Smart Home Automation by Internet-of-Things Edge Computing Platform

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***Abstract*—Internet of Things (IoTs) offer significant benefits to various applications, including homes automation (HA), environmental monitoring, healthcare, homeland security, agriculture, and many others. Consequently, the trend of IoTs is rapidly evolving in many new sectors leading to higher comfort, better quality of life, and conveniences that can offer optimum consumption of valuable resources for the users. This paper presents a low-cost and flexible HA system that uses different sensors and other resources to control commonly used home appliances and connected devices by establishing IP connectivity to access, manage, and monitor them remotely. To enable remote access, an android-based application was developed to monitor and control the home devices. Edge computing (EC) platform is used in the proposed system to enhance reliability and robustness when the computation offloading is required. The system operates automatically according to the environmental conditions in the home based on the home occupants' requirements. The outcomes of the proposed system reveal that it greatly supports the concept of smart HA and capable to significantly reduces the wastage of electricity via optimum utilization.**

Keywords—Smart home; Internet of Things (IoTs); home automation; android application; raspberry pi; edge computing

I. Introduction

Recent advancement in smart phones and inexpensive open-source hardware platforms has empowered the development of low-cost home automation (HA) systems using Internet of Things (IoTs). This decade has seen an enormous attention and interest in sensors and sensor networks. Billions of devices are connected to internet already and further increasing sharply with the passage of time. Considering the current progress and the importance of IoTs, 31 billion devices have been connected in 2020 and this figure can reach to 75 billion by 2025 [1-3] as detailed facts are represented in Fig. 1. The devices include smart appliances (lights, fans, refrigerators, air conditioners, ovens, washers etc.), security and safety systems (PIR motion detector sensors, monitoring cameras, smoke and fire detectors sensors etc.), and other smart home energy equipment, like smart lighting, thermostats, and actuators.

HA is a way of life by utilizing wireless sensors and other modern smart technologies that can make a home to accomplish different sets of operations or tasks automatically and remotely whenever they are required. Based on recent success of IoTs for HA system, it is becoming reality in improving the quality of living by making it more comfortable due to many embedding intelligences into sensors and actuators and connecting them intelligently for smart homes. The IoT market has generated revenue around $300 billion in 2020, and the value of Smart Home market worldwide has reached to $43 Billion. This is nearly three times more than that in 2014 [4-6].

Homes and offices chores can be automated by using the internet to control and monitor the household devices by considering the environmental conditions and the human comfort. Many vendors have introduced and producing a range of HA devices to regulate and control the indoor ventilation or environment. For this a variety of wireless sensors and home controlling products including home energy monitor, smart plugs, smart temperature thermostats, outlets, sockets, and smart vents etc. are available. Remote controlling or monitoring is not only the facility of HA system but more importantly it helps to minimize operating costs and saves electricity or other resources. Moreover, it can be ideal for the aged and disabled people [7].

The edge computing (EC) platform has a lot of advantages and useful applications related to smart HA. Its prominent benefits are minimizing the latency issues, providing location awareness and mobility support, real time response, less cost for data processing in terms of less bandwidth consumption, home inside environment control without the home resident's intervention, timely weather predictions and many more. In IoTs, each equipment can consume a huge amount of energy if its communication is not optimized [8, 9]. Further, many applications are response sensitive so to satisfy time critical applications, EC can be greatly helpful. In addition, for the smart devices, local computation is cheaper in terms of energy consumption due to less physical distance for data communication because devices may generate data at every single moment and required processing on the collected data. During their data transmission, they required more energy if the transmission time is high, and they utilize more communication channels as well. For instance, when CCTV cameras' data is stored in the cloud, it means far away from the end devices that it requires more bandwidth and more time for data transmission comparatively to the EC. So, in the case of EC, due to less distance it takes less time and consumes less bandwidth for data transmission. In this example EC is therefore saving resources in terms of energy, time, and communication channel cost etc. [10].

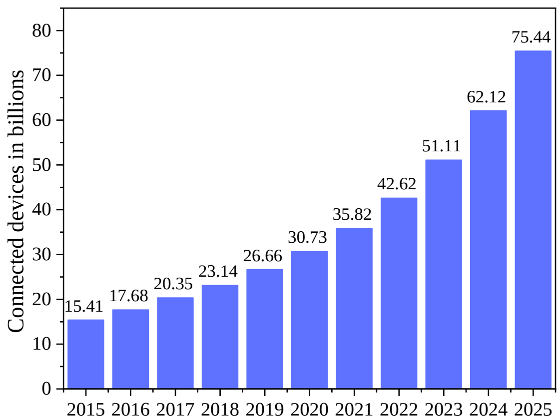

Fig. 1. The Current and Expected Number of Devices that will be connected to Internet on Yearly basis.

In this paper we present a HA system using IoTs, android application, that involving the EC platform. The significance of our designed system is that there is no need to change or replace the current household appliances, as it offers options to connect these devices through a control panel. The main component in the control panel is Raspberry pi which controls all the home appliances. Several sensors are connected/integrated to Raspberry pi for it to receive various measurements like temperature, humidity, light intensity etc., for which it can control the appliances in considering the resident requirements. The whole system consists of commonly used home appliances (lights, fans, switches, power plugs, air conditioners etc.) different sensors (light sensor, PIR sensor, temperature sensor etc.), Raspberry pi 4, power relays, and a touch screen panel as shown in Fig. 5. The effectiveness of the designed system (i.e., for integrated sensors with the home devices and switches), reveals that it greatly achieves the concept of smart HA.

A. Some Major Applications of HA

Some major applications are discussed here to support the concept of HA. With the help of IoTs, it can recognize or notice the resident's certain habits or activities e.g. exercising, showering, sleeping times, hence IoT can regulate the home interior environment accordingly [11] such as changing the temperature or environment of a house, by smartly controlling windows/door entry points. Doors can be operated automatically only when residents enter or leave the room. Same concept can be applied to the car garage. Windows shutters can be adjusted according to the outside temperature and light intensity, or closed fully in case of raining [12, 13].

Security or safety is always the prime concern of any house. It can be greatly improved by IoT concepts. For example, human presence or any moving object, particularly at the room entrances and the main gate, can be detected by using PIR motion detection sensor, hence enhancing the security. The safety of home residents can certainly be attained efficiently by installing some sensors for smoke or fire detection, sensing the odd materials in water, and storms prediction etc. An automated safety alarm can mitigate the loss or harm based on the received information. Security and safety systems can be beneficial to elderly and disabled people for them to control or react appropriately to the home appliances/devices during critical conditions [14].

Home gardens, lawns, indoor plants can be made smarter by IoT. Sensor(s) can be fixed in root of plant or in the soil to identify the moisture level to trigger a motor pump to irrigate/water the plants [15]. Other than that home devices can be controlled according to an individual routines and behaviors. For example, music can be turned on/off or its volume can be tuned depending on the routines or schedules of the home residents. Likewise, it is possible to define morning or evening routines to adjust the bathroom water heater or windows shatters to operate in considering the weather conditions [16, 17]. The aforementioned and some other major examples of IoTs are illustrated in Fig. 2.

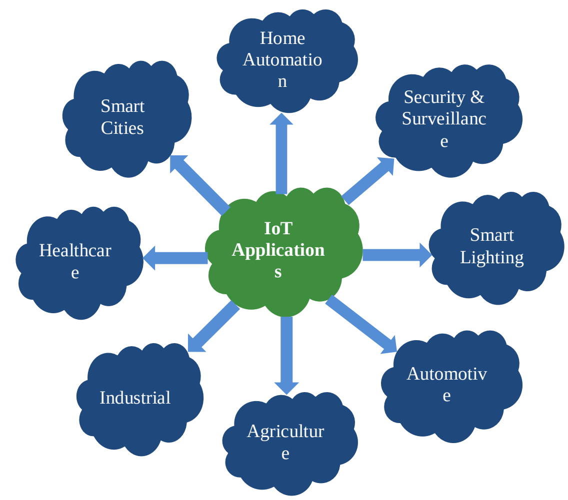

Fig. 2. Major IoT Application Domains.

II. Related Work

The use of IoTs to control the home appliances to achieve the concept of smart home keep attracting the researchers and engineers [18, 19]. Adding IoT based facilities to home environment can enhance the quality of life for home resident and proving blessing for the elderly and disabled people that depends on caregivers or institutional care [20]. There are various wireless technologies suitable for remote data transfer such as Wi-Fi, RFID, and cellular connectivity has been utilized to embed various levels of intelligence in the HA. Further, by introducing the IoTs, the research and implementation of HA are getting more and more attention from the research community.

An IoT based system was proposed in [21] to reduce the cost and power consumption by utilizing the solo computing platform. The system used Arduino and Android smart phones through virtual buttons and sliding switches, user could control and observe the home devices using text and voice commands. A similar work was presented in [12] to provide the facility for monitoring smart home and was especially useful for the disabled persons. The proposed system was customizable to allow changes be made according to the needs of future requirements.

In [22], the Bluetooth 4.0 protocol was used to provide the communication among the users and smart home devices.

Users could control the home devices with their mobile phones or tablets. The drawback of the system was the control was restricted to a short range due to Bluetooth technology. To conserve the home energy, the authors have designed a system by using different sensors like temperature sensors, motion detection sensors and luminance sensors to automate the home appliances like air conditioners, fans, lights, etc. and the proposed system can save electricity usage as well [23].

A reliable and low cost HA system using Arduino microcontroller and various other sensors was offered in [24] to access and control the home devices (fans, lights, TV, etc.) with the help of smart phone application or web-browser. Similarly, another HA system was presented in [25] which used a micro-web server at home side with the IP connectivity allowing user to interact home devices with the smart phone. Different sensors were used like current sensor and temperature sensor to automate the home appliances. Further, authors proposed [26] a system to control the home appliances for HA. In the proposed system four types of sensors were considered i.e., temperature sensor, PIR sensor, smoke and gas sensor, and ultrasonic sensor to automate the home environment and intrusion detection.

For the home security purposes, many systems have been proposed, few of them are discussed here. In [27], authors designed a system to improve the home security by utilizing the cameras to capture pictures to share the information on who entered the house or room. Another system was presented in [28], to enhance the home security by using some sensors, and the advantage of this system was cost effectiveness. Data could be transferred between the devices and controllers by using one or more communicating technologies like Wi-Fi, GSM, ZigBee or Ethernet. ZigBee and Bluetooth were used for data sending among the sensors and CPU. These data sharing technologies were used due to easy implementation and low power usage.

Involving the edge/fog computing in smart home system can be very effective and useful for computation offloading to minimize the latency and gives good real time response. So, researchers have integrated edge/fog computing in their smart HA systems. In [29], authors presented a framework for HA system by involving the fog computing to achieve the concept of energy optimization. With their proposed system, the network traffic and delays were minimized for smart homes. In addition, by involving the EC platform, a system for electrical demand prediction for the smart homes was presented in [30]. An intelligent edge node was used for their system that stored heterogeneous data, but the analysis and processing were done at the cloud node. The system can collect data by the IoT devices from the environment, and provide a better quality of service and greater scalability of computing resources through the EC.

Further in [31], the authors proposed an IoT based system by involving the EC for the smart buildings and homes. In the designed system, the facilities like temperature control, energy consumption monitoring, safety, comfort level were considered. The system addressed issues like scalability and interoperability. A brief comparison of characteristics of IoT, edge and cloud computing are presented in Table I.

TABLE I. CHARACTERISTICS OF IOT, EDGE AND CLOUD COMPUTING [32]

Characteristics	**IoT**	**Edge**	**Cloud**
Deployment	Distributed	Distributed	Centralized
Components	Physical devices	Edge nodes	Virtual resources
Computational	Limited	Limited	Unlimited
Storage	Small	Limited	Unlimited
Response time	NA	Fast	Slow
Big data	Source	Process	Process

Many literatures have made significant contributions to the design and development of HA systems. However, most of these efforts mainly focused on switching and controlling the home appliances rather than remotely monitoring the home environment. The system provided in this article carried a unique architecture for IoT based HA with the help of an android application which saves energy via optimum utilization and reduces the latency when the data is required for computation offloading, hence can be beneficial irrespective of regional or location dependencies.

III. PROPOSED SYSTEM

Considering the factors and challenges discussed in literature review, we designed a low cost, flexible and standalone home monitoring and controlling system. The developed system contains different controllers, relay modules, Raspberry Pi with Wi-Fi support, and various sensors. The main equipment and devices used are: light sensor, air sensor, PIR (passive infrared sensor), smoke detecting sensor, hall effect sensor, Raspberry Pi, display panels (touch screen), and Android application.

To manage and control the home appliances or against the data measurements by various sensors, a smart interface is designed with the help of an Android-based application to enhance the system usability. The significant feature of the system is that it is customizable according to various requirements and scenarios with little configurations and minimum re-coding. The major advantage of our system is that there is no need for replacement of the current household appliances, the existing devices can be connected to a control panel forming part of the smart HA system.

In the designed system, we utilize the Hall Effect sensor and passive infrared (PIR) sensor to observe and monitor moving activities when these are required. The mentioned sensors are positioned or installed at the entry and exits points to and from the rooms and relevant home space. In addition, these activity monitoring sensors can be useful in dealing with suspicious or intrusion activities. To identify the light intensity, light sensor is utilized so that system can decide when the room or house lights will be turned on/off. Measuring the air temperature and its intensity helps to make auto switched on/off of air conditioners and fans or making decisions regarding air control in the smart home. For smoke detection, smoke detector sensor is installed to make timely alarm warnings to escape from fire disaster. Various other sensors can be equipped or considered according to the needs or requirements of the system or the home residents.

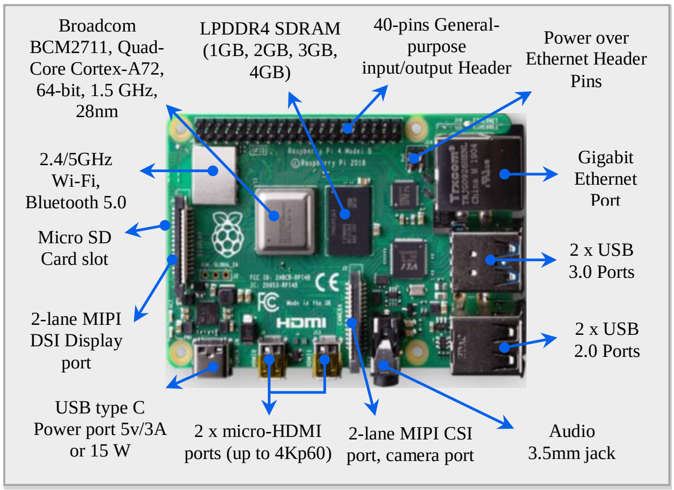

Fig. 3. Raspberry Pi 4 Model B Overview.

Raspberry pi plays the role of main controlling unit where all the sensors pass their measurements to it for taking further actions. Raspberry pi has many features like Wi-Fi connectivity, Bluetooth facility, and it can be connected to a display panel. In case of extra memory requirements, external memory storage can be used [33]. For utilizing the Wi-Fi or wired internet connection facility, it can be connected to the internet where we can easily control its operations through the android application. In the case of unavailability of internet, Raspberry pi can be connected via Bluetooth. To make it functional we have written a code for it, so that it could perform various tasks for our proposed system. Raspberry pi receives instructions as inputs from different sensors or from residents then it sends command(s) to home appliances via power relays. Various components and specifications of Raspberry Pi 4 model B are shown in Fig. 3.

Fig. 4 (block diagram) illustrates the basic components for the proposed system, where raspberry pi is connected to smart phone, to a display screen, and to an internet connection. It is coupled with different sensors and power relays and these power relays perform the operations of switched on/off the home appliances according to the given instructions of Raspberry pi. In the diagram, it shows how the proposed HA system components interact with each other.

In the proposed system we have considered eight power relays, but these can be extended according to the needs or number of appliances. The power relays are used to switch on/off the appliances according to the instructions from Raspberry pi. As mentioned, the Raspberry pi is connected to the internet via wired or Wi-Fi connection, so Android-based smart phone or smartwatch can be used to control the operations of Raspberry pi. It can receive the instructions as an input from the smartphone or smartwatch or can send the notifications to them for the HA system. Further, a display panel is attached to Raspberry pi where user can see the operations accomplished or by touching the digital buttons on the screen to control the home appliances. Fig. 5 illustrates example of equipment and appliances that can be setup for the proposed HA system.

The designed system can automatically open or close the doors or garage when detecting the human presence. The Raspberry pi can also receive the current weather forecasts from internet then it can automatically open/close the windows or curtains, or on/off the required appliances and home temperature can be regulated accordingly.

If the number of cameras is higher and they record a huge volume of data, then the produced data can be stored in the EC where later on features extraction or processing tasks can be done at this platform (i.e., EC). So, for the computation offloading, EC is added which makes our proposed system more robust and more reliable especially when the task is time stringent or having more data size for computation.

If the resident doesn't have mobile phone and wants to control something at home, then it can regulate the home appliances by using touch screen which as displayed in Fig. 6. But this is not the main motive of our designed system, although we can say it is a facility whenever in the case of unavailability of mobile phone.

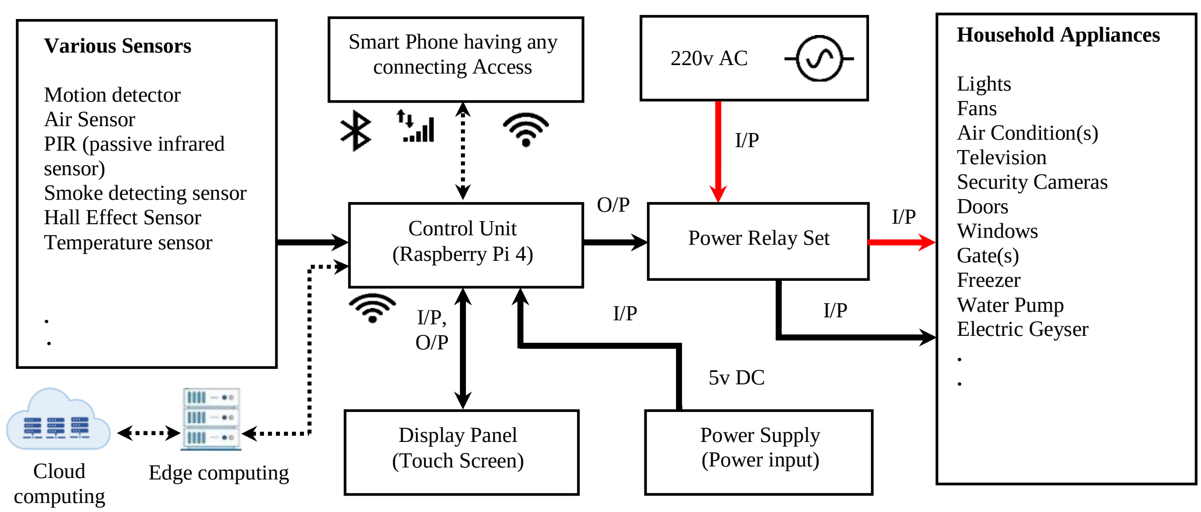

Fig. 4. Block Diagram for the Designed System.

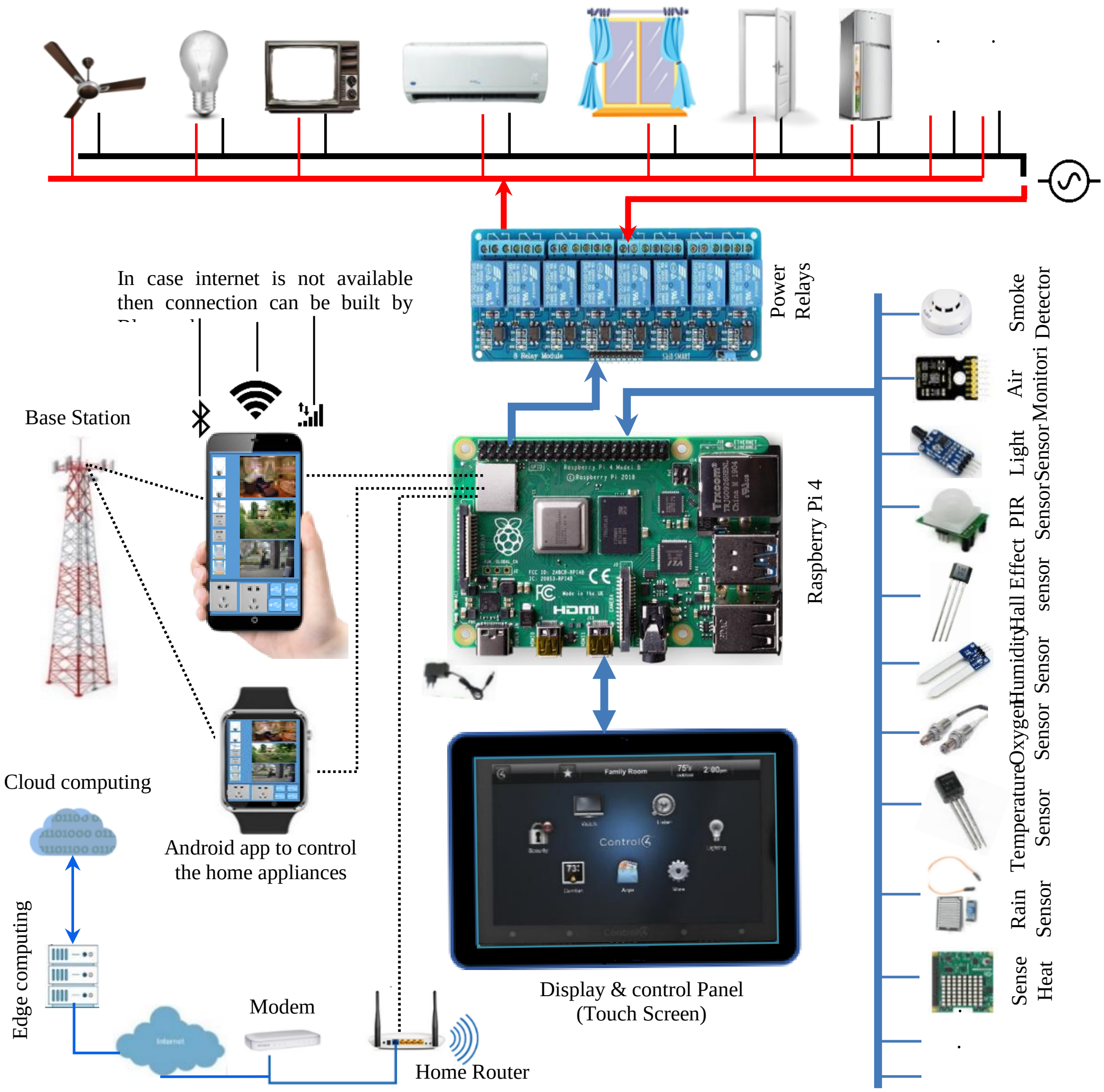

Fig. 5. Example of Equipment and Appliances Connected for the Proposed HA System.

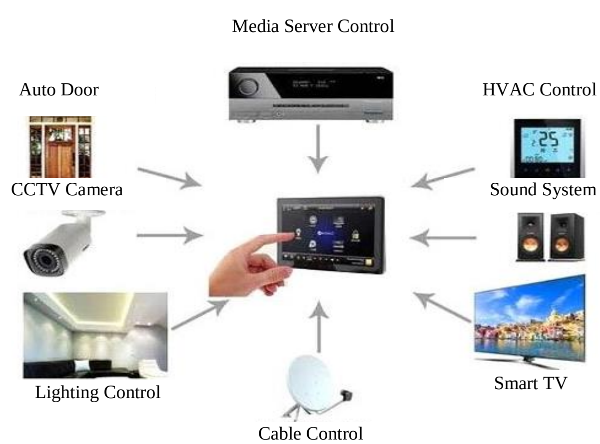

Fig. 6. Illustrates when the Mobile Phone is Unavailable, Touch Panel can be Utilized.

To use the designed system, the user needs to install the developed application. After checking the internet connectivity, user will use its user id and password for login to access the home appliances. Afterward login access, the system shows the available rooms, where a specific room will be selected for switching on/off the device(s).

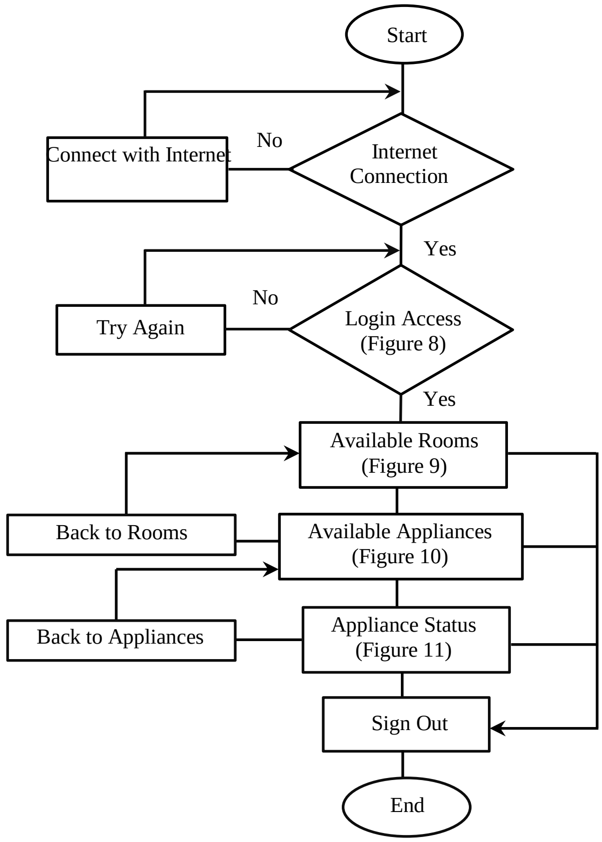

Fig. 7. Process Flow for the Developed System.

Algorithm 1: Smart HA System

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1:  Input: Instruction from Android App, 220-volt input to home
        appliances, inputs from different sensors to Raspberry Pi 4
2:    if Internet connection available then
3:    |   if Login Access granted (Figure 8) then
4:    |   |   show Available Rooms (Figure 9) || Sign out
5:    |   |   if select Available Room (Figure 9), then
6:    |   |   show Available Appliances (Figure 10) || Sign out
7:    |   |   if select Available Appliances (Figure 10), then
8:    |   |   show Appliance Status (Figure 11) || Back to
    |   |          Room || Sign out
9:    |   |   if select Back to Rooms, then
10:   |   |       goto line number 4
11:   |   |   if  select Appliance Status (Figure 11) then
12:   |   |       Modify the applicane status (i.e., ON/OFF
    |   |       etc.) || Back to Appliances || Sign out
13:   |   |   if select Back to Appliances, then
14:   |   |       goto line number 6
15:   |   |   end if
16:   |   else Try Again
17:   |   end if
18:   else Connect with Internet
19:   end if
20: Output:  Home appliances are operated automatically
           according to the residents' desires
```

Next, the screen will display the information of available appliances in that room. By clicking on the desired appliance user can see its status like either it is on or off. By choosing the options on the display, resident can on/off the household devices or manage the desired operation. Fig. 7 (flowchart) and the Algorithm 1 present the whole mechanism and working behavior of the proposed system.

A. Android Application

After installing the HA system application, the user can login by using theuser ID and password or can create an account as shown in Fig. 8. After successful login, Fig. 9 shall appear as the main interface screen. The information about room environment and weather conditions like temperature will be available on this screen. Further this main screen has a list of all available rooms. User will select the desired room for controlling the appliances, for example if the user selects bedroom 2, then the next screen is opened as in Fig. 10 showing the list of all available appliances for the selected room. Here, the user can control or navigate the desired appliance for the selected room and also the user can see the current status of a particular appliance.

User can select any appliance from the list. For instance, if the desired appliance is air conditioner, then user can switch on/off this appliance like in Fig. 11 (screen), and can change its functions/intensity like temperature or fans speed, etc. An additional feature of this application is that user can set the timings for different appliances like when the lights to be turned on/off. The system is capable for reminding the owner by sending the notification(s) about the current weather and home environment conditions. It can send the alert(s) when motion sensors detect suspicious activities or when someone trying to access application as unauthorized user.

B. Challenges during System Designing and Application Development

Installation of different types of sensors in home appliances particularly when these are designed by different vendors, can be a major challenge in developing a HA system [34, 35]. Hence, there must be an appropriate mechanism for data controlling and processing capabilities to manage the entire system effectively. Although availability of reliable internet connectivity plays a key role in many cases, at certain locations they may not be feasible. Further, professionals are needed to develop the system by considering the various home situations and the dependability of sensors on the home devices. Another issue is that the confidential information of a person in house can be leaked during the data transmission, so proper data security mechanisms must be well defined for home data. To achieve the goal of "HA or connected home", several professions like electrician, builders, locksmith, gasman, etc., may be involved for their skills, expertise, and businesses according to market demands. Often the mentioned occupations may not have entire knowledge about the HA and there must be some predefined standards when they are installing the home devices especially when these devices are from different vendors.

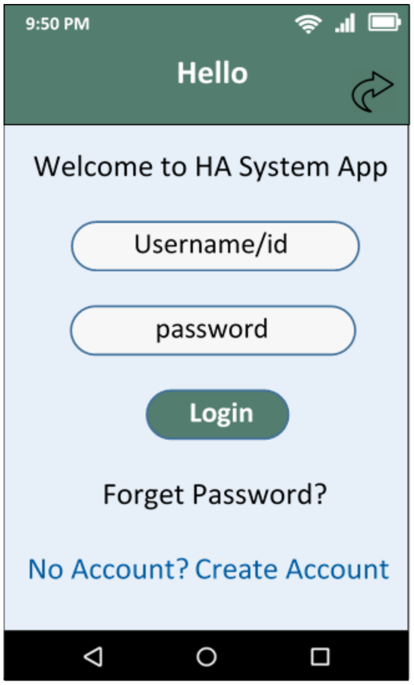


Fig. 8. Sample Screenshot of the Developed Application for Login Access.

Fig. 9. Sample Screenshot of the Developed Application for Selecting the Desired Room.

It is usual that smart home automation systems come with regular upgrades or patches, so customized configurations or alterations must be supported in such system.

It is normal that appliances or devices are of different types and manufactured by multiple manufactures. So, there should be one application that can deal with all of them. As such, developing a generic application for HA system not only comes with a variety of technological problems but security is also a major challenge that must be considered. Risk factors are often involved when sending or exchanging a home's confidential information on the internet. It is important to examine all the technicalities of home appliances or devices and security matters when sharing the private information like presence of location to someone whom are unauthorized. Our developed application effectively deals with the above-mentioned situations.

Fig. 10. Sample Screenshot of the Developed Application for Selecting the Desired Appliances.

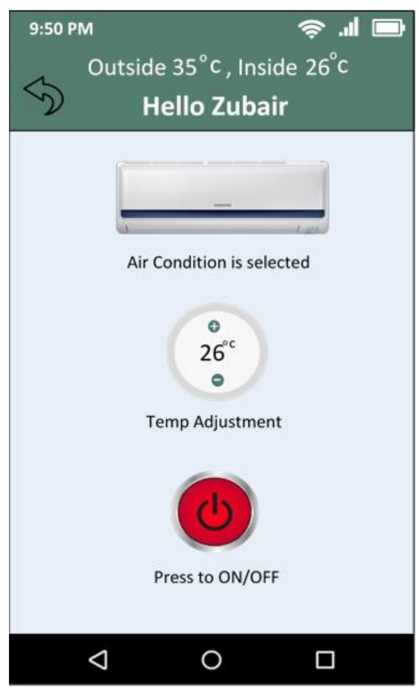


Fig. 11. Sample Screenshot of the Developed Application for Adjusting the Functions of Desired Appliances.

IV. Result and Discussion

Our design has considered an average size of house consisting of two bedrooms, one guest room, one TV lounge, one dining hall, one kitchen, and one car garage. It has appliances including three air conditioners, 3 room heaters, one fridge, one water heater, seven fans, one microwave oven, one washing machine, and 12 lights. We assumed that it is in Multan city, Pakistan where the weather conditions are normally around 5°C to 20°C in winter and 30°C to 45°C during the summer. Electricity bills are higher in summer comparatively to the winter due to more air conditioners usage.

A. Electricity Consumption of Existing System against the Designed HA System

For electricity consumption analysis 'current and voltage clock meter' are utilized, to capture key energy consumption information. Data from these meters, allow us to calculate the electricity usage in the aspects of cooling, heating, and lighting of the house. Three methods were used to measure the electricity utilization i.e., day-wised, monthly, and annually. In the first case, power consumption is calculated for a single day by comparing the existing electricity system with the designed HA system and this is demonstrated in Fig. 12. By this method, owner(s) know the home power consumptions at different times of a day. So, with this data, resident(s) can plan at which time to save the electricity or the timings when the wastage of electricity can be best avoided.

The electricity consumption is measured in per Kilowatt hour (kWh). That is, one unit of electricity or kWh can be calculated as follows:

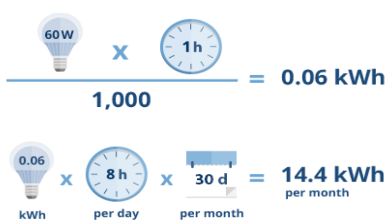
$$\text{Energy consumed} = \text{Power} \times \text{Time}$$

$$\text{Electricity unit (kWh)} = \frac{\text{Power (in watts)} \times \text{Time (hours)}}{1000}$$

A lightbulb of 60 watts used for 8 hours per day (240 hours per month) will consume electricity in one month as follows:

(watts/1000 = .06 kilowatts)

06 kW * 8(hours) * 30(days) = 14.4 kWh



In the second case, these calculations were perfomed on monthly-wise. The months in which more cooling are required are May to August and are considered as the peak of hot weather in Pakistan. To attain the comfort level of 20°C-27°C (68-80°F), a normal size home consumes average of 700 to 900 kWh per month of electricity in these months. Whereas to maintain the comfort level for the winter months which required more heating, i.e., December to February, it required nromally 500 to 600 kWh. In considering the same house environemnt but with the involvement of the designed HA system, the power consumption was around 100 to 130 kWh per month lesser than the existing system. This comparison of the electricity consumption shows that the proposed HA system significantly lowered the power consumption. The developed HA system, helps to save the electricity by 15%-20% per month. Fig. 13 presents the comparison, and clearly showing that the developed system consumed less electricity than the existing system.

To attain the comfort level of 20°C - 27°C (68-80°F), one house can consume around 7180 kWh per year when it is not using the designed HA system, but when it is integrated with the desigend HA system then the consumption drops to around 6100 kWh annually. Comparison of these power consumptions annualy are depicted in Fig. 14.

The proposed HA system saves on average of 1080 kWh of electricity per year for one house. It is beneficial to mentioned that this amount can be greater when considering to integrate this system in larger number of houses. Conservatively, for a housing society having 8000 houses, the saved electricity can be reaching to 8,640,000 kWh per year. This amount is saved within one year.

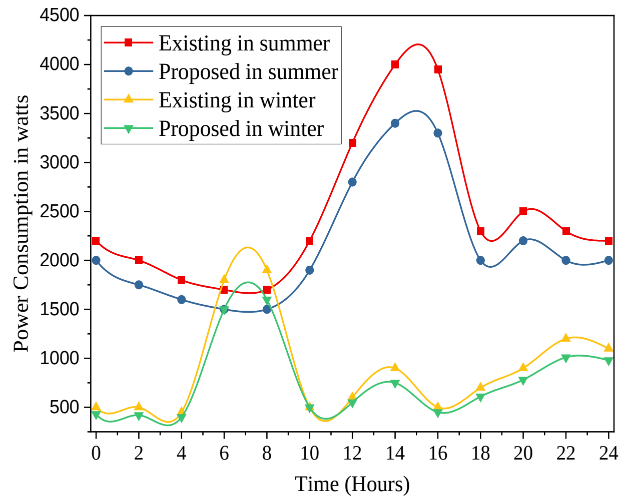


Fig. 12. Hourly Energy Consumption Graph for One Day, Comparing the Existing System to the Designed HA System.

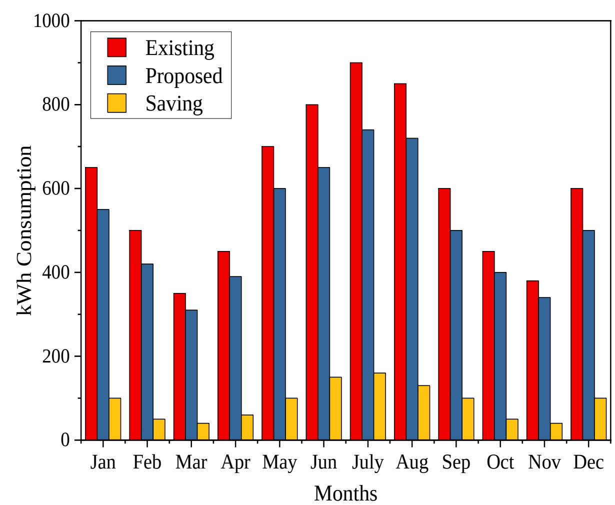


Fig. 13. Comparison of Monthly kWh Consumptions between Existing System and the Developed HA System.

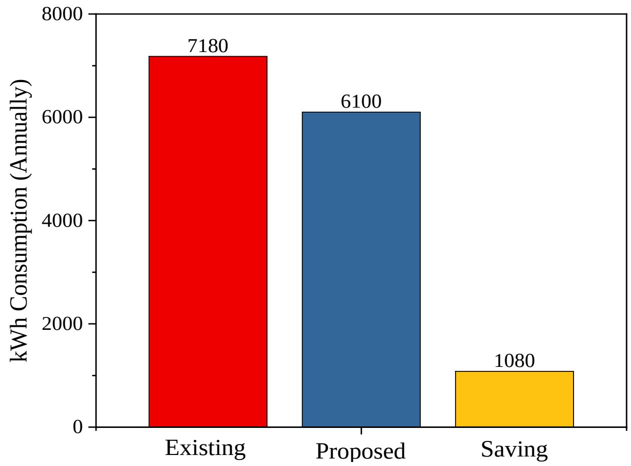


Fig. 14. Yearly Comparison of kWh Consumptions.

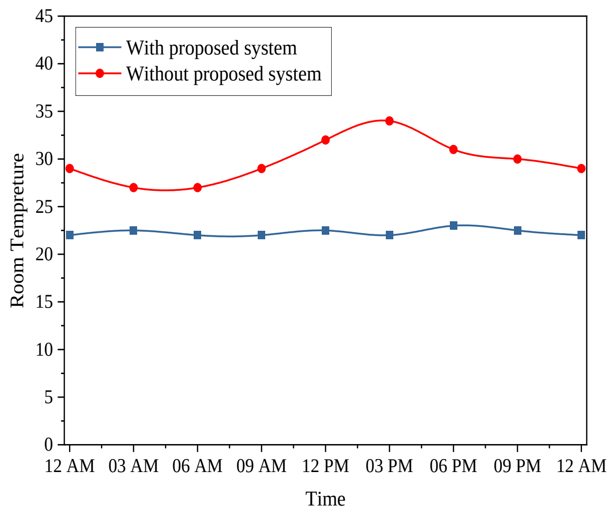


Fig. 15. Room Temperature in Summer Season with and without the Involvement of the Designed HA System.

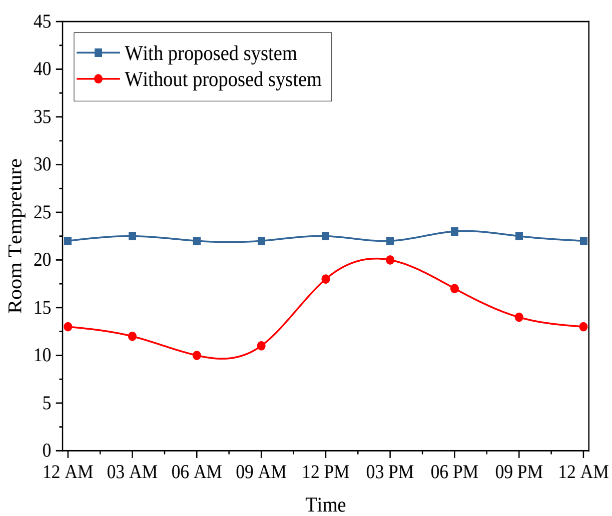


Fig. 16. Room Temperature in Winter Season with and without the Involvement of the Developed HA System.

The comparison of the room temperature in summer and winter seasons, with and without the involvement of the developed system is illustrated in Fig. 15 and Fig. 16, respectively. The temperature was measured with respect to hourly time for a single day. It can be seen that the designed HA system is able to maintain the desired room temperature without major fluctuations in both seasons (summer and winter). The temperature data was taken by using temperature sensor. With the available data, the residents of a home can analyze the home environment from anywhere and can take the necessary actions to save electricity. It is clear that without the involvement of the proposed system, there are large variations in room temperature. So, the concept of our smart HA is greatly beneficial to consumers.

B. What have been Achieved?

- Smart use and control of home devices or appliances by the proposed HA system.
- Designed HA system saves energy because appliances operate only when they are required, while automatically switched off when they are not needed, thus reduces the wastage of electricity (around 18%).
- No need to replace the current appliances because changes are made and required only for the control unit.
- Connectivity with internet makes HA system more robust and provide intelligent work flow according to the prediction on home appliances.
- HA system provides home alarms and warnings features to prevent any loss of home appliances/properties.
- Generate timely notification for voltage fluctuations that helps to save home appliances from potential faults or problems.
- The system is good enough and capable to control a large size of house with the variety of electronics and electrical devices easily.
- EC is integrated in the proposed system to improve its reliability and making it more robust for the computation offloading.
- The motion monitoring sensors can be greatly useful in sustaining the home security by sending timely alert to the resident or house owner.
- It is an Android app that can be easily installed and used by users with Android smart phone.

The developed HA system can control how and when a home device will respond and act to attain desired home environment. It offers a fully controlled and convenient environment and helps to reduce the energy expenditures. It can assist the users and residents to control any mishap and unpredicted incidents that may happen at home.

V. Conclusion

In this paper, an energy efficient and flexible HA system is presented for controlling and monitoring the home appliances using the smart phone-based Android application. Edge computing is used in the system to enhance reliability and robustness in computation tasks offloading. The system uses IoT-based networking functions to remotely control and monitor the home appliances. The proposed application allows home user/resident to conveniently control the commonly used appliances in a home. The application and the overall hardware architecture for controlling are flexible for easy modification when new appliances or new features in application to be added or remove to support new home requirements. The system operates automatically according to the home environmental conditions set by the home occupants' requirements. The developed HA system enhances the automation, security, remotely controlled, user friendly, more home comfort by saving around 15% to 20 % electricity through the properly configured HA system.

In future work, we are planning to enhance the system's features and its coverage area, as well as adding more functions and options to extend its robustness. The enhanced system can cater for garden and lawn. Adding in extra intelligence to the future system to capture the behavior of the home residents, thus setting the home environment more naturally.

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References

[1] S. Shome and R. Bera, "Narrowband-IoT base station development for green communication," in Advances in greener energy technologies: Springer, 2020, pp. 475-487.

[2] Y. Deng, Z. Chen, X. Yao, S. Hassan, and A. M. Ibrahim, "Parallel offloading in green and sustainable mobile edge computing for delay-constrained iot system," IEEE Transactions on Vehicular Technology, vol. 68, no. 12, pp. 12202-12214, 2019.

[3] Z. Sharif, L. T. Jung, I. Razzak, and M. J. I. I. o. T. J. Alazab, "Adaptive and Priority-based Resource Allocation for Efficient Resources Utilization in Mobile Edge Computing," 2021.

[4] A. Bujari, M. Furini, F. Mandreoli, R. Martoglia, M. Montangero, and D. Ronzani, "Standards, security and business models: key challenges for the IoT scenario," Mobile Networks and Applications, vol. 23, no. 1, pp. 147-154, 2018.

[5] D. C. Khedekar, A. C. Truco, D. A. Oteyza, and G. F. Huertas, "Home Automation−A Fast - Expanding Market," Thunderbird International Business Review, vol. 59, no. 1, pp. 79-91, 2017.

[6] T. Chakraborty and S. K. Datta, "Home automation using edge computing and internet of things," in 2017 IEEE International Symposium on Consumer Electronics (ISCE), 2017, pp. 47-49: IEEE.

[7] R. Sokullu, M. A. Akkaş, and E. Demir, "IoT supported smart home for the elderly," Internet of Things, vol. 11, p. 100239, 2020.

[8] J. Ren, H. Wang, T. Hou, S. Zheng, and C. Tang, "Federated learning-based computation offloading optimization in edge computing-supported internet of things," IEEE Access, vol. 7, pp. 69194-69201, 2019.

[9] Z. Sharif, L. T. Jung, and M. Ayaz, "Priority-based Resource Allocation Scheme for Mobile Edge Computing," in 2022 2nd International Conference on Computing and Information Technology (ICCIT), 2022, pp. 138-143: IEEE.

[10] V. C. Leung, X. Wang, F. R. Yu, D. Niyato, T. Taleb, and S. Pack, "Guest Editorial: Special Issue on Blockchain and Edge Computing Techniques for Emerging IoT Applications," IEEE Internet of Things Journal, vol. 8, no. 4, pp. 2082-2086, 2021.

[11] X. Guo, Z. Shen, Y. Zhang, and T. Wu, "Review on the application of artificial intelligence in smart homes," Smart Cities, vol. 2, no. 3, pp. 402-420, 2019.

[12] S. K. Vishwakarma, P. Upadhyaya, B. Kumari, and A. K. Mishra, "Smart energy efficient home automation system using iot," in 2019 4th international conference on internet of things: Smart innovation and usages (IoT-SIU), 2019, pp. 1-4: IEEE.

[13] Z. Sharif, "Internet-of-Things based Home Automation System using Smart Phone," Sir Syed University Research Journal of Engineering Technology, no. 2, 2021.

[14] D. Mocrii, Y. Chen, and P. Musilek, "IoT-based smart homes: A review of system architecture, software, communications, privacy and security," Internet of Things, vol. 1, pp. 81-98, 2018.

[15] A. A. Zaidan et al., "A survey on communication components for IoT-based technologies in smart homes," Telecommunication Systems, vol. 69, no. 1, pp. 1-25, 2018.

[16] H. Ghayvat, S. Mukhopadhyay, B. Shenjie, A. Chouhan, and W. Chen, "Smart home based ambient assisted living: Recognition of anomaly in the activity of daily living for an elderly living alone," in 2018 IEEE international instrumentation and measurement technology conference (I2MTC), 2018, pp. 1-5: IEEE.

[17] N. Ahmad, Z. Sharif, S. Bukhari, and O. J. I. J. o. A. R. i. B. Aziz, "Insights Into Functional and Structural Impacts of nsSNPs in XPA-DNA Repairing Gene," vol. 12, no. 1, pp. 1-12, 2022.

[18] B. Hafidh, H. Al Osman, J. S. Arteaga-Falconi, H. Dong, and A. El Saddik, "SITE: the simple Internet of Things enabler for smart homes," IEEE Access, vol. 5, pp. 2034-2049, 2017.

[19] M. Uddin et al., "Cloud-connected flying edge computing for smart agriculture," vol. 14, no. 6, pp. 3405-3415, 2021.

[20] G. A. A. de Oliveira, R. W. de Bettio, and A. P. Freire, "Accessibility of the smart home for users with visual disabilities: an evaluation of open source mobile applications for home automation," in Proceedings of the 15th Brazilian Symposium on Human Factors in Computing Systems, 2016, pp. 1-10.

[21] O. Hamdan, H. Shanableh, I. Zaki, A. Al-Ali, and T. Shanableh, "IoT-based interactive dual mode smart home automation," in 2019 IEEE international conference on consumer electronics (ICCE), 2019, pp. 1-2: IEEE.

[22] S. M. Patel and S. J. Pasha, "Home automation system (HAS) using android for mobile phone," International Journal Of Scientific Engeneering and Technology Research,, ISSN, pp. 2319-8885, 2015.

[23] V. Lohan and R. P. Singh, "Home Automation using Internet of Things," in Advances in Data and Information Sciences: Springer, 2019, pp. 293-301.

[24] L. M. Satapathy, S. K. Bastia, and N. Mohanty, "Arduino based home automation using Internet of things (IoT)," International Journal of Pure and Applied Mathematics, vol. 118, no. 17, pp. 769-778, 2018.

[25] R. Piyare, "Internet of things: ubiquitous home control and monitoring system using android based smart phone," International journal of Internet of Things, vol. 2, no. 1, pp. 5-11, 2013.

[26] T. S. Gunawan, I. Rahmithul, H. Yaldi, M. Kartiwi, and N. Ismail, "Prototype design of smart home system using internet of things," Indonesian Journal of Electrical Engineering and Computer Science, vol. 7, no. 1, pp. 107-115, 2017.

[27] S. Brundha, P. Lakshmi, and S. Santhanalakshmi, "Home automation in client-server approach with user notification along with efficient security alerting system," in 2017 International Conference On Smart Technologies For Smart Nation (SmartTechCon), 2017, pp. 596-601: IEEE.

[28] N. Vikram, K. Harish, M. Nihaal, R. Umesh, and S. A. A. Kumar, "A low cost home automation system using Wi-Fi based wireless sensor network incorporating Internet of Things (IoT)," in 2017 IEEE 7th International Advance Computing Conference (IACC), 2017, pp. 174-178: IEEE.

[29] B. R. Stojkoska and K. Trivodaliev, "Enabling internet of things for smart homes through fog computing," in 2017 25th Telecommunication Forum (TELFOR), 2017, pp. 1-4: IEEE.

[30] S. Zhou and L. Zhang, "Smart home electricity demand forecasting system based on edge computing," in 2018 IEEE 9th International Conference on Software Engineering and Service Science (ICSESS), 2018, pp. 164-167: IEEE.

[31] F.-J. Ferrández-Pastor, H. Mora, A. Jimeno-Morenilla, and B. Volckaert, "Deployment of IoT edge and fog computing technologies to develop smart building services," Sustainability, vol. 10, no. 11, p. 3832, 2018.

[32] W. Yu et al., "A survey on the edge computing for the Internet of Things," IEEE access, vol. 6, pp. 6900-6919, 2017.

[33] P.-J. Chen, T.-H. Hu, and M.-S. Wang, "Raspberry Pi-Based Sleep Posture Recognition System Using AIoT Technique," in Healthcare, 2022, vol. 10, no. 3, p. 513: MDPI.

[34] A. Hong, C. Nam, and S. Kim, "What will be the possible barriers to consumers' adoption of smart home services?," Telecommunications Policy, vol. 44, no. 2, p. 101867, 2020.

[35] M. Ayaz, M. Ammad-Uddin, Z. Sharif, A. Mansour, and E.-H. M. Aggoune, "Internet-of-Things (IoT)-based smart agriculture: Toward making the fields talk," IEEE Access, vol. 7, pp. 129551-129583, 2019.