STeSH: Intelligent Speech Technology Enabled Smart Home Automation Using IoT

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Abstract

Due to the advancement in recent technologies and emergence of Internet of Things (IoT), Smart Home Automation (SHA) plays a vital role in today's lifestyle. Many users are showing their keen interest to move towards this era of digital transformation in order to take the potential benefits of such intelligent and smart application. Traditional smart home systems have several limitations e.g. connectivity, coverage area, device dependability, platform supportability etc. which makes the system less sustainable. In this paper, the proposed technique introduces a novel scheme to operate the devices in an intelligent manner. The scheme implements a system named as "Speech Technology enabled Smart Home (STeSH)", which supports voice assisted

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home automation with extreme security and range-free localization. The idea of the proposed technique is to integrate the power of IoT with classical home automation by using an advanced speech technology service. The entire processing of Speech Enabled Services (SES) is applied with this proposed technique and the detailed analysis is presented with proper experimental proof.

Keywords: Speech technology, IoT, smart home automation (SHA), internet enabled services (IES), STeSH, speech recognition.

1 Introduction

This section presents motivation and background studies with a brief introduction followed by a comprehensive state of art of current research. In the end of this section the structure of the paper is also presented.

1.1 Motivation and Background

Now-a-days, smart things and modern technologies are leading over the world with their powerful approaches and provide many intelligent services to mankind to fulfil their needs in many aspects of leisure & commercial domains [1]. In parallel, the communication medium is another growing entity, which supports this gadget to work in intelligent manner to provide ultimate support to people to meet their global communication needs. Specialists do connect computerized gadgets with scientific and authoritative devices to make complex frameworks for quickly extending attributes of uses and physical pursuit. In this context, Internet of Things (IoT) is one of the most emerging technology helps to connect things/devices with each other and can be controlled or monitored remotely through the internet.

Furthermore, there is a need for switch to systematic mode of everything due to the growth of smart urban areas. So the idea of Smart Home Automation (SHA) system is a thought, which is utilized to make the city shrewd. Since the year of 1990, the concept of smart home has been brought into limelight. SHA is a framework, where individual electronic gadgets/appliances are interconnected with each other to develop an interactive space with the user by exploiting the use of internet enabled services (IES) [2]. A smart home gives solace, security and gives the comfort feel to individuals, but with some additional features like energy efficiency (EE), autonomous functionalities makes it more intelligent [3]. SHA implies the observing and control of white goods wisely for viable utilization. These household appliances ought

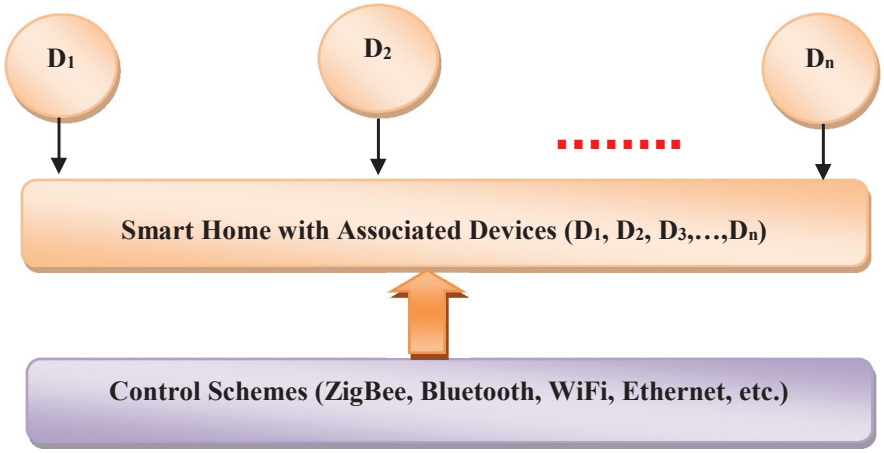

Figure 1 Classical smart home automation system working model.

to be shrewdly interconnected just as to give data for better activities. SHA expanded with IoT gives better adaptability in overseeing and controlling aspects in a more extensive angle. This will bolster the interconnectivity of countless smart homes for better asset use in more extensive territory. Again, with the advent of different speech recognition software like; Alexa-Amazon Echo, Google Assistant, Microsoft Cortana, SILVIA, the demand for SHA is tremendously increasing [4]. As IoT plays an essential role in developing SHA framework, integration of voice recognition techniques/Speech Enabled Services (SES) with IoT brings a new revolution in building intelligent smart home paradigm.

The traditional model of home automation systems as shown in Figure 1, are incorporated with many technologies in both operation and communication wise, but still those models are locked in certain issues and failures [5–7]. Generally, the electrical devices consume power in certain ranges, if you assist the traditional devices along with household device, then the power consumption of the assisting device is more due to its continual operation and uninterrupted power supply (because the system is always in ON state and monitoring the user trigger continuously even if the user don't want to trigger ON/OFF the device for next few days) e.g. refrigerator/washing machine etc.. The capital expenditure (CapEx) and operation expenditure (OpEx) are very high due to the single board operation as well as low-range of communication, energy efficiency and some other issues are also associated with traditional home automation model [8]. Furthermore, the operation methodology of such classical device is either by means of sending

Table 1 Limitations of different proposed techniques

Technology	Cost	Data Rate	Communication Range	Speed	Latency Time	EE	Security
GSM [9–15]	Expensive	Low	Long range	Fast	Low	Low	Less secure
Bluetooth [14–19, 46]	Cheap	Low	Short range	Fast	High	High	Less secure
Zigbee [14, 15, 19–25]	Cheap	Low	Mid-range	Low	High	Moderate	Less secure
Z-wave [14, 15, 26, 27]	Expensive	Low	Mid-range	Low	High	High	Less secure
WiFi [14, 15, 23, 24, 28–34]	Moderate	High	Mid-range	Fast	High	Very Poor	Less secure
IoT [34–38, 51–54]	Cheap	High	Wide range	Fast	Low	High	Highly secure
Voice Recognition [39–44, 47, 48]	Cheap	High	Wide range	Fast	Low	High	Highly secure

short text message or e-mail to operate the end device which increases the complexity and time consumption. Moreover, the factor of lacking in the classical approach is the range restriction, in which those devices are operated only within 10–15 feet coverage area. So the range restriction is also a crucial issue which needs to resolve over the traditional approach. To avail the fringe benefits, many researchers have been proposed several methodologies for SHA by embedding with various wireless communication technologies. Each proposed methodology leads with respective pros and cons. A comparative analysis of different proposed techniques with their limitations is briefly presented in Table 1.

In this paper, we have proposed a novel methodology which integrates the speech technology along with intelligent communication methods to automate the regular usable devices such as electronic gadgets, charging devices, A.C., Television and other household devices. This work mainly focuses on the application of SES to the SHA services for triggering the electronic devices/things by the mean of customer/user voice. In this context, if any other person or intruders tries to operate the device by using their voice, so there is an operating limitation for the device to manage this situation. Secondly, if a low-range communication scheme such as WiFi, Ethernet, Bluetooth ZigBee, etc. is used, then managing the communication limits properly is also another task. So, these problem statements are the major concern to deal with every SHA services. These constraints are rectified by using our proposed approach called Speech technology enabled Smart Home (STeSH), which collects the user voice and register it for their own home usages at one time and provide the separate authorization and authentication

norms for further operations or controlling of devices. In contrast to the authorization and authentication, the STeSH gathers the voice from respective user and verifies its authenticity. If the user is an authorized person, then the device will operate accordingly based on the voice commands raised by the user. And the second concern called communication range limitation is figure-out with IoT enabled services. The following sections clearly illustrate a comparison between existing and proposed system, as well as the result and discussion are clearly presented with the outcome proof and proper prototypical model.

1.2 State of Art

Combining different technologies to facilitate best Quality-of-Service (QoS) and user satisfaction in SHA system, many researches have under gone in various ways. Marie et al. [45] have proposed a SHA framework, which is based on Siri enabled application having the major limitation of device compatibility (supports only in iOS Apple devices). This proposed solution focused on implementation of home automation by speech recognition through Siri application and Raspberry Pi. It has been observed from different tests that, the accuracy and the average latency are 93.33% and 2.12 seconds respectively. The implemented Siri enabled Apple mobile application supports voice translation facility, where the users feel free regarding languages and operate the application in fault free manner. In this proposed technique, only the apple-mobile users are able to use this application and can control the household devices by using this system. In contrast to this, the proposed technique has several shortcomings such as: highly expensive, poor connectivity and platform dependability. A home automation system based on Bluetooth communication technology is presented in [46]. The proposed method uses Bluetooth services with arduino board base. A cell phone is used to send the commands to the Bluetooth and python script programme is for controlling of household devices. The major drawback of the implemented application is low coverage area and incapable for real-time applications. A new approach in SHA is introduced in [47], where human voice is utilized to enable the household devices. In this proposed technique, the system collects the human voice and passes that signal as trigger to respective household device via ZigBee and operates the device according to the respective voice trigger. Certain limitations have been identified in this proposed technique like; programme dependability, pulse based signalling and short-range communication.

The authors of [48] have proposed an approach which integrates Raspberry PI (RPi) as a main controller/CPU to the automation system. The RPi unit collects the voice command from the users and converts the collected commands as a digital signal. Then the converted signals passed as a command to the household devices and allow the device to operate accordingly based on the given trigger from the controller. The proposed solution has several advantages such as; scheduling functions are used to control (turn-on/turn-off) the electrical device, remote web based controlling application can be used to control the electrical equipment's, but followed with some weaknesses e.g. unable to manage ambient devices, requires strong internet connectivity and processing delay. Jain et al. have proposed and web server based home automation system by using RPi in [49, 50]. Based on the command received through e-mail the home device can be controlled by RPi. A special developed algorithm is used to read the command received from mail and fed to the RPi.

A home automation system with improved security by using IoT technology is introduced in [51, 52]. Here, the authors of [51] tries control the home appliances with the help of smartphone and low-range communication protocol like WiFi. The proposed system is also capable of detecting fire accidents. Where in [52], the authors have used Thing Speak with Blynk application to control and monitor the home appliances with the help of smart mobile. This proposed solution also facilitates safety protection for fire and other security issues. An interactive IoT based home automation system is proposed in [53]. This proposed system includes Google assistant to control the household devices based on voice based speech recognition technique. Based on the results and experimental studies in various scenarios, the system performance is observed to be 100% accurate. A SHA with customizable Graphical User Interface (GUI) and low-cost embedded system with internet connectivity is proposed in [54]. In this work, the home appliances can be controlled through a smart phone or any computer based application. The inclusion of GUI facilitates the user demands which are further communicated to control system via wireless technology. The control system incorporates a client-server based model for remote accessing purpose.

A hybrid-based intrusion detection system model for intruder detection is proposed in [55]. The proposed logic uses genetic algorithm (GA) with fuzzy to handle large data volume NSL-KDD dataset to improve effectiveness of detection and to reduce misclassification alarm rate. In addition, component analysis (CA) principle is used to improve the efficiency and accuracy by

eliminating the irrelevant/redundant data from large volume of data set. A non-intrusive approach by using machine learning (ML) for personalized aid living is proposed in [56]. This proposed solution presents a novel modelling scheme for technology instantiation of big data, IoT and non-invasive personalization collecting data from open standard IoT devices. Anathi et al. have proposed an artificial intelligence (AI) based dynamic network traffic restriction methodology by using MAC address verification strategy in [57].

Nevertheless, the entire above quote clearly describes the existing mechanism of SHA is failed to satisfy the user needs based on four different factors such as: time consumption, processing delay, cost, complexity and security. So, that a new approach is required to resolve all such issues and provide an efficient mechanism of operating household devices over home in intelligent and secured manner as well as consider regarding the range issues over existing approach and provide solution for that too. In this work, the proposed logic of STeSh uses the dataset nature to identify the face of the user. The robustness of the proposed system is verified in dual level authentication process i.e. face recognition and speech verification. We have also included the nature of MAC address verification process to eliminate the time consumption over triggering of loads which leads the system to perform faster compare to all other existing schemes.

1.3 Structure of the Paper

The rest part of the current paper is organized as follows,

Figure 2, illustrates the outline of the paper. The proposed system model and the process architecture are described in Section 2 whereas in Section 3, result and interpretation is realized. To end, the conclusion and future work is discoursed in Section 4.

2 System Model & Architecture

This proposed STeSH technique integrates different emerging technologies together, promising it as a more robust and secured mechanism over the operation of voice enabled smart home controlling. The integrated intelligent features are as follows: (A) Speech Recognition, (B) IoT and (C) SHA. All these will be described in details further. The proposed system model is Figure 3.

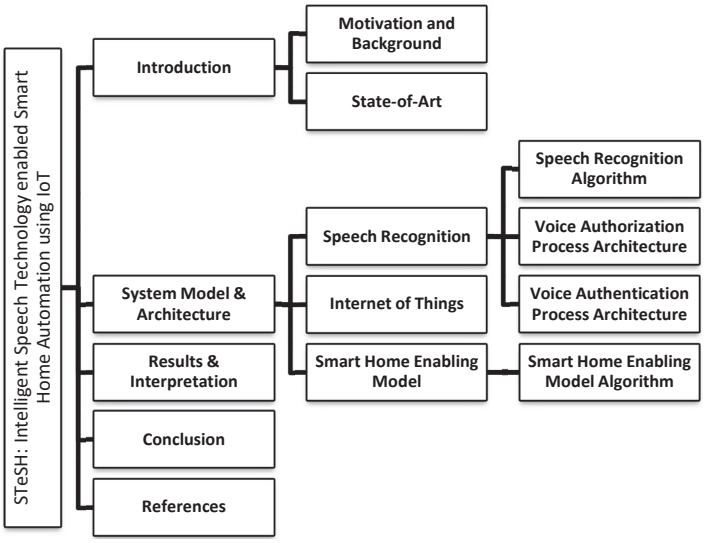

Figure 2 Schematic representation of the structure of this paper.

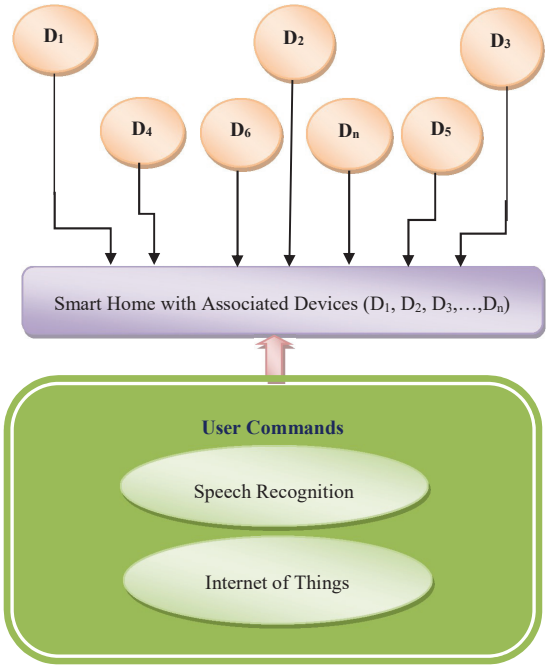

Figure 3 Proposed system flow diagram.

Table 2 Algorithm: Speech Recognition

ALGORITHM: SPEECH RECOGNITION
Input: Analog Human Voice
Output: Digital Conversion and Recognized Boolean Result
Step-1: Importing the respective Speech Recognition library.
Step-2: Create an object to assign the imported speech variables from library.
Step-3: Creating a class and object for audio recognition and it will recognize the audio is extracted from human voice or else any recorded medium (Ex. Class Audio Recognizer (Audio Source)).
Step-4: Assign the recognized voice into a variable (Ex. Aud = Audio_Recognizer [input]).
Step-5: Creating a loop for reading a voice from first to last.
Step-6: With Aud.Read() as Input, this statement will start the loop.
Step-7: Raise the printing statement to intimate to the user to give respective input voice to the system.
Step-8: System automatically changes the mode from query the user to listen the voice as; Aud = Audio_Source.Listen (Input).
Step-9: Add the exception statements to monitor the steps from 1 to 9 for managing the system robustness and fault tolerance from unpredictable exceptions.
Step-10: Extracting Proper Audio from input and change the modulation from input audio collected from user.
Step-11: Analyze the audio input and store the result into defined Boolean variable (Ex. Boolean R).
Step-12: R = Resultant_Voice (Input).
Step-13: Return R.

2.1 Speech Recognition

The Speech Recognition methodology collects the user speech and process the speech into many norms with voice-based feature extraction strategy. In this method each and every voice pulses are segregated and compare those pulses with the authorized user voice. If the user input voice signal is matched with the registered/authorized user voice, then the voice recognition mechanism recognize the voice and gives the positive trigger to the controller to operate the respective household device. The algorithm in Table 2, illustrates the logic of speech recognition algorithm step by step in detail.

The following pseudo-code illustrates the algorithm logic of speech recognition and describes the flow implementation.

PSEUDOCODE: SPEECH RECOGNITION

```
Import Speech-Recognition
define Speech-Recognition as SR_1;
define Audio-Identifier as Aud;

SR_1 = Audio_Recognizer (Audio_Source);
With SR_1.MicrophoneObject() as Input:
   PrintStmt("Input Voice Fully from start to End");
   Aud = Audio_Source.Listen(Input);
Try
   PrintStmt("System think you said improper word:" +
Audio_Source.Listen(Input));
Exception SR_1.UnknownValueError
   PrintStmt("Could not understanding the audio input:" +
Audio_Source.Listen(Input));
Exception SR_1.RequestSystemError as expc:
   PrintStmt("System Error{0}:" + expc);
End Try
```

A schematic representation of voice authorization process is shown in Figure 4. This methodology uses Google based voice assistance, which collects the user voice. The input user voice then processed (quantized and

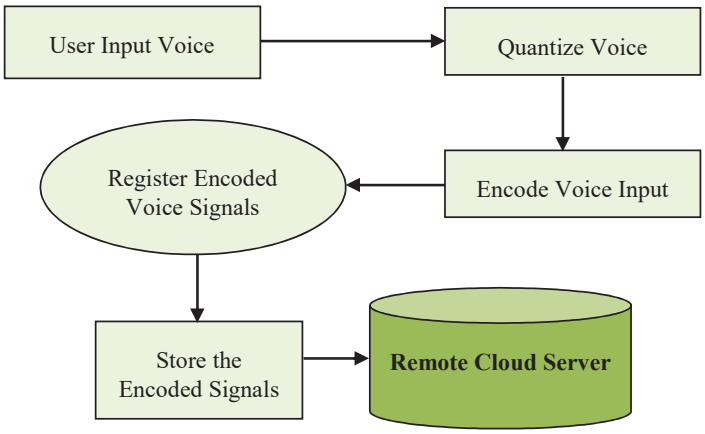

Figure 4 Voice authorization process architecture.

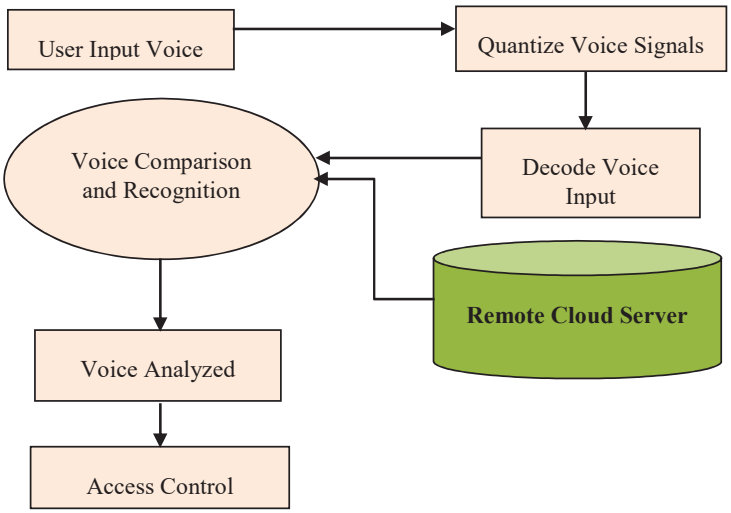

Figure 5 Voice authentication process architecture.

encoded) and the encoded user voice signal is stored in a remote cloud server. Then the registered voice signal is compared with the input voice signal for authentication purposes. If the registered/authorized voice signal satisfies the authentication process, provides the access permission to operate the corresponding devices. If the input/collected voice signal doesn't match with the authorized voice signals, then the system informs regarding the authentication error. The Figure 5 illustrates the overall work flow model architecture of voice authentication process.

2.2 Internet of Things (IoT)

IoT technology is ruling over the world with its power and connectivity, which is nothing but a refined form of network. IoT interconnect the remote cloud server with local devices, so that the user can communicate from anywhere at any time without any restrictions. By using IES user can speak and operate the device from anywhere in the globe without any range restrictions. The application of IoT technology is illustrated in the proposed approach with the help of Equations (1) and (2) [58];

$$IoT = \mathfrak{P}_{\mathbb{OT}} + \Lambda_{CSA} + I_E \tag{1}$$

$$I_E \rightarrow S_{BS} + S_x S_y + P_{\Xi_{x,y}} \rightarrow TTR \tag{2}$$

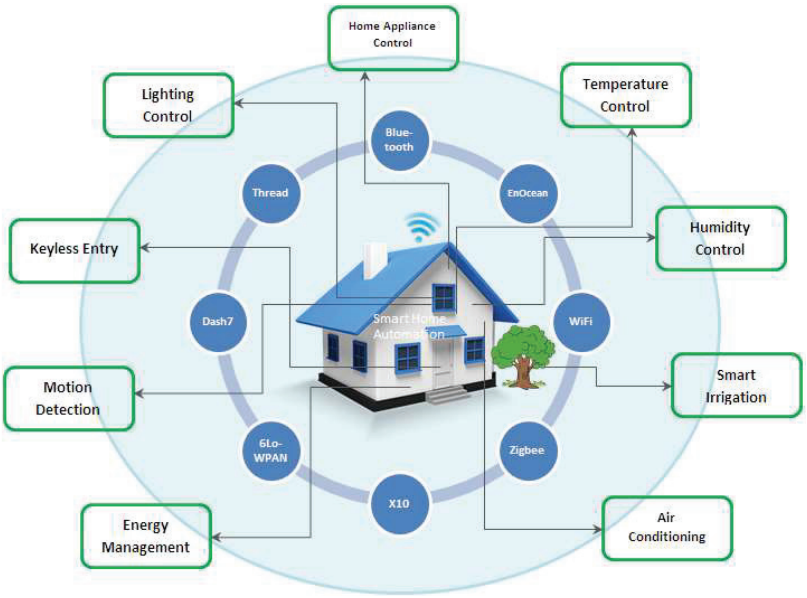

Figure 6 Internet of things service model.

Where, $\mathfrak{P}_{\mathbb{OT}}$ is physical objects/things, Λ_{CSA} refers to controller, sensors and actuators, I_E indicates IES, S_{BS} indicates the base station (BS) signal strength during connection establishment, $S_x S_y$ indicates the total signal strength for the respective coverage range w.r.t. x and y surroundings, P_{Ξ} indicates the associated port number with the established connection and TTR indicates the total traffic ratio over establishing the internet connection.

2.3 Smart Home Enabling Model

As smart home services allows user to operate the household devices from anywhere and at any time around the globe without any range restrictions. This process happens only if the devices are properly bound over communication medium. This support is assisted by means of IES over the proposed work model along with speech recognition technique. The speech recognition system receives voice from the user and process the input voice signal according to authentication norms. If the authenticated user is trying to access the device means it permits the flow. But if an intruder is trying to login into the system, the access permission is denied. The proposed framework is more secured and robust compared to the classical working model and it is more convenient to work with the proposed model because of its unlimited

range support and easy operation. The proposed system provides efficient and intelligent working model in results, which will be illustrated clearly in results further.

The Equations (3) and (4) illustrate the nature of collecting human voice and maintain it into the repository.

$$U_{v_x} \rightarrow V_{x_{i:\ 1\ ton}}, \quad \sum_{x=0}^{n} -1 \begin{pmatrix} n \\ x \end{pmatrix}^{x} i_{v_{\nearrow_i}} \tag{3}$$

Here, U_{v_x} represents the storage of user voice input and x indicate the upper limit variations, $V_{x_{i:\ 1\ to\ n}}$ is the collected input voice range signals which is starting from 1 and ending in n.

$$VR_X = 1 + \frac{Uv_x}{1!} + \frac{Uv_x^2}{2!} + \cdots, \quad Uv_x^{n<N} \tag{4}$$

Where, VR_x illustrates the storage of user voice storage repository and 'X' indicates the upper range of the repository, Uv_{x_i} is the collected input voice range signals which is starting from 1 and ending in n. All these voices are stored in order to the repository for managing the secured voice-based recognition to operate the smart home without any security issues. Following the Equations (2) and (3), Table 3 illustrates STeSH algorithm implemented smart home enabling model in detail.

Table 3 Algorithm: Speech Recognition

ALGORITHM: SMARTHOME ENABLING MODEL
Input: Human Voice or Recorded Speech input
Output: Convert Audio Transcriptions to Text and Triggered the Respective Load
Step-1: Importing the respective Speech Recognition library.
Step-2: Create an object to assign the imported speech variables from library.
Step-3: Declare a Voice_Recognizing class to clearly recognize the speech from user side. We are using Google_Speech recognition library over here.
Step-4: Speech file supported by Speech_Recognition in the format of "WAV/MP4".
Step-5: Google recognizer reads English usually but need to add some language libraries for multi-language supportivity.
Step-6: Match the input voice from the user voice repository.
Step-7: Identify the voice robustness and authenticity.
Step-8: Trigger the Respective Load according to the corresponding input.
Step-9: Return triggered load details to user reflection area.
Step-10: Stop gathering Voice and go to Step-3.

3 Results and Interpretation

In this section, the results of proposed solution are explained in detail. Based on the algorithms presented in Section 2 and evaluating the outputs with the traditional model it assures that; the proposed system is more robust and EE. A comparative analysis between the existing and proposed system in terms of voice capturing accuracy and performance ratio is presented in Table 4. This comparison is analysed by taking 50 different samples from persons of dissimilar age groups between 10 to 60.

The Figure 7 illustrates the graphical comparison view of the existing and proposed system voice capturing accuracy and performance ratio. From this graph it is clearly visible that the STeSH voice capturing accuracy level is better than the existing model.

Table 4 Voice capturing accuracy levels

Age Group	Existing Voice Capturing Accuracy	STeSH Voice Capturing Accuracy
10 to 15	80%	85%
16 to 20	79%	92%
21 to 25	78%	94%
26 to 30	82%	95%
31 to 35	84%	95%
36 to 40	85%	96%
41 to 45	80%	93%
46 to 50	85%	90%

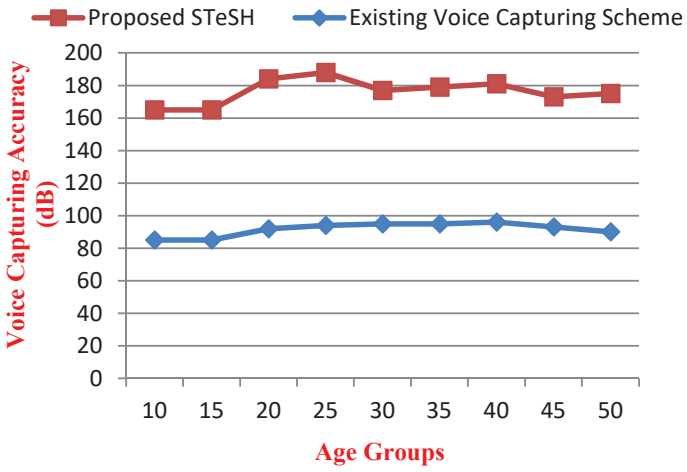

Figure 7 Existing model vS STeSH voice capturing accuracy levels.

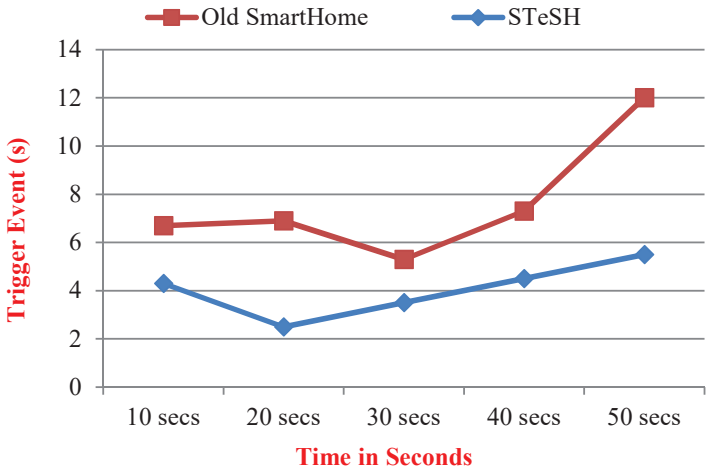

Figure 8 Time delay between existing model vs STeSH.

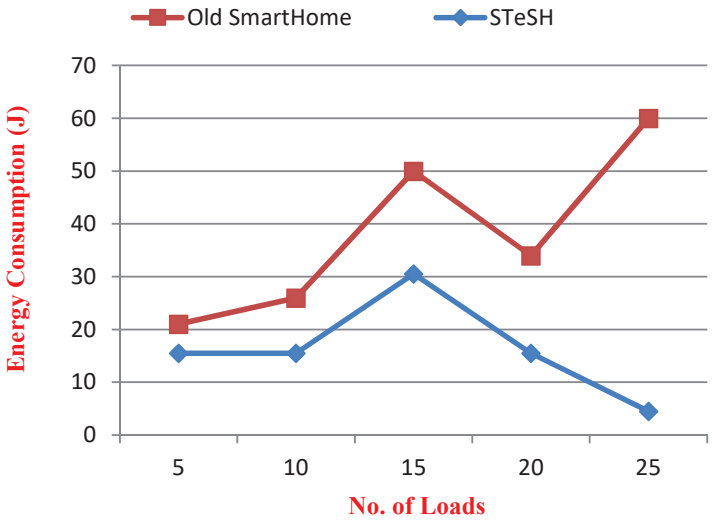

Figure 9 Energy consumption between existing model vs STeSH.

The Figure 8 represents a comparison between the existing home automation technique and STeSH home automation technique in terms of time delay to trigger the loads according to user control. It can be observed from the analysis that the processing delay of STeSH is quite small as compared to the existing model. The Figure 9 illustrates a comparison between the existing

home automation technique and the STeSH based home automation technique energy consumption ratio. The graph clearly shows that the proposed model consumes less power as compared to the existing traditional model. This reduction in energy consumption facilitates green communication by minimizing CO_2 emission.

4 Conclusion

The proposed STeSH based SHA system is implemented satisfactorily with advanced speech technology-oriented processing and intelligent operational features such as Voice/Speech Recognition strategy and IoT. The Google Assistant is used to collect the user voice and send it to the remote server for processing and storing. The server-side system converts the entire speech signals into encoded raw commands and stored it into the remote cloud server with proper access right specifications. Once the user authenticates into the system, automatically it crosschecks the voice input with the processed voice input over the server. If the authentication is successful, then the respective user is allowed to operate the home devices without any interruptions otherwise the system blocks the user to proceed further. From the result analysis it confirms that, the proposed SHA system ensures secured and robust way to automate the home with easy and scalable way. This proposed methodology also improves the EE of the SHA system.

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