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Survey and Analysis of Home Automation System Encompassing Embedded Systems, the Internet of Things (IoT) and AI Algorithms

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ABSTRACT

Home Automation Systems (HAS) enable smarter, safer and more energy-efficient homes by automating various functions like lighting, temperature, security and appliances. These systems rely on communication technologies such as Bluetooth, GSM, ZigBee and IoT to connect and control devices seamlessly. The embedded devices serve as the backbone for seamless communication and integration among connected devices, creating a cohesive smart home ecosystem. By adding sophisticated features like predictive analytics, intelligent decision-making, and customized automation, the combination of Artificial Intelligence (AI) and the Internet of Things (IoT) elevates HAS to a new level. AI enhances system responsiveness, learning from user behavior to maximize the use of resources, energy and provide a more intuitive user experience. This survey delves into various methodologies and architectures employed in HAS, offering a detailed analysis of their features and performance across real-world applications. It critically evaluates key parameters such as scalability, cost-effectiveness and system robustness. The survey also highlights the challenges and limitations of current technologies. By exploring the synergies between embedded systems and AI, this review underscores the transformative potential of HAS to create secure, adaptive and efficient living spaces.

Keywords: Home automation, IoT, Artificial Intelligence, Smart home, Embedded systems

1. INTROUDCTION

In recent years, the popularity of wireless technologies, such as remote control systems, has grown significantly in home automation and networking. These advancements offer numerous benefits over traditional wired systems. Additionally, wireless systems enable internet connectivity, allowing users to control smart home devices remotely from anywhere in the world via mobile phones. They are also highly scalable and expandable, making it convenient to extend the network to meet evolving requirements. Furthermore, these systems enhance security by enabling seamless integration of devices into a smart home security setup, while built-in security features ensure the integrity of the system [1].

HAS is the integration of technology and smart devices into the residential environment, designed to make everyday tasks easier, more efficient and more secure. It encompasses the integration of interconnected systems to oversee and regulate multiple facets of a residence, such as illumination, climate control, security measures, entertainment options, and household appliances [2]. In a typical home automation setup, a range of advanced devices including intelligent thermostats, lights, security cameras, locks and even kitchen appliances are interconnected through a central hub or mobile app [3]. The system allows these devices to work together to respond intelligently to user needs and environmental changes. For example, Illumination systems can be configured to activate autonomously upon the detection of movement or when the homeowner leaves or arrives at the house. Voice assistants such as Amazon Alexa, Google Assistant, and Apple Siri occupy a pivotal position, facilitating hands-free management of numerous systems. Smart thermostats exemplify technology that can adapt to user behavior, optimizing heating and cooling to reduce energy consumption while ensuring comfort is preserved. Similarly, security systems can be integrated with sensors, cameras and alarms to augment the security of the residence, offering immediate notifications and distant monitoring. These systems communicate with each other through the internet or other communication protocols, allowing users to control them remotely or automatically. With advancements in technology, home automation is transforming ordinary houses into "smart homes," providing users with greater convenience, improved energy management and enhanced safety.

1.1 Communication devices for home automation

A multitude of home automation systems leverage smartphones to interface with microcontrollers through an array of wireless communication technologies, including Bluetooth [4], GSM [5], and ZigBee [6].

1.1.1 Bluetooth

Bluetooth based HAS provide an economical and secure approach by integrating smartphones, Arduino boards, and Bluetooth technology. A system put forward by R. Piyare and M. Tazil [7] emphasizes a hardware design featuring an Arduino BT board alongside a mobile phone. The interaction among these components occurs wirelessly via Bluetooth, utilizing the Arduino BT board, which offers a range of 10 to 100 meters, a data transfer rate of up to 3 Mbps, and operates on a 2.4 GHz bandwidth. This configuration involves linking home appliances to the Arduino BT board through relays, complemented by a specialized smartphone application that enables users to manage these devices. To ensure security, the system incorporates password protection, permitting access only to authorized users. One key advantage is its compatibility with existing home setups, allowing easy integration. [8]

1.2.2 GSM

GSM-based home automation systems enable control through SMS, internet and speech. These systems are particularly effective in areas with limited internet access, using GSM as a reliable communication medium. User commands are processed via a server, often hosted on a PC, which communicates with home devices using Attention (AT) commands through a GSM modem. Feedback is provided via SMS, allowing real-time monitoring of device status. Mobile applications, often developed using J2ME or App Inventor, generate SMS commands and serve as user interfaces. These systems offer secure password authentication [9].

1.2.3 ZigBee

ZigBee wireless communication technology is a practical option for home automation, offering low-power connectivity. A typical system employs a PIC microcontroller and a voice recognition module. Voice commands are captured through a microphone, compared with stored voice data and processed by the microcontroller. The receiver processes the instructions and uses relays to control appliances. An additional feature of this system is the integration of a smoke detector. In the event of smoke detection, the system sends an alert to a predefined mobile number [8]. Table 1 shows the differences between various HAS.

Table 1. Comparison of different home automation methodologies [9]

System	Primary Communication	Remote access	Number of devices	Cost	Speed	Real-time
Bluetooth	Bluetooth and AT commands	Limited to a Bluetooth range of 10 meters	Boundless	Less	Quick due to proximity	Yes
GSM	SMS messages	Global access without limitations	Boundless	Significant expenses arising from SMS fees	Delayed because of delivery challenges	No
Zigbee	Zigbee and AT commands	Around 10 metres	Boundless	Fast	Fast	Yes

This transformation is propelled by embedded systems, which serve as the foundation of smart home devices by combining specialized hardware and software to perform dedicated tasks with accuracy and effectiveness. Embedded systems are essential for facilitating real-time data processing and ensuring smooth communication among devices.

1.2 Embedded Systems in Home Automation

The swift advancement of wireless technologies compels us to utilize smartphones for the remote control and monitoring of home appliances globally [10-11].

1.2.1 Key Embedded Devices for Home Automation

(i) PIC Microcontrollers (Peripheral Interface Controllers)

PIC microcontrollers are compact and versatile embedded devices that play a crucial role in home automation. These microcontrollers are specifically designed to control various peripherals, such as sensors, actuators and communication modules, making them ideal for a wide range of automation tasks. In home automation, PIC microcontrollers are commonly used for applications such as controlling lighting systems, monitoring temperature and humidity sensors and managing automated irrigation systems. Their advantages include being low-cost, energy-efficient and well-suited for simple control-based tasks, making them a popular choice for developers looking to implement cost-effective and reliable solutions in smart home environments. The authors in [12] introduced a HAS that utilizes voice recognition, employing a PIC microcontroller as the Central Processing Unit (CPU).

(ii) Arduino

Arduino is an ideal choice for DIY home automation projects and rapid prototyping. Its user-friendly interface and versatility enable developers and hobbyists to implement a range of smart home solutions. Common applications of Arduino in home automation include smart lighting and appliance control, home security systems featuring motion and smoke detectors and voice-controlled systems when integrated with modules like Alexa or Google Assistant. Satapathy et

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al. [13] highlights the use of Arduino UNO microcontroller for controlling the smart appliances remotely using Wi-Fi and ESP8266-01 module.

(iii) Raspberry Pi

The Raspberry Pi is a single-board computer offering significantly greater computational power compared to microcontrollers like Arduino or PIC, making it ideal for advanced home automation tasks. Its ability to run a full operating system, such as Linux, enables it to handle complex applications with ease. Common uses of the Raspberry Pi in home automation include setting up a centralized automation hub with platforms like Home Assistant, integrating sophisticated security systems with facial recognition or CCTV streaming and creating multimedia centers or voice-controlled systems. With the use of Raspberry Pi, Chakraborty and Sultana [14] developed a face recognition system that delivers audio messages and sends text notifications to the owner's device upon recognition.

(iv) ESP8266/ESP32

The ESP8266 and its advanced version, the ESP32, are cost-effective, Wi-Fi-enabled microcontrollers that are ideal for IoT applications and widely used in smart home projects. These devices offer built-in wireless connectivity and low power consumption, making them highly suitable for tasks such as controlling smart light switches via smartphone apps, monitoring home environments with temperature, humidity and air quality sensors and enabling voice-controlled devices integrated with platforms like Alexa or Google Assistant. The compact size of these devices, especially the ESP32 which also includes Bluetooth, ensures reliable connectivity, making them an excellent choice for IoT-based home automation solutions. In [15], a system was developed utilizing the ESP32 in conjunction with the Blynk app, IR remote, and manual control relays. This setup focuses on creating a cost-effective and dependable solution for monitoring and managing devices and appliances from a distance.

(v) BeagleBone Black

The BeagleBone Black is a robust single-board computer known for its advanced real-time processing capabilities and expandability, making it an excellent choice for complex home automation tasks. This is especially ideal for applications demanding accurate real-time performance, such as advanced home security systems with real-time monitoring, smart grid energy management systems for tracking and optimizing energy usage and automation hubs that control multiple devices while integrating with cloud services. With support for multiple operating systems, including Linux, the BeagleBone Black provides a versatile development environment. Additionally, its extensive GPIO pins and flexibility for hardware connections offer greater customization options compared to some alternatives, making it a powerful tool for sophisticated smart home solutions. Vaidya and Vishwakarma [16] detailed the development of an Android mobile application aimed at facilitating smart home management and predicting electricity energy consumption. The application employs Wi-Fi and GSM as communication channels to connect with the Beagle Bone Black, which functions as the CPU.

(vi) LoRa boards

Long Range (LoRa) boards are specialized devices designed for long-range, low-power wireless communication, utilizing LoRa technology. These boards are particularly well-suited for smart home applications that require connectivity over large distances without relying on Wi-Fi or cellular networks. In [17], the LoRa module was connected to a ESP32 module to control appliances by a smart phone application.

1.2.2 Key Sensors in Home Automation

Sensors are an integral part of home automation systems, providing critical data that embedded systems use to make intelligent decisions. Table 2 presents the most frequently utilized sensors in smart home environments.

Table 2. Frequently Employed Sensors in Smart Homes

Sensor	Use
Temperature Sensor	Monitors temperature for climate control in homes (smart thermostats, HVAC systems).
Motion Sensor	Identifies motion for security systems, lighting control, and energy efficiency solutions.
Light Sensor	Measures ambient light levels to adjust lighting automatically for energy efficiency.
Humidity Sensor	Monitors humidity levels to control air conditioning or humidifiers, enhancing comfort.
Gas Sensor	Detects hazardous gases (e.g., carbon monoxide) for safety and alerts the user to potential dangers.
Proximity Sensor	Senses the presence of objects or people in proximity for security and automation (e.g., automatic doors).
Smoke Sensor	Detects smoke in the environment for fire safety and sends alarms to users.
Pressure Sensor	Measures air pressure and is used in weather monitoring and controlling devices like smart windows.
Sound Sensor	Detects sound levels and can be used for noise monitoring or voice-controlled devices.
Vibration Sensor	Detects vibrations and can be used for security (e.g., door/window sensors) or appliance monitoring.
Camera Sensor	Captures visual data for security cameras, motion detection, or facial recognition.

Water Leak Sensor	Detects water leaks or floods for prevention and early warning in bathrooms, basements, or kitchens.
Occupancy Sensor	Identifies the presence of people in a room for lighting, HVAC control, or energy-saving automation.
Voltage Sensor	Measures electrical voltage for monitoring and controlling power consumption in smart appliances.

By leveraging the capabilities of embedded systems and sensors, smart home devices can make intelligent decisions, optimize energy usage and provide tailored responses to user preferences and environmental changes. This seamless integration of technology into daily life not only enhances user experience but also represents a significant step toward creating homes that are adaptive, efficient and intuitive, bridging the gap between technology and everyday living in meaningful ways.

Beyond just providing convenience and ease of use, these systems also offer greater energy efficiency, security and comfort. For instance, HAS can monitor and adjust usage of energy, reducing waste and lowering utility bills. They improve safety by keeping an eye out from afar, sending out notifications in real time, and responding automatically to dangers, such as triggering security cameras when motion is detected. As technology continues to evolve, the integration of AI and machine learning can further personalize user experiences and increase system efficiency, ultimately making smart homes even smarter, safer and more responsive to the individual needs of the users.

The use of AI in home automation is revolutionizing how smart homes operate, making them more intelligent and adaptable to user behavior. Systems powered by AI can sift through data collected from a wide range of sensors and devices to identify trends and personal preferences, enabling features such as predictive maintenance, energy optimization and personalized automation. AI algorithms process large volumes of data generated by IoT devices, analyzing patterns and making real-time decisions to optimize operations. For instance, by spotting impending system breakdowns, ML models pave the way for predictive maintenance. based on device behavior and historical data, thereby preventing breakdowns and reducing downtime [18].

Advanced AI-powered natural language processing (NLP) allows voice assistants to interpret user commands with high accuracy, enabling seamless control of home devices. Computer vision techniques integrated into security cameras can perform facial recognition, object detection and motion analysis to enhance home security. Additionally, reinforcement learning can optimize energy usage by dynamically adjusting appliances and systems based on consumption patterns and environmental factors, such as weather forecasts. As AI models become more sophisticated, they enable deeper integration and interoperability among smart devices, creating a cohesive ecosystem capable of autonomous operation and advanced personalization. Both the system's efficiency and the user experience are enhanced by this technical synergy in smart home settings. The layout of a smart home is shown in Figure 1.

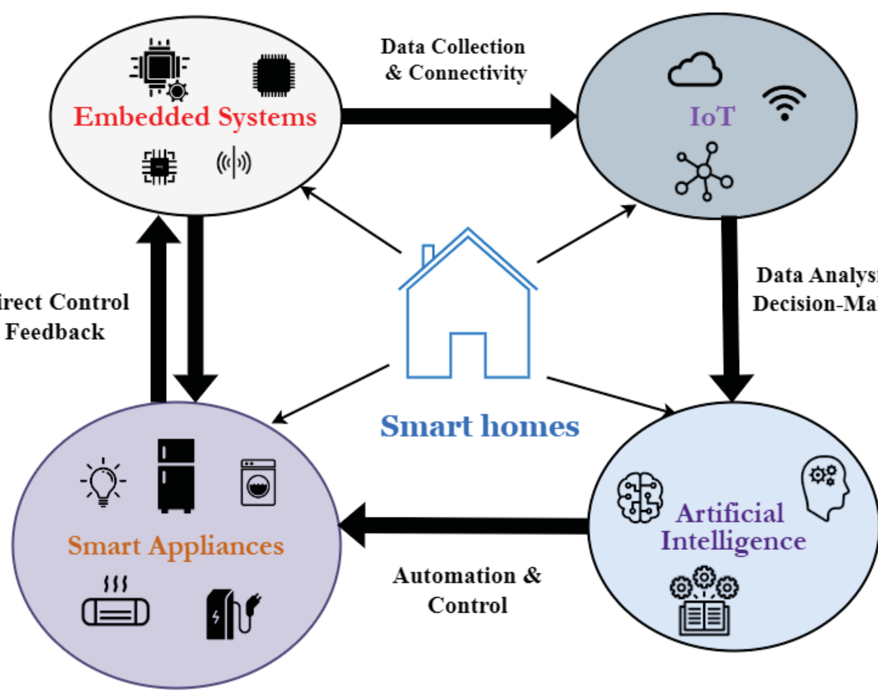

Figure 1. Smart home architecture

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The technology behind HAS is rapidly advancing, allowing for more sophisticated features and smoother integration across devices and platforms. As IoT expands, the number of connected devices in homes continues to grow, further continuing to expand the realm of home automation. From health monitoring systems to smart kitchens and energy-efficient appliances, home automation is revolutionizing the manner in which individuals engage with their environments, making homes more responsive, intelligent and efficient. The generalized block diagram of the workflow inside the smart home is illustrated in Figure 2.

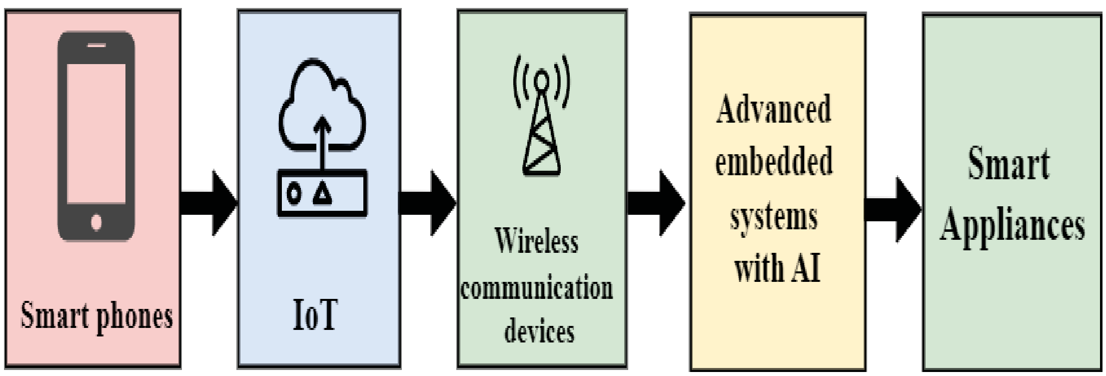

Figure 2. Block diagram of smart home using advanced embedded systems and AI

2. SURVEY ON HOME AUTOMATION USING ADVANCED EMBEDDED SYSTEMS AND ARTIFICIAL INTELLIGENCE

Khan et al. [19] developed a smart HAS to control energy consumption efficiently using ML and DL techniques. The system functions through three distinct phases: (1) a 1-dimensional Deep Convolutional Neural Network (1D-DCNN) is employed for the extraction and classification of historical energy data, (2) a Long Short-Term Memory (LSTM) model is utilized to predict energy load based on the features extracted, and (3) a scheduling algorithm, informed by the forecasted load, implements Q-learning reinforcement to enhance the operational timing of smart home appliances. This system aims to reduce energy consumption and automate appliance scheduling without the need for renewable energy sources.

Machorro-Cano et al. [20] introduced an advanced HAS that leverages IoT, big data and ML to ensure comfort, safety and efficiency. The system employs the J48 ML algorithm to analyze user behaviours and Weka API to analyse energy consumption designs, classifying homes based on energy usage. Furthermore, it employs RuleML and Apache Mahout to produce tailored energy-saving suggestions. In a case study, the system's effectiveness is confirmed by monitoring a smart house to guarantee comfort and safety while simultaneously lowering energy usage.

Iqbal et al. [21] devised an Electricity Dispatcher system for smart home automation, focusing on power consumption management. This system combines software and hardware technologies, using Arduino Uno, sensors, switches and relay modules to control household devices. The system supports three modes of control: local, web-based and app-based. In the local mode, the system automatically controls appliances based on sensor readings (e.g., human presence and temperature). The web-based mode allows users to control appliances remotely through a web page, while the app-based mode uses a Blynk app connected to a NodeMCU to control appliances via the internet. Additionally, the system includes an emergency mode that automatically switches off appliances in response to critical voltage fluctuations, preventing damage. A server setup with Ubuntu and Apache hosts the web-based interface for the system.

Khan et al. [22] presented an intelligent sensor duty cycling scheme for smart HAS to optimize energy consumption and activity detection in wireless sensor networks (WSNs). This scheme utilized Bidirectional Long Short-Term Memory (BiLSTM) model for accurate prediction of home users' activities and the Dynamic Time Warping (DTW) technique for sensor grouping based on activity similarity. The system divided sensors into three states: Active State (AS), Guard State (GS) and Standby (SB) to balance energy consumption and accuracy. The BLSTM model forecasted future activities, allowing for the intelligent selection of active sensors while the DTW technique grouped sensors with similar data patterns. The proposed scheme efficiently managed sensor energy by rotating GS roles and switching sensors between states, significantly prolonging battery life to approximately 137 days.

To enable diverse home automations, Stolojescu-Crisan et al. [23] introduced the qToggle system, a versatile and potent home automation platform that connects different sensors, actuators, and data sources. Mainly based on Raspberry Pi boards and ESP8266/ESP8285 chips, this system uses a configurable Application Programming Interface (API) to enable communication between devices. Through a smartphone application, users may operate home appliances and sensors with the qToggle system, providing flexibility and easy management. The system's architecture employs a local Wi-Fi or Ethernet network, with Raspberry Pi and ESP8266 modules forming the hub-and-spoke setup. The API allows for efficient device management, including remote control of hardware ports, firmware updates and automation through role-based access control. Additionally, qToggle implements security measures like HTTPS for external communication and SSH for remote administrative access. It also features Over-the-Air (OTA) firmware updates to ensure devices run the latest versions for security and performance.

Taiwo et al. [24] suggested a cloud-based intelligent HAS that integrates IoT and ML for enhanced privacy and energy efficiency. The system employs a range of IoT devices, including smart thermostats, lights, cameras and sensors, to monitor and control home appliances and environmental factors. The security module employs a camera to record images of objects activated by motion detection. In order to mitigate the occurrence of false alarms, the system utilizes the Support Vector Machine (SVM) algorithm to discern between images of typical home inhabitants and potential intruders. The SVM classifies the captured images based on unique features like face shape, skin tone and eye color. The system notifies the user upon the detection of an intruder, ensuring improved home security. The implementation of the system utilized ESP8266 and ESP32-CAM boards, alongside a relay module and various sensors.

Yar et al. [25] presented an IoT-driven HAS using a resource-constrained Raspberry Pi (RPI) device. This system integrated automation, security, safety and energy management by employing a cost-effective edge-computing approach. The architecture was based on a five-layer framework comprising the device layer for data collection and command execution, the broker layer for secure communication via MQTT, the service layer for data processing and decision-making, the application layer for user interaction and the cloud layer for storing and analyzing non-sensitive data. The RPI served as the central controller, enhancing system efficiency and modularity while ensuring user privacy.

Islam et al. [26] developed a smart home automation system that combined long-range utilizing Wide Area Network (LoRaWAN) and Bluetooth technologies for efficient and flexible controlling of household devices. The system employed an Android application for user interaction, where commands were transmitted via Bluetooth to a Node MCU microcontroller at the sender station and further relayed via LoRaWAN for long-range communication. A server-based LoRa gateway ensured reliable operation in case of Bluetooth failures. The system utilized relay circuits to safely convert 220V high voltage to 5V for operating AC appliances and integrated a multi-layer communication architecture that supported ranges from 8–10 m (Bluetooth) to 8 km (LoRaWAN). The hardware included sender and receiver stations equipped with Node MCU microcontrollers, LoRa RYLR400 modules and 5V DC power supplies. This system achieved robust home automation by ensuring seamless communication, safe operation and reliable fall-back mechanisms, providing users with efficient control of appliances in both urban and rural settings.

Khan et al. [27] developed a HAS that seamlessly integrates a multitude of devices and sensors through IoT, resulting in a sophisticated, secure, and efficient network for home automation. The system employs Raspberry Pi boards, ESP8266 chips, and Wi-Fi modules to facilitate uninterrupted communication among devices. A mobile application enables users, including those with disabilities, to remotely manage household appliances. The HAS operates through a central server and utilizes an API for communication between devices. It features automated firmware updates, secure communication through HTTPS and supports multiple roles with specific access permissions. The system aims to improve the management and monitoring of household appliances while ensuring security and ease of use.

Lin et al., [28] devised an advanced home energy management system (SHEMS) for HAS which utilizes a GPU-accelerated neuro computing-based time-series load modeling and forecasting mechanism. The system employs energy decomposition to model and forecast electrical energy consumption, focusing on appliance-level tracking without the need for intrusive networked plug-level power meters. The proposed approach compares autoregressive multilayer perceptron (MLP) and stacked LSTM methodologies for the neuro computing-based load forecasting mechanism. This mechanism non-intrusively analyzes and models the daily behavioural patterns of residents by studying the energy consumption trends of electrical home appliances, enabling smarter home automation.

Alabdullah et al. [29] suggested a marker less hand gesture recognition system that can be integrated into home automation systems for enhanced interaction without requiring gloves, markers, or expensive hardware. To identify the movements, this system employs six stages: removing noise, detecting the hand, extracting features, optimizing, and classifying. In order to train the hand movements, the adaptive median technique was used for pre-processing. The two-way approach was subsequently used for hand detection, and the action, a Single-Shot Multibox Detector (SSMD), was used to extract the hand skeleton. Merging the hand and skeleton points allowed us to extract fusion features such as neural gas, joint color cloud, and directional active model. Using the active bee colony approach, the characteristics were optimized.

Irugalbandara et al. [30] developed an offline HomeIO system to overcome the shortcomings of current cloud-dependent systems, as it operates independently of internet and cloud services. HomeIO incorporates a sophisticated on-device speech-based user interface designed for the control of devices and incorporates a CNN-based Speech-to-Text (STT) model for audio conversion, alongside a BERT-based Natural Language Understanding (NLU) model for intent detection. The system includes a smart hub for centralized control and smart plug sockets for device management. Power usage tracking is facilitated by the HLW8012 energy monitoring IC, while a Wi-Fi-based mesh network and MQTT messaging protocol ensure secure and reliable communication. The mesh network enhances connectivity, while MQTT enables efficient, encrypted messaging.

Alam et al. [31] devised a smart home system grounded in edge computing, utilizing a Raspberry Pi 3 Home Server (RHS) and propelled by the SVM algorithm. The system incorporates real-time detection of fire and smoke through the utilization of MQ2 gas, dust, temperature, and flame sensors. The SVM algorithm enables the integration of diverse data sources, whereas tools such as Network Mapper (NMAP) play a crucial role in safeguarding network security, and databases like MariaDB and InfluxDB are instrumental in the management of data storage. An MQTT broker facilitates the efficient exchange of information among devices. The proposed system achieves low latency and provides a multi-level alert mechanism with alarms, SMS, notifications and emails for threat mitigation. It supports home automation, real-time monitoring, anomaly detection, appliance tracking and cloud backup.

Drăgoi et al. [32] suggested a Brain-Computer Interface (BCI)-based home security system to assist individuals with disabilities, particularly those with paralysis or amputations. The system utilizes EEG signals collected by the EMOTIV Insight™ headset to control devices such as a door and a light. The prototype is comprised of a Raspberry Pi 4, a servo motor designed for the operation of the door, and an LED for illumination purposes. The system also includes a Flutter-based mobile application that sends notifications about the status of the door and lights to a smartphone. This solution enables disabled individuals to control the door and lights using their brain signals, providing a helpful alternative to traditional methods like remote controls.

Sanjay et al. [33] created an advanced HAS that includes an inhabitant module, a design module, and a decision-making module. The resident's module allowed users to remotely control appliances such as bulbs, TVs and fans via a smartphone application, providing real-time notifications and live surveillance streaming over Wi-Fi. The smart home design module incorporated IoT devices including temperature-humidity sensors, human activity recognition (HAR) sensors, and surveillance cameras, all linked to a Raspberry Pi 4 microcontroller featuring a built-in Wi-Fi module for smooth connectivity. The decision-making module utilized a collection of pre-set and captured images to differentiate between residents and outsiders. It used a convolutional neural network (CNN) for image recognition and classification, leveraging its ability to identify significant characteristics in initial layers and intricate patterns in subsequent layers. The CNN model integrated noise reduction using a median filter and feature extraction with a Softmax classifier. The system raised alarms and sent smartphone notifications if unauthorized activity was detected, ensuring a secure and automated home environment with advanced threat mitigation capabilities.

3. COMPARATIVE ANALYSIS

Table 3 compares various HAS techniques highlighting their AI techniques and embedded devices employed, their merits and demerits and also their application.

Table 3. Comparative analysis of existing HAS techniques

Ref No	Author & Year	AI algorithms employed	Embedded devices employed/Dataset used	Advantages	Disadvantages	Applications
[19]	Khan et al. (2020)	1DCNN, BLSTM, Q-learning, ANN	MAC00050 dataset	This system makes a message-passing system which makes even the appliances more smarter	It is not practically implemented	• Electricity firms • Meter data reading
[20]	Machorro-Cano et al. (2020)	J48, Weka API,	ZigBee, TCP/IP, HTTP/IP	The system lets people change home device settings.	It is limited to number of domestic devices	• Smart home residents
[21]	Iqbal et al. (2021)	-	D6T mems thermal sensor, Arduino, NodeMCU, ESP8266	It is cost-effective regarding electricity consumption of hardware and software.	Voltage or other sensors for load control in extreme conditions must be addressed.	• Household
[22]	Khan et al. (2021)	RNN, DTW, BLSTM	Aruba, Kyoto datasets	This system uses the BLSTM to forecast smart home	This is not practically implemented	• Residential areas

				user activity to balance accuracy and energy consumption		
[23]	Stolojescu-Crisan et al. (2021)	-	Raspberry Pi 4, ESP 8266 Wi-Fi modules	qToggle's adaptability and ease of use are its strongest points.		• Indoor areas • Gardening/ Irrigation purposes
[24]	Taiwo et al. (2021)	SVM	ESP8266 Wi-Fi	This model permits additional appliances with a configured point and is expandable	The system only alerts the user if an intruder is detected	• smart cities, • office areas, • hotels, • malls, • university
[25]	Yar et al. (2021)	-	Raspberry Pi, MQTT, Node Red	The proposed system responds quickly.	This system find it difficult if a new sensor is detected	• Domestic appliances
[26]	Islam et al. (2021)	-	NodeMCU	Despite of many obstacles, the system provides higher effectiveness		• Colleges, • Universities
[27]	Khan et al. (2022)	-	Raspberry Pi, ESP8285	This technology alerts customers if indoor humidity fluctuates too much		• Residential smart home

[28]	Lin et al. (2022)	MLP, LSTM, DNN	Unknown dataset	The model uniquely uses GPU-accelerated neuro computing for load forecasting, reducing the need for extra sensors and devices		• load forecasting
[29]	Alabdullah et al. (2023)	RNN, Active bee colony, SSMD	HaGRI, Egogesture, Jester, WLASL datasets	the system has the ability to manage computational costs through an efficient architecture.	Frames with poor camera angles make it hard to capture critical points	• Domestic devices • healthcare, • robotics, • sports, • industries
[30]	Irugalbandara et al. (2023)	GMM, ANN, BERT	ESP32 Node MCU, HLW8012, Raspberry Pi	The system uses Wi-Fi mesh networks, which raises security concerns		• Elderly care • Disabilities care
[31]	Alam et al. (2024)	SVM,	Raspberry Pi 3 Model B+, Arduino mega,	MQTT app adaptability, SVM monitoring, bandwidth efficiency	Linked to Cloud loosely.	• farms, • garment • industries, • school and college students' attendance
[32]	Drăgoi et al. (2024)	-	Raspberry Pi zero,	This system is affordable and provides real-time	After 20 minutes, customers found the	• Hospitals • Patient-care

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				notifications.	headset unpleasant	
[33]	Sanjay et al. (2024)	CNN	Unknown dataset	This system is highly effective in terms of accuracy		• Persons with disabilities • energy conservation • Monitoring environmental conditions.

In the above table 3, the common disadvantage across many of the systems mentioned in the table is their resource-intensive nature, which includes challenges like high computational cost, limited scalability and security concerns. As a result, future research could focus on reducing the computational demands by improving system efficiency, simplifying sensor requirements and enhancing security to ensure smoother integration and lower operational costs in smart home automation.

4. CONCLUSION

HAS are transforming modern living by offering smarter, safer and more energy-efficient solutions through operating essential systems like lights, temperature control, security and appliance management. The integration of communication technologies like Bluetooth, GSM, ZigBee and IoT, along with embedded devices, forms the foundation for seamless device connectivity, creating a cohesive smart home ecosystem. The incorporation of AI into HAS further elevates their capabilities, enabling predictive analytics, intelligent decision-making and personalized automation that optimizes energy efficiency and enhances user experience. This survey highlights the various methodologies, architectures and performance parameters of HAS, emphasizing the importance of scalability, cost-effectiveness and system robustness. However, challenges such as computational demands, security concerns and limitations in existing technologies remain. By exploring the synergies between embedded systems and AI, this review underscores the transformative potential of HAS in creating adaptive, secure and energy-efficient living environments for the future.

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