manual sorting, if a paper is found to include keywords and could provide necessary details to satisfy the inclusion criteria for this review, it was selected. For this purpose, a set of inclusion and exclusion criteria were created. The inclusion criteria for review materials are provided as follows:

(i) The article's keywords must match at least some of the search terms defined.
(ii) Simple and understandable English is used to write the paper.
(iii) Articles/papers that concentrated on the activity recognition of inhabitants, monitoring, and gathering information about the user experience and comfort.
(iv) The article must be published within the last six years.

The exclusion criteria were as follows:

(i) Potentially duplicate reports on the same research
(ii) Papers that are not published in the English language

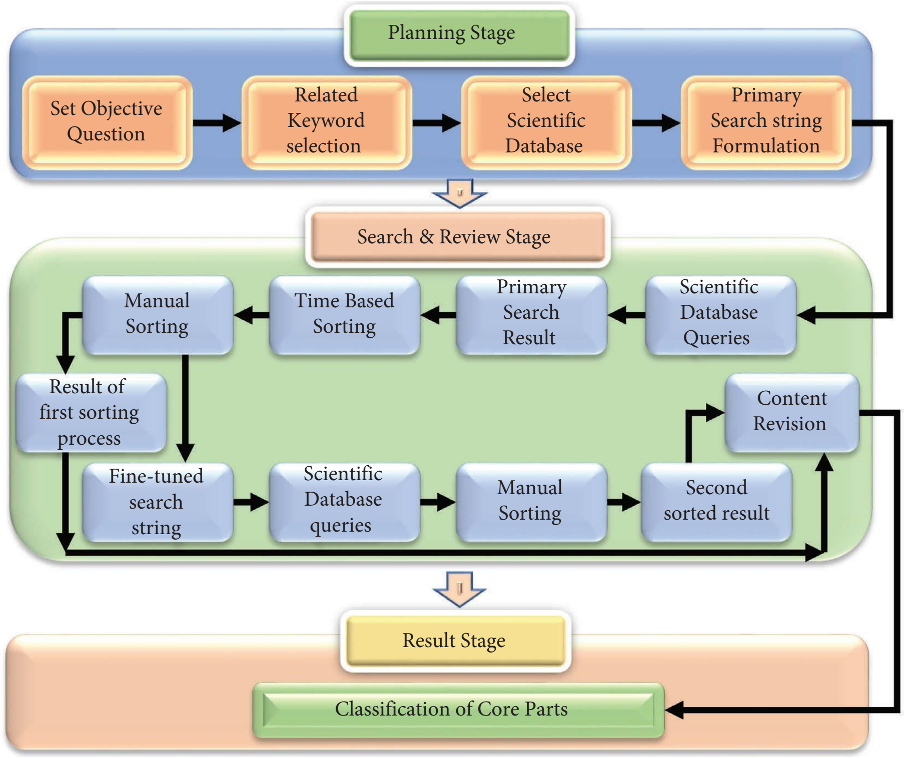

Figure 2: Research method in detail.

Table 1: List of electronic databases used for searching articles.

No.	Electronic databases
1	IEEE Xplore
2	SpringerLink
3	ScienceDirect
4	ACM Digital Library
5	MDPI
6	Hindawi

(iii) The research focused on smart grid-connected smart homes, smart cities, and outdoor intelligence services

(iv) Specifically, tailored studies on certain smart home appliances such as smart refrigerators, smart mirrors, and robots

(v) Not related to the research question

After filtering the papers through these criteria, for more accurate and definite results, the primary search string was modified with additional keywords such as “smart sensors,” “risk,” “threat,” “elderly,” “AI,” “IoT,” and “wireless.” Using this modified search string, the electronic databases were searched again, and the resultant papers were again manually inspected. Finally, all the selected research materials were meticulously revised for the result stage. Figure 3 represents the article selection process from different databases through multiple searches.

2.3. Result Stage. In the last phase of the review process, an analytical report is presented, which includes the year of studies, the research process, the region of technology considered, and publishing organizations. The findings were utilized to establish the fundamental segments of this review and reveal the technological developments in the smart home system throughout the years.

A total of 111 research papers were selected (excluding review papers) after the methodological process of sorting them. Based on the selected articles and the information provided, five important graphical portrayals can be achieved. Figure 4 depicts the year-wise amount of the literature published from 2012–2021, based on the selected papers. This representation shows that the highest number of papers was published during the 2018–2020 period.

Figure 5 depicts the publisher-wise number of the literature collected. Five different electronic databases have been used for collecting papers. The highest number of papers was collected from IEEE Xplore totaling 47 papers, 9 from ScienceDirect, 19 from MDPI, 16 from SpringerLink, 10 from ACM Digital Library, and 10 from Hindawi.

Figure 6 represents the types of research material published by the authors. It can be seen that the majority of the authors (66) tended to create experimental design-based articles. The other types include 45 theoretical or conceptual works, 16 reviews, and 3 case studies. It should be noted that the review articles and case studies were not used as review materials for this article; instead, they were used for academic references.

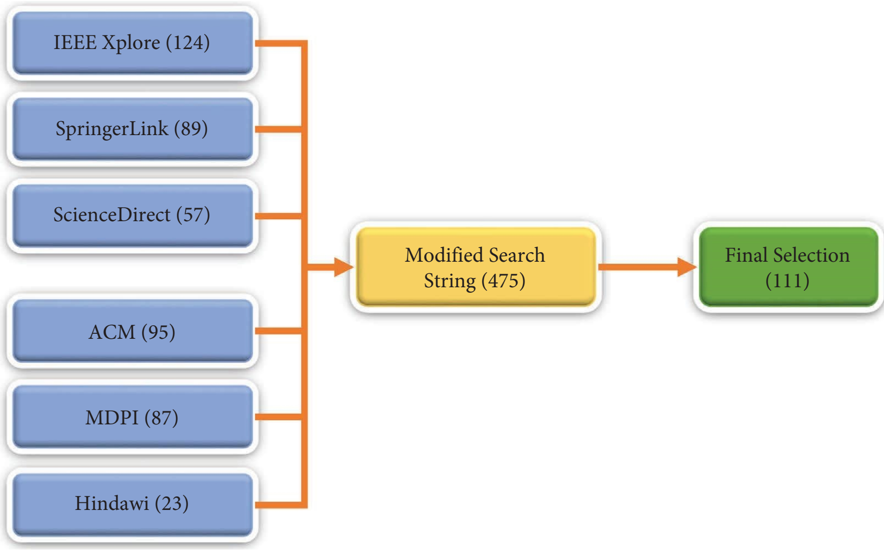

Figure 3: Paper selection process from different databases.

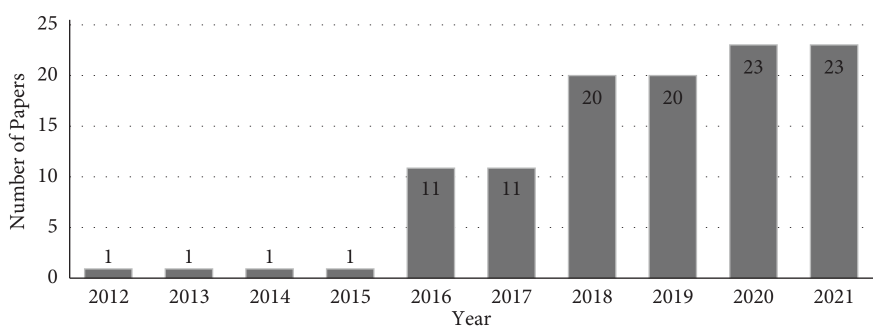

Figure 4: Year-wise frequency of literature publication.

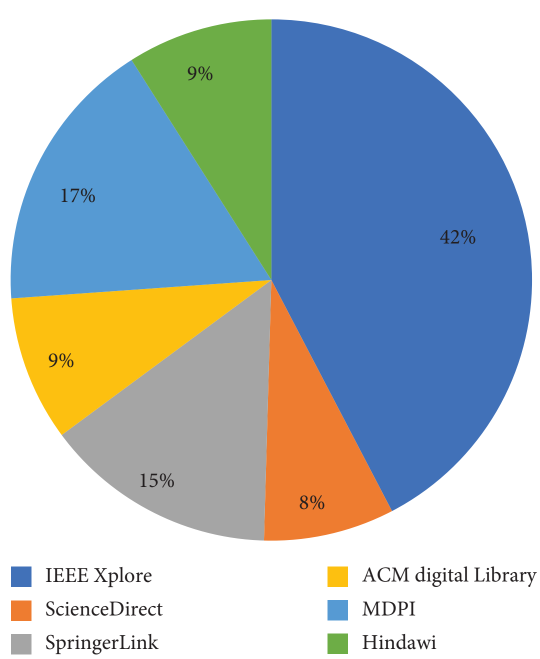

Figure 5: Publisher-wise percentage of the papers reviewed in this work.

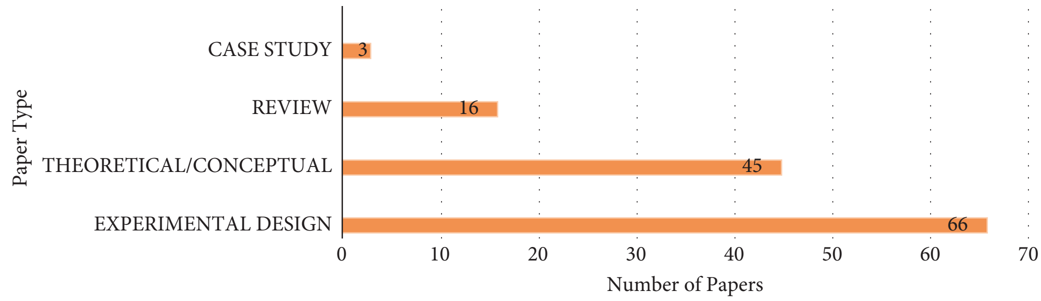

Figure 6: Types of research covered by the literature in the reviewed articles.

3. Smart Home System

In the last decade, the SHS has achieved unprecedented success, and researchers are continuously working to improve on its past works. With the help of IoT, it is now easier than ever to establish communication between home appliances and users. An IoT-based SHS has become the most popular choice in recent years. By connecting all of the devices through the Internet, it is now possible to maintain all of the home equipment simultaneously. Users can now monitor and control several aspects of their house from anywhere in the world with the help of IoT-enabled devices. Through machine learning and artificial intelligence, smart homes can now recognize shapes, sounds, and gestures, thus making the smart home experience much more comfortable. The availability of powerful processors facilitates the implementation of much more complex and processor-hungry smart home systems. To provide such services, all smart home systems are built following a basic structure as provided in Figure 7. It involves three phases as follows:

(i) Collection of information through sensors, cameras, microphones, and other home appliances
(ii) Storing and processing the collected information with the help of the main processing unit
(iii) Generating results and delivering services depending on the processed information

In the first step, the SHS uses sensors such as motion, temperature, humidity, flame, gas, and LDR for collecting atmospheric data alongside other devices such as a camera and microphone for recording video and audio of home occupants. Aside from these, the system can also use home devices connected through IoT to collect information about their status.

After collecting the information, it is sent to the main processing unit either wired or wirelessly. The processor stores and analyzes the data and determines the next action based on this information. For example, home temperature and humidity are compared against a predetermined value, and if the current value exceeds or vice versa, then a notification is sent to the owner for further action. Similarly, any intrusion detected on the camera is immediately reported.

In the final step, the information collected and processed is used to provide various services such as home comfort, intrusion alert, elderly care, and appliance control. Users can control room temperature remotely and have the home heated or cooled down before arriving. Similarly, by using flame and gas sensors, any fire breakout or gas leakage can instantly be found, and necessary steps can be taken. With the help of machine learning, voice commands can be carried out and gestures can be used to control appliances, and with the help of artificial intelligence, camera feeds can be used to differentiate between an intruder and home occupants.

4. Technological Approaches to SHS

After thoroughly reading and analyzing the research articles selected for this review, a variety of technological approaches to SHSs have been detected. A thorough analysis and evaluation of these technological approaches utilized by the SHS have been presented in this section.

4.1. Wireless Sensor Network (WSN)-Based SHS. Wireless sensor network (WSN) can be defined as a network of spatially scattered sensors that are wirelessly connected and dedicated to observing various environmental characteristics such as temperature, sound, humidity, force, and pressure. Apart from environmental aspects, other sensors detect movement, smoke, gas, flame, and various other things. All these sensors are part of a WSN that collects the data from all these sensors wirelessly and then sends the data to processing. In [22], a WSN of smoke, gas, and temperature sensors is proposed to detect and alarm early fire detection in a smart home. A WSN system for elderly people's care is proposed in [23]. The sink node is connected to the sensors in a WSN system via a wireless connection [24–26]. A wireless sensor network has been used in [27] along with Raspberry Pi to design and implement a smart home environment monitoring structure.

Due to its flexibility, low cost, and scalable structure, the WSN has gained exceptional popularity among SHS developers. Many of the research articles reviewed in this paper utilize the WSN system.

4.2. Multiagent System-Based SHS. A multiagent system (MAS) is a problem-solving approach based on self-organizing computing that utilizes multiple intelligent methods to solve problems that are otherwise difficult to solve for a single system [28, 29]. Due to the effectiveness of the system, researchers have applied MAS in the

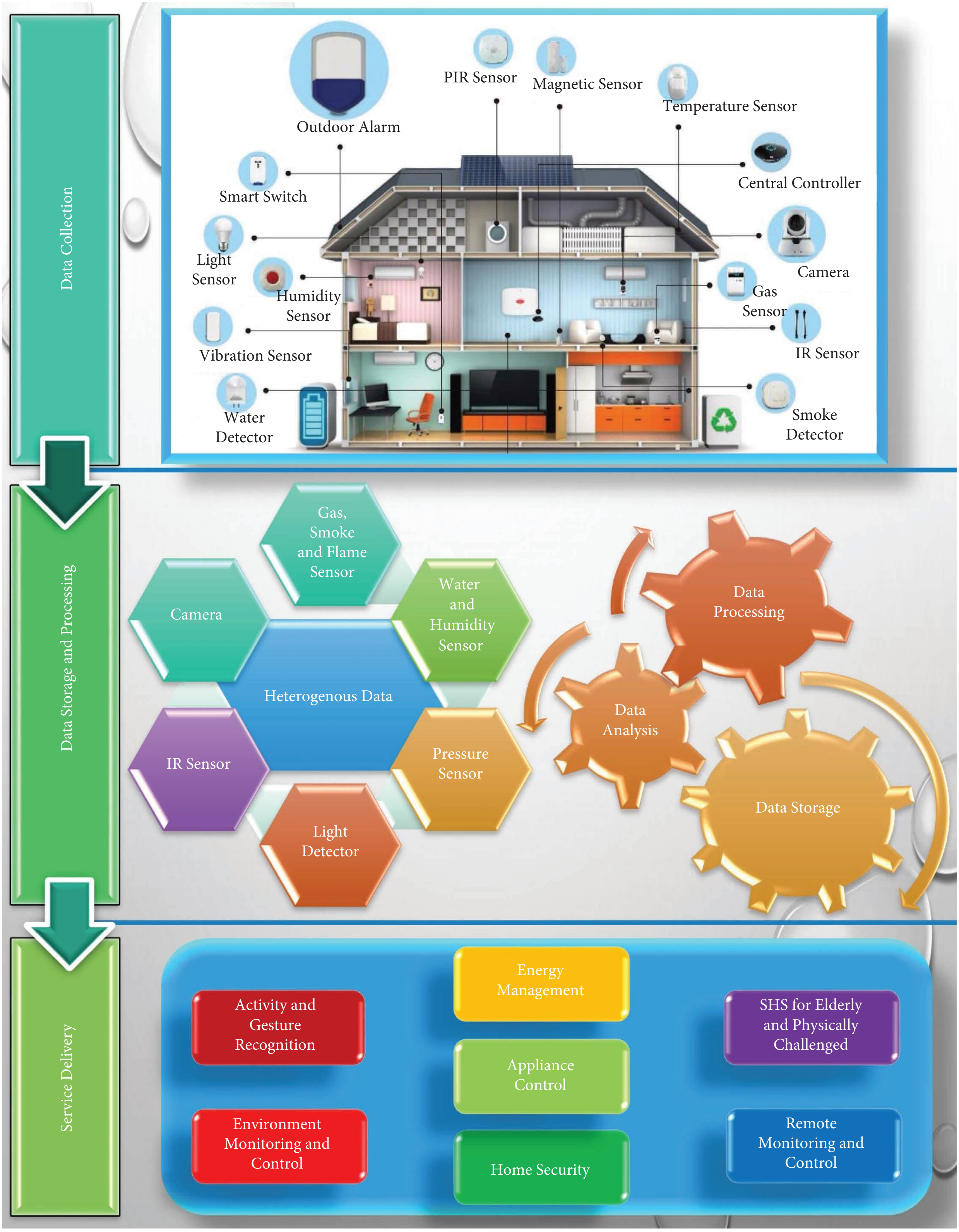

FIGURE 7: Smart home system.

development of SHSs. An MAS reduces the total computational and data transmission time of the total system which results in reduced energy consumption.

4.3. Image Processing (IP)-Based SHS. Image processing in SHSs deals with the analysis of data collected from single or multiple cameras to obtain various services such as gesture control of smart homes [30], smart home security systems based on object detection [31], gesture controlling features for elderly people [32], and smart home antitheft systems [29]. Since these image processing systems are dependent on real-time videos and images from the smart home, image processing-based SHSs generally have a high rate of data transmission between the camera and the data processing section. Image processing has been utilized by several authors because of its wide range of functions, from antitheft systems to elderly support. However, since cameras are affected by shadows, distortions, insufficient light, and other factors, the image processing system sometimes fails to deliver the expected result.

4.4. Internet of Things (IoT)-Based SHS. The Internet of things (IoT) is an arrangement of interconnected computing devices, mechanical and digital machines, sensors, microcontrollers, and other electronic devices that are uniquely identifiable, and these unique devices can communicate through the Internet with one another without requiring human or computer interaction. IoT is a relatively new technology and has gained excessive popularity among researchers [16, 33]. IoT has been used to design and implement smart homes in [34]. In [28, 29], the authors utilized IoT to design a security system for SHSs. An energy management system based on IoT is proposed in [35]. An IoT-based smart home energy management system has been explored in [36] alongside the usage of sensors to monitor the occupants of the smart home. IoT is used in [37] to detect the early stages of dementia with the help of machine learning. IoT has become one of the key technologies in the development of SHSs. In an IoT-based SHS, the main controller, sensors, and computational devices are all internally connected through the Internet. All these devices can receive and transfer data automatically without any human intervention. In an IoT system, the connection between nodes (sensor node, computational node, etc.) can be established wired or wirelessly.

4.5. Artificial Intelligence (AI)-Based SHS. Artificial intelligence (AI) is defined as a computing system that is capable of performing tasks that generally demand human intelligence, such as visual object detection, speech recognition, and decision-making [38]. AI has been used by researchers frequently due to its wide range of functions. In [39], the authors developed a smart home system for emotion detection based on AI. An AI-based image processing system has been developed for an antitheft system in [29]. An IoT elderly care system based on AI is proposed in [40]. Artificial Intelligence is paving the way for more intelligent SHSs. Furthermore, developments in this field can result in more resilient, interactive, and comfortable smart homes [41].

4.6. Machine Learning (ML)-Based SHS. Machine learning is a subsection of artificial intelligence that deals with learning patterns from given data by a machine to make sense of previously unfamiliar data [42]. It also deals with the processing of a large amount of data to recognize images, patterns, and speech. In a machine learning-based SHS, the data collected from the smart home are analyzed and used to predict the status and control of the home equipment [43]. Machine learning is used in [37] to detect the early signs of dementia among elderly people. Machine learning-based systems can also monitor the security systems of smart homes [44].

4.7. Deep Learning (DL)-Based SHS. Deep learning is a segment of a wider group of machine learning techniques that are based on artificial intelligence. It imitates the human brain with data processing and feature extraction and decision-making [45, 46]. As proposed in [28], deep learning can help with smart home automation and energy reduction. An object detection system for SHSs with the help of image processing was developed in [47]. Deep learning has also been used for healthcare purposes along with IoT [48].

4.8. Neural Network (NN)-Based SHS. A neural network tries to copy human brain function through a set of algorithms and extracts traits and fundamental relationships from the collection of data [49]. A neural network is used in SHSs for smart decision-making such as information extraction, image and speech recognition, and text detection [25].

4.9. Fuzzy Logic-Based SHS. Fuzzy logic is a multivalued logic-based reasoning method that computes data based on "degrees of truth," which is quite different from Boolean logic (0 or 1) used by modern computers. Fuzzy logic does not have any absolute truth or absolute false value [50]. A smart home for dementia care based on fuzzy logic is proposed in [51].

4.10. Global System for Mobile (GSM)-Based SHS. GSM is a standard for second-generation (2 G) digital mobile networks. The short message service (SMS) is a very popular feature of the GSM mobile network. GSM-based SHSs use this SMS feature to send a warning message to the user's phone about various dangers, including smoke, fire, and theft [22, 52]. Also, smart home appliances could be monitored and controlled by sending an SMS from the user's phone as described in [53].

4.11. Bluetooth-Based SHS. Bluetooth is a short-range, wireless communication method that allows data transfer between electronic devices such as mobile phones, computers, and peripherals over a short distance. A smart home-controlled system based on Bluetooth can control home appliances through an app installed on a user's phone [54–56]. A smart home system for blind people based on IoT and Bluetooth communication is proposed in [57].

4.12. Classification of Reviewed SHSs According to Technological Approaches. A summary of the different approaches taken by the authors in their research to develop SHSs is provided in Table 2.

5. Central Processors/Controllers Used in SHS

A processor or controller can be described as a miniature computer on a single metal oxide semiconductor-integrated circuit chip that is designed to carry out a specific operation. A microcontroller usually consists of one or more central processing units (CPUs), storage or memory units, and input/output peripherals. In SHS development, microcontrollers are used for a wide range of operations, such as controlling sensors, computing data, executing commands, and storing information. All the microcontrollers used in the development of SHSs are evaluated, and an overall summary is presented in this section.

5.1. Arduino. Arduino refers to a family of open-source microcontrollers that are famous for their low price, flexibility, and easy-to-use interface. Basically, two Arduino boards are used in SHS-Arduino Uno, which is based on an ATmega328P microchip, and Arduino Mega, which uses an ATmega2560 microchip. Arduino microcontrollers are well equipped to control multiple sensors and devices as demonstrated in [52, 65]. Due to their low power consumption, Arduino boards are very popular among SHS developers [24]. Arduino Mega has more input ports than Arduino Uno and is capable of handling more input data because of its better microchip [84]. Energy management systems for SHSs can also be designed and implanted based on Arduino microcontrollers [35]. All in all, Arduino boards have become a cornerstone in the development of SHSs.

5.2. Raspberry Pi. In simple terms, Raspberry Pi is a small computer that can receive, store, and compute data and can control and monitor electronic components such as sensors and cameras. It is famous for its low cost, modularity, and open design. Raspberry Pi can be used for face detection and image processing [66, 67]. It is fully capable of accessing the Internet and controlling home equipment through IoT [69, 85] and functions as a virtual assistant [62]. An AI-based voice recognition system for remote home appliance control for elderly people has been implanted in [79], which uses Raspberry Pi as its computing device. Raspberry Pi can also receive commands from the user via GSM or the Internet and use them to control home appliances [53]. A low-costvoice-activated SHS, which can be incorporated with many essential subsystems and can be personalized to individual needs, is designed in [86]. The system uses a dual-mode of interaction where the user has the option to control the appliance from a graphical user interface (GUI)-based app or a chat system, where text or audio commands are used to control the system. Due to its small form factor and high computational power, Raspberry Pi has gained a lot of popularity in the field of SHSs.

5.3. ESP32/ESP8266. ESP32 and ESP8266 are both members of the ESP family, which is a series of cheap and energy-efficient microcontrollers with integrated Wi-Fi and Bluetooth. Cost-effective, convenient, and comfortable smart home automation system development is facilitated with the help of ESP microcontrollers [88]. ESP32 is latest in the series and is more powerful than the previous version of ESP8266. ESP microcontrollers have gained popularity mainly because of the integrated Wi-Fi feature, which helps make an IoT system [89]. Despite being an old version, ESP8266 is still used due to its high efficiency and multiple electronic component handling capabilities [26, 136]. A cost-effective smart home automation system (SHAS) with ESP8266 in [90] showed that it is easier for the user to connect a new device to the system without worrying about configuration. In [91], the ESP8266 board is used alongside an ATmega16 microcontroller to design and develop an IoT-based SHAS where the system can wirelessly control multiple loads and monitor vital environmental data such as temperature and humidity. An ESP32-based smart home monitoring and controlling system that utilizes external LoRa connectivity is proposed in [70], which demonstrates the versatility of the microcontroller.

5.4. FPGA. Field-programmable gate array (FPGA) is a type of integrated circuit (IC) board that can be programmed by the user after being manufactured and hence the name 'field programmable.' FPGAs are built around a matrix of configurable logic blocks that are connected through programmable interconnects. Smart home systems based on FPGA boards have been gaining ground among the research community due to their flexibility and the ability of logic level programming which gives FPGA boards faster processing speed [77]. Due to their easily changeable functionality, FPGA boards could be programmed to perform various tasks such as controlling sensors and security monitoring [92].

5.5. PIC Microcontroller. Programmable peripheral interfaces (PICs) are a series of programmable microcontrollers that can be used to perform a wide range of operations. PICs are very energy-efficient, cheap, and fast. In smart home systems, PICs are used for a variety of tasks including controlling appliances [80], setting up a smart elderly care system [23], and monitoring home security [81]. PIC microcontrollers are used more frequently in SHSs because they are very reliable and less prone to be faulty.

5.6. LPC. LPC is a series of ARM core-based32-bit microcontrollers. These microcontrollers are superfast, very reliable, and cheap. Smart homes based on LPC microcontrollers are as capable as any other microcontrollers. These microcontrollers are suitable for multiple purposes including home automation [68], appliance control, security [59], and IoT.

Table 2: Classification of SHSs according to technological approaches.

Reference	Technological approaches										
	WSN	Multiagent	Image processing	IoT	AI	Machine learning	Deep learning	Neural network	Fuzzy logic	GSM	Bluetooth
[22]	+			+						+	
[23]	+									+	
[24]	+			+							
[25]	+			+				+			
[26]	+			+							
[27]	+										
[28]		+					+				
[29]	+	+	+		+						+
[30]			+							+	
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[54]											+
[55]											+
[56]				+							
[57]				+						+	+
[60]			+	+		+					
[61]				+							
[62]			+								
[63]				+							
[64]						+					
[65]				+							
[66]			+	+							
[67]			+	+							
[68]				+						+	+
[69]				+							
[70]	+			+							
[71]				+							
[72]				+							

Table 2: Continued.

Reference	Technological approaches										
	WSN	Multiagent	Image processing	IoT	AI	Machine learning	Deep learning	Neural network	Fuzzy logic	GSM	Bluetooth
[73]					+						
[74]					+		+				
[75]			+	+		+		+			
[76]						+	+				
[77]				+						+	+
[78]				+						+	+
[79]			+	+							+
[80]											+
[81]				+							+
[82]				+							+
[83]				+		+					
[84]				+							
[85]				+							
[86]					+						
[87]			+			+	+	+			
[88]				+							
[89]	+			+							
[90]				+							
[91]				+							
[92]										+	
[93]			+	+						+	
[94]	+			+							
[95]										+	
[53]			+							+	
[96]				+							
[97]	+			+						+	
[98]				+							
[99]				+							
[100]	+			+							
[101]				+							
[102]				+							
[103]				+							
[104]										+	
[105]						+				+	
[106]	+			+							
[13]						+					
[107]			+								
[108]			+		+			+			
[109]				+							
[110]				+							
[111]			+								+
[112]				+							

Table 2: Continued.

Reference	Technological approaches										
	WSN	Multiagent	Image processing	IoT	AI	Machine learning	Deep learning	Neural network	Fuzzy logic	GSM	Bluetooth
[113]				+							
[114]				+							
[115]	+										
[116]	+			+							
[117]				+							
[118]				+		+					
[119]			+					+			
[120]	+			+		+					
[121]	+			+							+
[122]				+							
[123]				+							
[124]				+							
[125]				+							
[126]			+			+					
[127]						+	+				
[128]			+	+		+					
[129]				+							
[130]				+							
[131]				+							
[132]				+		+					
[133]				+							
[134]				+							
[135]							+				
[136]				+						+	
[137]			+	+							
[138]			+	+		+					
[139]				+							
Total	19	2	24	78	8	18	8	6	1	17	14

5.7. Other Microcontrollers. Apart from the popular microcontrollers mentioned so far, there are a few more that a handful of researchers have used in their work. S5PV210 is a 16/32-bit, programmable, and high-performance minicomputer that has been used to design an IoT-based SHS [93]. It uses a Samsung S5PV210 application processor that gives it unparalleled performance but makes it too expensive. AT89C2051 is an 8-bit, high-performance, energy-efficient, and programmable microcomputer that can process a wide variety of operations. It can control multiple electronic appliances and send data with the help of additional networking devices [54]. With the help of its powerful 32-bit ARM processor, LM3S8962 is fully capable of SHS automation and control as demonstrated in [94]. In [82], the Xiaomi Mi smart home device is used to control sensors and appliances. Finally, STM32F103C8T6 is another microcontroller that has been used in the development of SHSs [95].

5.8. Classification of Reviewed SHSs According to Microcontrollers and Microprocessors. A summary of the various types of microcontrollers used by the authors for developing SHSs is provided in Table 3.

6. Sensors Utilized

Sensors play a significant role in the development of SHSs. The application of multiple types of sensors was identified in the literature review stage conducted previously. The following section presents the details of the sensors used to design, develop, and implement SHSs.

6.1. Infrared (IR) Sensor. Theoretically, all the objects and life forms that have a minimum amount of temperature emit IR radiation. An IR sensor is an electronic device that is capable of detecting and measuring the IR radiation in its surrounding environment. The main reason for using IR sensors is motion detection and temperature measurement. There are two types of IR sensors available: active infrared sensors and passive infrared (PIR) sensors. Among these two, PIR is the most frequently used IR sensor.

A PIR sensor detects the change in electromagnetic radiation levels in its surrounding environment. It does not actively emit IR radiation like an active IR sensor. The main application of PIR is motion detection. When an object comes in the range of a PIR sensor, it measures the difference in IR levels and detects the object. In SHSs, PIR is used for intruder alert [31, 78, 92], detecting the occupant activity in an SHS [24, 35, 103], and creating an elderly healthcare system [51, 79]. However, PIR sensors are usually used inside of a house because they are affected by environmental changes such as snow and rain.

6.2. Temperature Sensor. A temperature sensor by sensing the temperature of its surrounding environment can ensure comfortable living. Multiple types of temperature sensors have been used in the development of SHSs, and the most popular is LM35 [77]. Temperature sensors are used for measuring room temperatures based on which other appliances are controlled such as fans, air conditioners, and heaters [25, 70].

6.3. Humidity Sensor. Humidity sensors detect and measure the change in the amount of water vapor or moisture in the air surrounding them. The most popular humidity sensor used by SHS researchers is DHT11, which can measure temperature as well. In SHSs, a humidity sensor is generally used for monitoring room moisture levels [26, 78], home automation [75], and early warning systems [52].

6.4. Gas Sensor. Gas sensors detect the presence of certain gases in the air in their range. They are used for detecting harmful or dangerous gases such as LPG, propane, methane, carbon monoxide, I-butane, and alcohol and are particularly important in the development of SHSs because they give a warning about harmful gases in the house [24, 34, 57, 93].

6.5. Smoke Sensor. A smoke sensor is an electronic device that detects smoke in its vicinity and triggers an alarm. Smoke sensors are used as a precautionary measure of an early fire warning system. In SHSs, a smoke sensor is generally programmed to trigger an alarm or send a warning signal to the home occupants via a GSM message or app [22, 95, 104, 105].

6.6. Ultrasonic Sensor. An ultrasonic sensor emits and receives ultrasonic sound waves and measures the distance of a certain object by emitting sound waves and receiving the reflected sound wave from that object which the sensor transforms into an electronic signal. In SHSs, an ultrasonic sensor is used for implementing an automatic door system [78], water level monitoring [104], and basic smart home automation [24].

6.7. Flame Sensor. A flame sensor is an electronic device designed to detect the presence of fire in its operating range and respond by triggering an alarm or other warning mechanism. Any security-centric smart home system usually employs flame sensors for early detection and warning of flame in the house [65, 70, 97].

6.8. Light Detection Sensor. A light detection sensor is used to measure the intensity of light in an area. It is a photoelectric device that is capable of converting light energy surrounding it into electrical energy. There are a few types of light detection sensors in use, such as photoresistors, photodiodes, and phototransistors. In SHSs, these sensors are used for automating the lighting system of the house [34, 81]. In one particular system, a light detection sensor is used to inform the blind occupant of the house whether it is day or night [57].

Table 3: Classification of SHSs according to microcontroller and microprocessor usage.

Reference	Microcontrollers and microprocessors						
	Arduino	Raspberry Pi	ESP32/8266	FPGA	PIC	LPC	Others
[22]		+					
[23]					+		
[24]	+		+				
[25]		+					
[26]			+				
[27]		+					
[28]	+	+					
[29]		+					
[30]					+		
[31]	+	+					
[32]	+	+					
[34]	+		+				
[58]	+	+	+				
[59]						+	
[35]	+		+				
[37]							+
[39]							+
[40]							+
[43]	+		+				
[44]		+					
[47]	+	+	+				
[48]			+				+
[51]		+					
[52]	+						
[53]	+	+					
[54]							+
[55]	+						
[56]	+						
[57]	+						
[60]							+
[61]		+					
[62]		+					
[63]			+				
[64]		+					
[65]	+						
[66]		+					
[67]		+					
[68]						+	
[69]		+					
[70]			+				
[71]							+
[72]	+		+				
[73]							+
[74]							+
[75]		+					
[76]							+
[77]				+			
[78]	+						
[79]	+	+					
[80]					+		
[81]					+		
[82]							+
[83]							+
[84]	+		+				
[85]							+
[86]		+					
[87]							+
[88]			+				
[89]		+	+				

Table 3: Continued.

Reference	Microcontrollers and microprocessors						
	Arduino	Raspberry Pi	ESP32/8266	FPGA	PIC	LPC	Others
[90]							+
[91]			+				+
[92]	+			+			
[93]							+
[94]							+
[95]							+
[53]	+	+					
[96]	+	+					
[97]	+	+	+				
[98]	+		+				
[99]	+		+				
[100]	+		+				
[101]	+		+				
[102]		+					
[103]			+				
[104]	+						
[105]		+					
[106]							+
[13]		+					
[107]		+					
[108]	+						
[109]							+
[110]							+
[111]	+	+					
[112]		+					
[113]			+				
[114]	+						
[115]							+
[116]	+		+				
[117]							+
[118]							+
[119]							+
[120]		+					+
[121]							+
[122]		+					
[123]		+					
[124]							+
[125]							+
[126]					+		
[127]							+
[128]		+					
[129]							+
[130]							+
[131]	+						
[132]							+
[133]							+
[134]	+						
[135]							+
[136]		+	+				
[137]	+		+				
[138]							+
[139]							+
Total	35	36	25	2	5	2	38

6.9. Pressure Sensor. A pressure sensor is an electronic device that can measure the pressure of liquid or gas through a pressure-sensitive element. In an SHS, it could be used for multiple purposes such as room atmosphere monitoring [26], measuring the blood pressure of home occupants for health monitoring [23], or monitoring home activities [51, 82].

6.10. Accelerometer. An accelerometer is an electronic tool that measures acceleration forces accurately. In SHSs, accelerometers are used to detect the acceleration of a person who is static or dynamic [23], identify intrusion [68], and detect the mobility and condition of a patient in a smart home [13, 106].

6.11. Door Sensor. A door sensor is a device that detects a door opening or closing and notifies the user. A pair of electrical connectors detects the opening or closing by making or breaking an electrical circuit in the sensor. These sensors are being used increasingly in SHSs for detecting door opening and closing status in elderly care systems [23, 102] and overall home occupant activity monitoring.

6.12. Gyroscope. A gyroscope or angular velocity sensor is a device that can measure and maintain the orientation and angular velocity of an object. In SHSs, it is used for detecting the orientation of a person [23], along with an accelerometer, and in gesture control systems, it is used for detecting gestures [107, 108].

6.13. Pulse Sensor. A pulse sensor is a device that is capable of detecting and monitoring human heart rate continuously. In smart homes, it is mainly used for elderly health care [23, 78].

6.14. Fluid/Water Detection Sensor. A fluid detection sensor, sometimes known as a raindrop sensor, is an electronic device that can detect water via an extended pad that can sense water on its surface. It is usually used to detect water leakage and water level monitoring [65, 95, 100].

6.15. Camera. The application of a camera or a network of cameras is becoming more and more popular in SHS designs. SHS researchers have used the camera with various computational methods such as image processing, machine learning, gesture recognition, and artificial intelligence for enhancing smart home security and monitoring [29, 52, 109], object detection [47], gesture detection [60], and live feed monitoring [72]. Cameras provide a reliable method of setting up security for smart home users. The only drawback to using a camera is its cost of deployment and maintenance.

6.16. Force-Sensing Resistor. A force-sensing resistor (FSR) is an electronic device that is capable of measuring the amount of force, pressure, or mechanical stress applied to it. FSRs use a type of material that changes its resistance when force is applied to it. These are special types of sensors used in SHSs to detect the home occupant's activity [103] and set up special systems for elderly people's care [110].

6.17. Flex Sensor. A flex sensor is used to measure the amount of deflection or bending of certain objects. The sensor works by changing the resistance when bent. The flex sensor is usually used in gesture-controlled systems to detect gestures [32, 111].

6.18. Other Types of Sensors. Aside from the types of sensors mentioned previously, a few other types of sensors combining several other sensors, such as bed sensors [71], chair sensors, and posture sensors, have been demonstrated. These sensors cannot be categorized as a single type of sensor as they often have multiple other sensors such as motion, accelerometer, and gyroscope sensors inside them.

6.19. Classification of Reviewed SHSs According to Sensors. A summary of the various types of sensors used by the authors for developing SHSs is provided in Table 4.

7. Networking Technologies Used in SHS

It is necessary to have a networking setup between the sensor, processing unit, and user-end device, to process the data generated by sensors and other devices or to send the analyzed result of the data to end users. The data generated from sensors are useless if these data cannot reach the processing unit, and the processing unit cannot function properly without the necessary data. The result will be the user not getting the necessary warning or update about the SHS [140]. A network system creates a continuous channel between sensors, processors, and users. Generally, the network system can be divided into two separate networks: sensor-processor networks and processor-user networks. In this section, the networking systems are described.

7.1. Sensor-Processor Network. A network must be established between sensors and processors that are capable of continuous data transmission. This network could be set up wired or wirelessly, though most of the time a wired connection is preferred. In the case of wireless communication, there are a few networking standards that SHS systems can use, such as Wi-Fi, ZigBee [115], LoRa [70], and RF communication [34].

7.2. Processor-User Network. The data processed by the processing unit cannot be used by the user if there is no communication link or network between the processor and the user. The network between the processor and end-user can be used for house monitoring, appliance control, weather control, etc. This network is mostly created wirelessly and uses networking technologies such as Wi-Fi, LoRa, GSM [30], Bluetooth [54], LAN [89], and cellular networks.

8. User Interfaces Used in SHS

In SHSs, a user-end communication interface is set up for the user to receive important messages from the system and send commands. This interface could be a smartphone application or a website. This section presents a description of the interfaces used in SHSs.

Table 4: Classification of SHSs according to the sensors used.

Reference	Sensors used in SHSs																	
	PIR	Temperature	Humidity	Gas	Smoke	Ultrasonic	Flame	LDR	Pressure	Accelerometer	Door	Gyroscope	Pulse	Fluid detection	Camera	FSR	Flex	Others
[22]		+		+	+													
[23]		+							+	+		+	+					
[24]	+	+		+	+	+												
[25]	+	+	+															
[26]	+	+	+	+	+													
[27]		+	+					+										
[28]	+	+	+					+										
[29]															+			
[30]															+			
[31]	+														+			
[32]																	+	
[34]	+	+		+				+										
[58]	+	+	+				+	+						+				
[59]		+	+															
[35]	+							+										
[37]	+	+						+										
[39]		+	+					+										
[40]	+							+										
[43]		+						+										
[44]															+			
[47]															+			
[48]		+																+
[51]	+								+		+							
[52]		+	+	+											+			
[53]	+	+	+	+											+			+
[54]								+							+			
[55]		+						+										
[56]		+	+															
[57]	+	+		+				+										
[60]	+														+			
[61]	+							+										
[62]															+			
[63]										+		+					+	
[64]	+				+						+							
[65]	+	+	+				+							+				
[66]	+														+			
[67]	+														+			
[68]		+						+		+								
[69]		+	+					+										
[70]		+	+	+			+											
[71]	+										+							

TABLE 4: Continued.

Reference	Sensors used in SHSs																	
	PIR	Temperature	Humidity	Gas	Smoke	Ultrasonic	Flame	LDR	Pressure	Accelerometer	Door	Gyroscope	Pulse	Fluid detection	Camera	FSR	Flex	Others
[72]	+														+			
[73]																		+
[74]																		+
[75]		+	+	+														
[76]	+										+							+
[77]		+			+		+											
[78]	+	+	+			+							+					
[79]	+														+			
[81]								+										
[82]	+	+	+						+		+							
[83]	+	+																+
[84]	+	+	+															
[85]																+		
[86]																		+
[87]																+		
[88]	+	+																
[89]	+	+																
[90]																		+
[91]		+	+															
[92]	+	+																
[93]	+	+	+	+											+			
[94]		+	+															
[95]	+	+	+	+	+						+			+				
[96]		+	+	+					+									
[97]	+	+	+	+			+											
[98]																		+
[99]		+	+															
[100]		+	+	+				+		+				+				
[101]		+	+															
[102]	+										+							
[103]	+	+	+					+								+		
[104]	+	+			+	+												
[105]		+			+			+										
[106]	+																	
[13]	+							+										+
[107]																		+
[108]		+		+														
[109]															+			
[110]																+		
[111]										+	+						+	
[112]															+			

Table 4: Continued.

Reference	Sensors used in SHSs																	
	PIR	Temperature	Humidity	Gas	Smoke	Ultrasonic	Flame	LDR	Pressure	Accelerometer	Door	Gyroscope	Pulse	Fluid detection	Camera	FSR	Flex	Others
[113]		+																
[114]	+														+			
[115]		+																
[116]	+																	+
[117]																		+
[118]	+	+	+					+			+							
[119]															+			
[120]															+			+
[121]	+										+							
[122]	+				+		+	+			+				+			
[123]	+																	
[124]	+	+	+					+										
[125]	+	+																
[126]																	+	
[127]																		+
[128]	+										+							+
[129]	+	+	+															
[130]	+														+			+
[131]							+											
[132]																		
[133]																		+
[134]								+										
[135]	+	+						+							+			
[136]		+	+															
[137]	+	+	+	+											+			
[138]															+			+
[139]	+	+			+						+				+			
Total	52	55	32	16	11	3	7	25	4	5	13	2	2	4	26	4	4	19

8.1. Web Application-Based SHS. A web application-based interface provides a graphical user interface (GUI) for monitoring and controlling SHSs. These web applications are mainly based on the Hypertext Transfer Protocol (HTTP) and Transmission Protocol/Internet Protocol (TCP/IP). A user can access the sensor reading from the SHS, turn on/off certain appliances, get a security breach alert, and check the health condition of the elderly by using these web applications [95, 113].

8.2. Smartphone Application-Based SHS. Since the introduction of Android and IOS devices, the usage of smartphone applications has become widespread. As a result, SHS researchers are opting more and more for application-based interfaces [116]. Similar to web applications, smartphone applications also provide the user with a GUI for interaction, and the user can get a real-time update about SHSs. Smartphone applications provide all types of data and information just like web applications [34, 112].

9. Computational Approaches in SHS

In every SHS, one of the most crucial parts is the computational unit. It can either be a physical unit placed inside an SHS or a cloud platform employed for this purpose. The next segment contains a summary of the computational methods utilized by the paper reviewed in this study.

9.1. Big Data. Big data is the method of systematically analyzing and extracting information from large sets of data that are otherwise too big and complex to analyze through traditional data processing methods. A large-scale SHS, which employs several sensors and appliance control mechanisms, often generates an enormous amount of data. The big data computational method offers a system that enables us to handle such a huge amount of data [72, 117, 118].

9.2. Cloud Computing. In SHSs, cloud computing provides access to computer system resources such as data storage and processing power on demand. This way, instead of directly purchasing extra storage and processors, the system can use cloud resources to satisfy its needs [22, 97, 104].

9.3. Fog Computing. Fog computing or fogging is a dispersed computing architecture that exists between cloud and data-generating devices. It uses optimized edge devices to process, store, and communicate with the user end through the Internet. Fog computing reduces the energy consumption of SHSs by decreasing the amount of data required to transmit [72, 74, 117].

10. Services Provided by SHS

This next section mentions some of the services provided by smart home systems. In recent times, several types of services have been introduced for SHSs, but this section discusses the most popular ones.

10.1. Security Systems of SHS. Security is a big concern in any SHS, be it security from intruders or security against data theft [141]. Smart homes are gradually employing more and more robust security systems thanks to the ongoing research on SHS security [142]. In this section, the security aspect of SHSs is explored in brief.

The smart home intrusion warning is a system that detects and alerts smart home users about possible unauthorized entry into home. Various approaches have been undertaken by researchers to secure smart homes from intrusion. A real-time intrusion alert based on image processing that can detect human faces and warn the SHS user is proposed by the author in [29]. The authors in [81] present a low-cost Bluetooth and smartphone-based security system that uses voice recognition and an eye scanner to identify the user. A cloud-based security system that enables the user to lock all the doors and windows, alerts about intrusion via SMS, and allows wireless home monitoring through cameras is discussed in [114]. Alexa or the Amazon voice service and Raspberry Pi are used to secure doors of a smart home in [86], where a push notification is sent to the user if the door is opened without authorization. In [79], a security system for elderly and physically challenged people has been discussed, which uses a PIR sensor to detect an object or intruder and, with the help of a camera connected to Raspberry Pi, captures a photo of the intruder. In [119], a robot is used to monitor the smart home and detect intrusions or abnormal events. Equipped with a camera, this robot can differentiate between intrusion and private moments such as nakedness and can avoid monitoring sensitive activities of home occupants.

The SHS that employs Internet, IoT, remote home monitoring, and wireless appliance controlling systems uses wireless communication systems and thus is vulnerable to data hacking. It is essential to set up a secure network for a comfortable smart home experience. As the number of devices connected to IoT-based systems is continuously growing, a secured network is essential [143]. To terminate the security threats of an IoT network, the authors in [61] proposed a smart card-based security system that is based on the secure addressing and authentication (SCSAA) scheme, which upgrades the standard IPv6 protocol. An internal security framework for smart devices has been proposed in [109], which ensures devices' security against data leakage, modification, or false code integration into systems. A password-protected user interface has been developed in [59] that requires user authentication to access the monitoring interface. In [118], machine learning and big data have been used to detect anomalies in the network with the help of a hidden Markov model (HMM) that can sense the presence of cyber anomalies in the system. An intrusion detection and mitigation framework (IoT-IDM) structure has been developed in [120]. This framework continuously monitors the devices connected to the system in an IoT-based smart home and looks out for any malicious activity or anomalies in the network. Upon detecting any unauthorized activity, the system blocks the intruder and protects devices. Smart devices connected to the system can authenticate one another and create a secure data transmission network. The system proposed in [121] is able to monitor IoT network traffic and extract information. This extracted information is then used to detect abnormal behavior in the system. An SHS security architecture is proposed in [122], which is efficient, reliable, and accurate and manages the SHS network safely. By using private Ethereum blockchain, the authors in [123] proposed an SHS network security system.

10.2. Energy Management Systems in SHS. A vital part of the SHS is energy management, and several studies have been conducted in this field. Smart home energy management systems are designed based on a framework that can satisfy energy demands and monitor available resources without the involvement of the user [144]. Researchers have used methods such as artificial neural networks [145], machine learning, deep learning [28], and artificial intelligence [73] to develop an energy management system for SHSs. Smart homes that are fully capable of producing the required amount of energy are one of the main focuses of researchers, and several breakthroughs have been achieved [124]. The authors in [146, 147] proposed a nonintrusive load monitoring (NILM) system for better energy management. Automatic scheduling of household appliances and electric vehicles to reduce energy costs has been proposed in [148]. To decrease energy costs, a new energy management system with the help of photovoltaic cells that satisfies consumer needs without putting too much pressure on the national grid has been proposed in [149]. Photovoltaic cells have been a huge part of the energy-saving scheme in the SHS. AI-based PV production systems have been proposed in [150, 151]. A cloud server-based energy management system has been proposed in [125]. Multiagent energy optimization systems have been presented in [152]. PV-based smart homes now play an active role in the national grid. Extra energy generated through photovoltaic cells in smart homes can now be traded through an electric grid [153, 154].

10.3. Activity and Gesture Recognition. The process of detecting and recognizing human body movements such as handwaves or facial expressions to control and interact with a computer system is defined as gesture control. It is a subdivision of image processing and computer vision. In SHSs, mostly hand gestures are used to control certain appliances connected to the system. SHS researchers are trying to develop a more accurate gesture recognition system that would make home appliance control easier. A computer vision-based hand gesture recognition system for home appliance control that does not require the user to wear any extra wristband or other device is demonstrated in [126]. A Kinect v2 sensor was used to capture body gestures in [107], which are used to recognize a set of hand state combinations to control home appliances. Kinect is a motion-sensing device that is capable of gesture and voice recognition [155]. Kinect v2 is again used in [127] for both speech and gesture recognition systems that are specially tailored for elderly people of age 65–80 years. In [128], the authors used Kinect again to register body posture and control home appliances. Another image processing-based hand gesture recognition system is proposed by the authors of [30] that uses MATLAB simulations. A very interesting experiment was carried out by the author in [138], where a radar device is used to detect objects and identify gestures. A body sensor-based gesture recognition system has been explored in [32], where flex sensors are used with a hand glove to register gestures and control appliances. A secure blockchain-based smart home health monitoring system has been proposed in [63], which uses a sensor device for gesture recognition. A wearable wrist-mountedmotion-sensing device is used for gesture recognition in [108]. The device consists of an inertial sensor to detect the hand motion, an Arduino microcontroller board for processing the data, and an RF wireless transceiver to communicate and send the data to the main processor.

10.4. Elderly and Physically Challenged People Care. With the advancement in smart home technology, it is becoming more and more capable of providing health care and health monitoring facilities for occupants, especially for the elderly and physically challenged people [156, 157]. Researchers are constantly working to provide a more comfortable and safer environment for elderly people, which gives them more safety and independence [18, 158]. The SHS could provide great physical and health support for elderly people [159]. Several studies have been carried out to investigate the current situation of elderly care in smart homes and the perception of elderly people towards the smart home system [124, 147]. A low-cost smart assistance system for elderly people has been explored in [131], which generates reminders to take medicines and alerts certain people about significant events such as fire eruptions or intrusions. Apart from that, it also provides a wireless appliance control option. The authors in [98] developed a voice and text-based home appliance control system that uses voice commands or text messages to turn on and off various appliances. This method is very useful for elderly and physically challenged people as it enables them to remotely control their appliances. A hidden Makarov model (HMM) is used in [76] to detect abnormal activity among smart home occupants, especially elderly people. The study used only sensor data to detect abnormalities in their behavior. A patient monitoring system is discussed in [132], where audio and video data are collected through a microphone and camera. The collected data are then processed in the cloud, and depending on the result, doctors can prescribe or assist the patient through audio, video, or text messages. The researchers in [133, 139] designed a two-way telemedicine interaction system that allows simultaneous communication between the elderly and a physician. An IoT-based elderly care system has been proposed in [79] that uses AI for voice recognition and offers wireless appliance switching as well as home monitoring and intrusion alert.

10.5. Smart Home Appliance Control. Home automation and wireless appliance control are two of the main fields of research in SHSs. SHSs are gradually adapting home automation and allow the user better control over their home [17]. Several types of methods are available for appliance switching, such as wireless control over a smartphone app [134] or website [95], voice command [86], and text command [98]. In general, smartphone apps [70] or websites [24] are the most popular means of appliance control in SHSs because of their simplicity and less complicated installation process. Other methods, such as gesture recognition, where the user can control devices just with some simple gestures, have also been developed [107, 126]. Recently, the SHS with dual modes of appliance control such as speech and gesture control is becoming a more popular topic of research [127]. IoT-based SHS systems, where the user can monitor the home environment as well as control various home appliances such as lights, fans, and other switches, are already in development [137]. For better speech recognition in appliance control, researchers are working to develop a better speech recognition algorithm [160–163].

11. Discussion

Reviewing and analyzing all the articles based on the study, in this section, a thorough discussion is presented on all the topics mentioned in this study.

11.1. Discussion on SHS Approaches. Figure 8 represents a graphical illustration of the technological approaches shown in Table 2. Although the table does not contain the data of all the papers reviewed in this study, it contains a substantial amount of information from which we could conclude the overall trend of SHSs. We can see that 31 SHSs, or nearly 60%, used multiple approaches instead of depending on a single method. 20 articles, or about 40%, used only one method to develop an SHS. It can also be seen that IoT-based SHSs are by far the most popular choice among researchers, which is mainly due to the low cost. Other methods, such as WSN, GSM, and Bluetooth, are also fairly popular. Machine learning, deep learning, and neural network-based SHSs are also gaining ground among researchers.

11.2. Discussion on Microcontrollers Used in SHS. After a thorough investigation, we have identified the most popular microcontrollers used in the development of SHSs. The data shown in Table 3 can be represented in Figure 9, which shows the trend of microcontrollers in SHSs. Undoubtedly, Arduino and Raspberry PI are the most used microcontrollers. Arduino is cheap, versatile, and reliable, while Raspberry Pi has better computational power than most other microcontrollers. The ESP32 and ESP8266 boards are popular due to their built-inWi-Fi modules, which help the SHS connect to the Internet. Other microcontrollers such as FPGA, PIC, and LPC are also used. Some researchers have also used not-so-familiar components such as S5PV210 and LM3S8962. Overall, 33 papers, or 61%, used a single microcontroller method to develop SHSs, while 21 papers, or about 39%, opted for multiple microcontrollers.

11.3. Discussion on Sensors Used in SHS. The sensor usage data shown in Table 4 are graphically represented in Figure 10. We can see that the temperature sensor is the most used sensor in SHSs. They are often used alongside other sensors such as flame or gas sensors to detect any unusual difference in temperature, which could mean that a potential fire breaks out. The PIR sensor is the second most used sensor due to its popular application as intrusion detection. It is considered a cheap substitute for a camera as it can detect human presence up to a certain level and warn about any possible intrusion. The humidity sensor keeps an eye on the humidity level of home and helps maintain a comfortable humidity level. Gas, smoke, and flame sensors are very useful and are used as a safety system to detect gas leakage, smoke, or fire breakout. The camera is mainly used for security purposes, image processing, and gesture recognition. LDR sensors help automate the lights in the house, which saves energy. Other sensors, such as doors, accelerometers, and pressure, have their own specific usage and are used accordingly.

11.4. Discussion on Networking Technologies and User Interfaces of SHS. After reviewing all the studies on SHSs, we can say that most of the development routes choose both wired and wireless communication media to connect sensors and other devices to the main controller, while mainly wireless connectivity is preferred in the connection between the smart home and the user. Even though wireless connectivity between the sensor and processor is a trend, it is comparatively more expensive than a wired connection since another device is required for the majority of microprocessors to wirelessly receive and send data.

In the case of user interfaces, both web application-based and smartphone application-based interfaces are popular. Though the latter might be preferred since web-based interfaces need to remember the web address or user credentials to log into the system, smartphone-based applications are not that complex. The extra steps required in web interfaces to access the system might be considered unnecessary annoyance by the user, while smartphone-based interfaces are specifically designed to reduce the amount of complexity for the user.

11.5. Discussion on Services Provided by SHS. Recent developments in SHSs have introduced different types of services in SHSs that make smart homes more secure, comfortable, and user-friendly. High emphasis has been given to networks and home security, which makes home less prone to security threats. Systems to neutralize both physical and network threats have been developed over the years. Energy management has been another major sector of development that helps smart homes be energy efficient and environmentally friendly. With the help of image processing, machine learning, and deep learning, gesture recognition

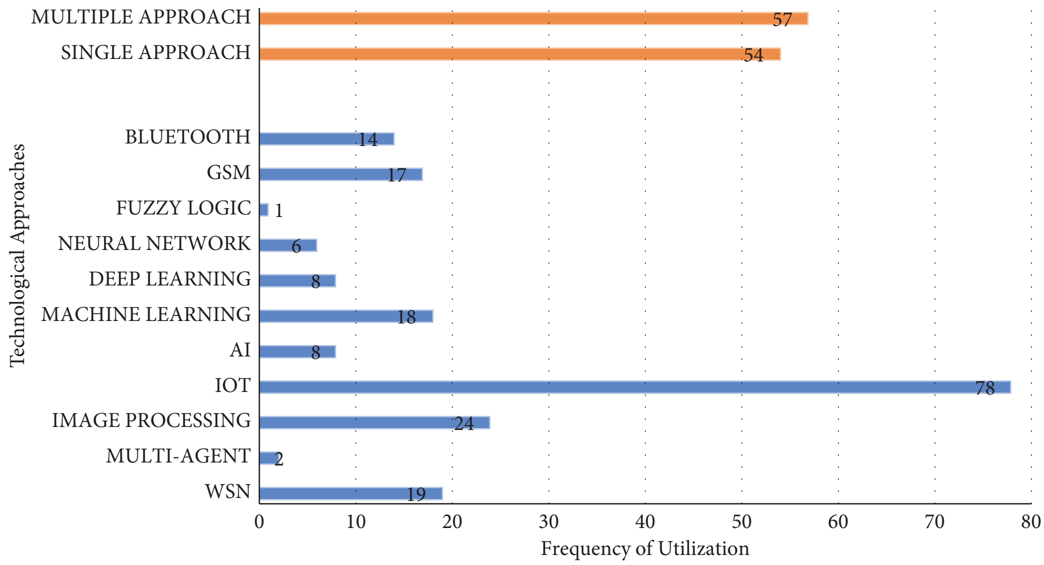

Figure 8: Comparison of technological approaches of SHS.

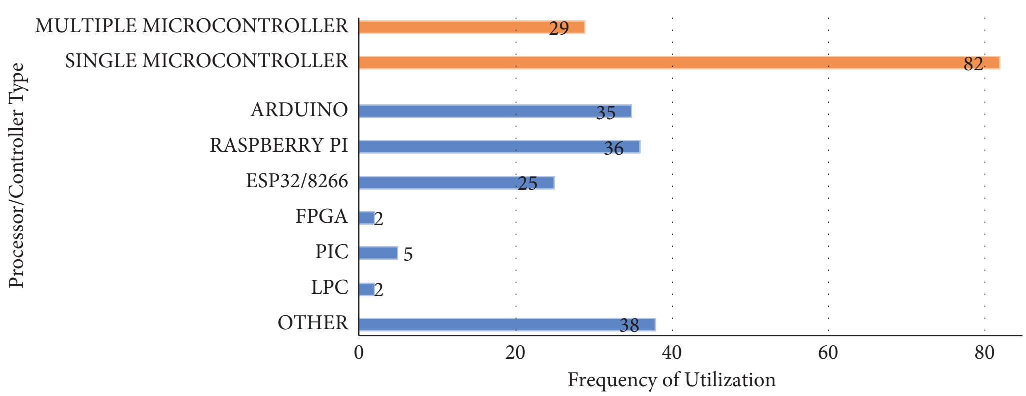

Figure 9: Comparison of microcontroller usage in SHSs.

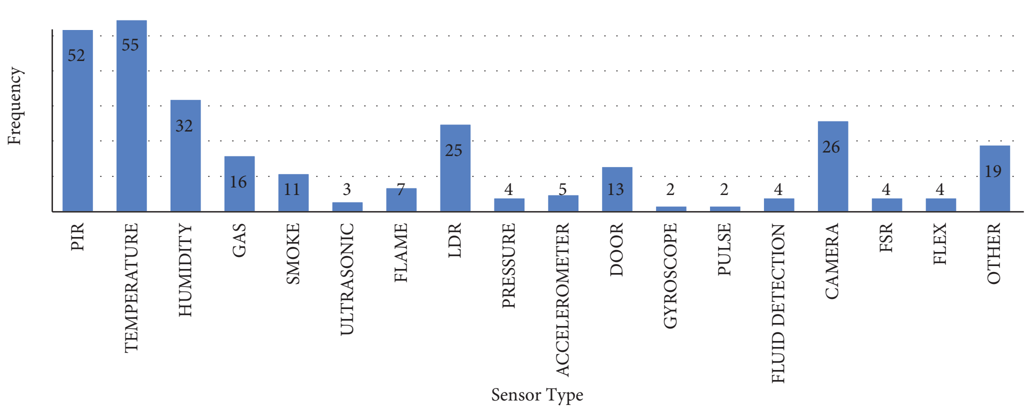

Figure 10: Frequency of different sensor usage in SHS.

has become more accurate and efficient, which allows users to control appliances with mere gestures. For elderly and physically challenged people, researchers have developed specialized smart homes that make the lives of elderly people easier, more comfortable, and more attentive to medical needs. Moreover, finally, remote appliance control has added a new dimension to the comfort level of the smart home user, which allows remote access and control of home appliances.

12. Conclusion

The development process of SHSs has been going on for decades, and breakthroughs have been achieved by researchers in this field. In recent years, due to population blasts and rapid industrialization, the standard of living has been decreasing rapidly. Smart homes provide a secure, comfortable, and efficient way of living. In this study, we have presented a thorough analysis of the recent development of SHSs. This systematic literature review sheds light on the various technological approaches taken by researchers in the development of SHSs as well as the types of microcontrollers and sensors used. We have identified 11 major technological approaches, 6 most popular microcontrollers, and 17 different types of sensors used by researchers in their work and provided an in-depth comparison among them to ascertain the popularity and trend in research. Aside from these, a detailed analysis and review of the networking technologies adopted, user interfaces provided, computational methods utilized, security systems established, and several services such as energy management, gesture recognition, elderly care systems, and appliance control mechanisms have been presented in this study. Moreover, a detailed comparison of the data collected from the various articles has been provided in the discussion part, where it can be seen that multiple approach-based SHSs are becoming more popular due to their added functionality from the utilization of multiple approaches. For that same reason, multiple microcontroller-based SHSs are also coming in trend. An IoT-based SHS is becoming a dominant competitor. For the user interface, smartphone application-based interfaces will play a key role in the future due to their ease of access and better functionality. Because the network and physical vulnerability will remain a major threat in the SHS, more and more emphasis is being given to networks and physical security, and this research for a better secured SHS can be expected to continue.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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