A Voice-Controlled Multi-Functional Smart Home Automation System

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***Abstract*—Current availability of interactive technologies infrastructure such as internet bandwidth, increased processing power and connectivity through mobile devices at affordable costs have led to new concepts related to human living. Smart cities, smart life and internet of things etc. are few such evolving research domains. A prominent concept among these is 'Smart Home', which involves automation and interactive technologies. This paper proposes a multi-functional 'Smart Home Automation System' (SHAS), where users can use voice-commands to control their home-appliances and gadgets, for different functionalities and purposes. The proposed system can be adapted to a user's voice and recognise the voice-commands, independent of the speaker's personal characteristics such as accent. The system is aimed to be cost-effective, flexible and robust. The voice command recognition is achieved using a dedicated hardware module and an Arduino micro-controller board for commands processing and control. Performance evaluation is carried out by developing a multi-functional miniature prototype of the SHAS. Results of the experiments conducted are quite promising. The prototype SHAS can be used for converting existing homes into smart homes at relatively low cost and with convenience.**

Keywords: smart home automation system, voice-command recognition, multi-functions, multi-sensor, voice-command

I. INTRODUCTION

A *smart home* is a home that provides its residents the comfort, convenience and ease of operation of devices at all times, irrespective of where the resident actually is within the house. A smart home usually consists of *electrical appliances* such as lighting, fans, air-conditioners, room-heaters, air-coolers and microwave oven etc.; and *electronic gadgets* such as television, computers, audio systems, laptops, music-systems and mobile devices etc. All these appliances and gadgets can be connected and controlled remotely, over a secure channel using Wi-Fi or internet through software application, from within or outside the house. A *smart home* consists of three elements: (i) internal home network, (ii) intelligent control and (iii) home automation with wired/wireless access gateways. These systems and devices within a home can also be managed either from inside home, or can be linked to services and systems from outside the home [1].

These appliances and gadgets are generally connected to specific sensors, so as to make these automatically adapted to certain situations and in-turn make the occupants feel comfortable. An *adaptive smart home* would be the one that utilizes machine-learning techniques to discover patterns in the residents' daily activities, and generate automation rules and actions that mimic these actions [2]. Once these systems become aware of the requirements of residents, the residents can then be provided with a better living experience, by predicting their future needs and perform routine tasks. The aim would be to reduce physical movements and labour by the humans, by sensing and proactively responding to their needs. This important application domain is predicted to steadily increase in the future [3], [4].

In recent years, more research on smart homes has been carried out in applying the principles of ubiquitous computing. A smart home adjusts its functions as per the inhabitants' needs, according to the information it collects from the residents, home computers and context. In such an intelligent environment the steps involving the information processing and network technology are transparent to the user. Interaction between the smart home and its devices here usually takes place via advanced *'natural' user interaction* techniques involving human-speech [5].

An essential part of a SHAS is to enable the various electrical devices and electronic gadgets in it to interact and communicate with each other. In SHAS, simple remote-controlled systems to complex computer/micro-controlled home automation technologies and different wired/wireless technologies may be used for this. Few widely used wireless technologies with globally accepted standards are: GSM, Wi-Fi, NFC and Bluetooth. These can be used to communicate with the smart electrical devices via smart mobile devices such as smartphone or tablet [6]. A SHAS can make use of multiple interactive technologies such as voice-recognition, gesture-control, retina eye movement and more.

In this paper, we use *voice-recognition* to control smart home appliances. Moving away from the traditional methods such as keyboard or switches to control the devices, voice-control is one of the easiest methods to give input commands. Also, voice recognition is a more personalized form of control, since it can be adapted and customized to a particular speaker's voice. Voice recognition differs distinctly from speech recognition. In speech recognition the subject of analysis is the spoken text, while in voice recognition the subject of analysis is the voice of speaker and the spoken text remains secondary here,

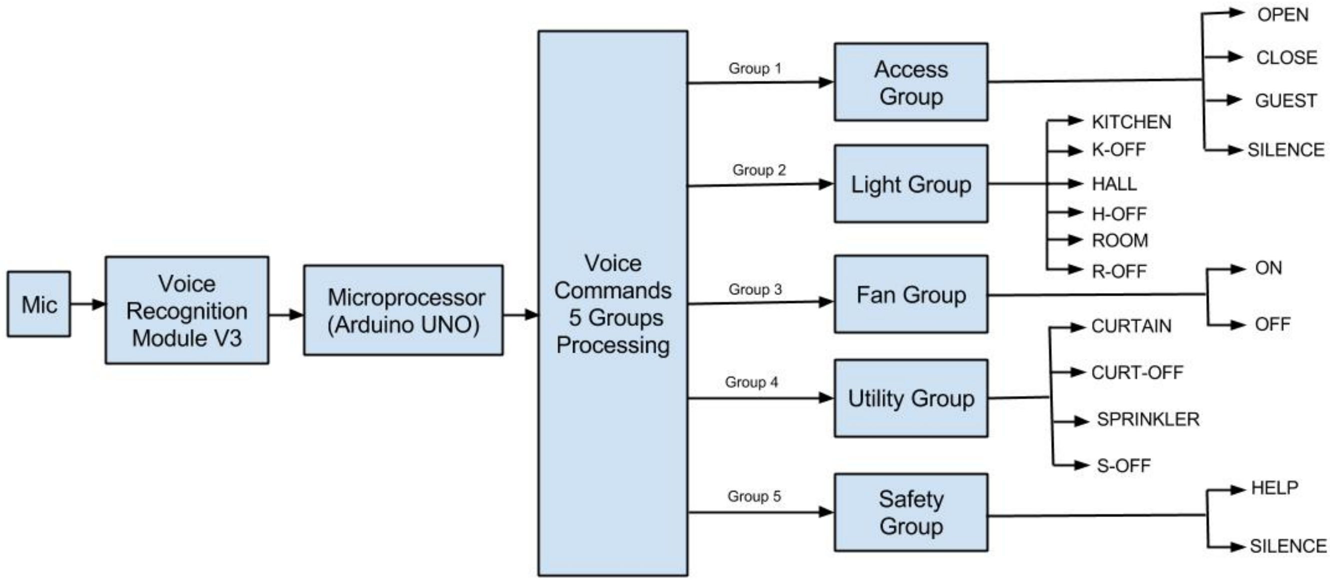

Fig. 1: Block diagram of the prototype Smart Home Automation System with 5 groups of Voice-Commands

though both are taken into account. Thus, voice recognition is better for controlling and accessing the appliances.

This paper focuses on controlling the home appliances using voice-commands, divided into five groups of functionalities. The voice-commands are recognised using a dedicated hardware *'Voice Recognition Module'* (V3) [7] and a micro-controller (Arduino-UNO) [8]. Performance evaluation is carried out by developing a miniature prototype of the SHAS. Various experiments are conducted for different speakers' (male and female) voices and varying the distance between the microphone and mouth. Responses for different voice-commands are analysed, using different parameters. Results of the experiments are encouraging and indicate feasibility of converting an existing home into a smart home at low cost.

The paper is organized as follows. In Section II, existing home automation technologies are discussed under three major categories. The construction details of a voice-command based prototype SHAS are discussed briefly in Section III. In Section IV, we discuss the smart home functions along with the controls implemented in the SHAS prototype. Section V discusses the voice-commands, their processing and control operations. Section VI discusses various experiments conducted for performance evaluation and the results obtained. A summary of the paper is given in Section VII, along with scope of further work in this domain.

II. Home Automation Technologies

Home automation is infact the residential extension of building automation concept. It is the automation of a home, some house-work or some house-activity. Home automation need has been increasing significantly in recent years due to higher affordability and simplicity of using smart phones and tablets with seamless connectivity. The concept of *'Internet of Things'* (IoTs) is closely related to home automation concept. A *'Home Automation System'* (HAS) inter-connects all the electrical devices, appliances and gadgets in the house through a home network set-up. Access to HAS may be allowed using a personal computer or by remote access through Internet, Bluetooth, or Wi-Fi communication. These HASs differ in varying degree of intelligence and automation. All existing *Home Automation Technologies* (HAT) can be categorised as: (i) Voice command-based HAT using a micro-controller and/or speech-to-text conversion, (ii) Radio-Frequency Remote-Control based HAT and (iii) Smart Phone based HAT.

A. Voice-Command based Home Automation Technology

Using this technology, the home devices can be controlled remotely, by a user's voice-commands. This concept aims at making the voice-commands customized during application run-time, so that a user can use his/her own voice-commands for controlling various home appliances. The voice-based HAT involves speech signal processing methods. The HAS should automatically function or operate some device in response to a resident's voice-commands. In this technique, the tasks such as 'search' are performed using a micro-controller that could be Arduino, Intel Galileo, or Raspberry-Pi etc.

This is a low-cost home automation technology. The simple installation procedure makes it possible for anybody to install and implement this system. Another advantage of the voice-based HAT is added safety for both the family and the home. The disadvantage of this home automation technology is *latency*. It takes a few extra fraction of seconds to execute the voice-commands and obtain a response back. Though this is

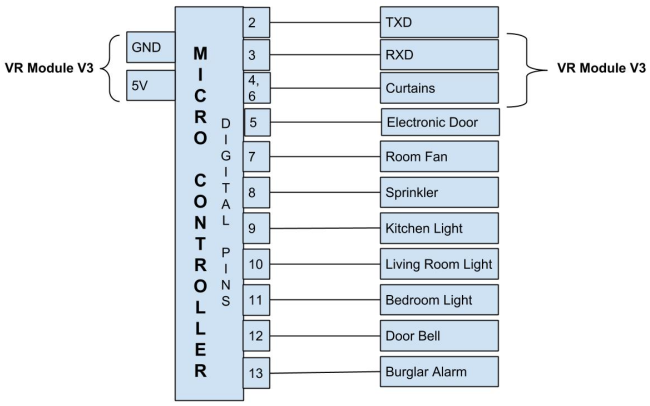

Fig. 2: Micro-controller Connections

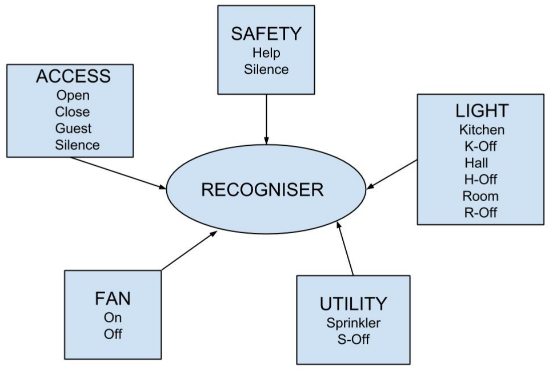

Fig. 3: Voice Recognition Command Groups in Recognizer

not a major problem because as the voice recognition module uses bigger training set, the response time is reduced.

B. RF Remote-Control based Home Automation Technology

It is a Radio Frequency (RF) based Home Automation Technique (HAT), in which the home appliances are controlled by a RF remote control, and not through voice. It involves a RF transmitter, a RF receiver and few relays connected to the home appliances. Each home appliance consists of a RF Transmitter/Receiver. The transmitter has an integrated chip based pulse signal generator and a multi-vibrator circuit that modulates the signal. The receiver has an Infra-Red (IR) amplifier/detector circuit to detect the modulated signal.

Advantages of this HAT are low latency and affordable cost of installation. It is well-suited to a scenario where home appliances have an in-built receiver circuit and the manufacturer provides a Remote (transmitter) to control the device. The problems of understanding different commands faced in the voice-based HAT would also be avoided here.

C. Smart-Phone based Home Automation Technology

This is a low-cost and wireless remote-control technology for a HAS. Several wireless technologies available to provide network connectivity are: Bluetooth [9], Wi-Fi [10], GSM [11] and NFC [12]. Each has its own unique specifications, merits and limitations. Each can communicate with the HAS via the Graphical User Interface of a smart phone, wirelessly.

Different wireless technologies can be used for different purposes. (i) *Bluetooth* provides good wireless connectivity and is globally available. It uses a carrier frequency 2.4 GHz and has a range 50 m (Bluetooth 4.0+). It can be used to connect to most home devices, but it has less data transfer speeds [13]. (ii) *Wi-Fi* can be used for data intensive communication such as streaming media content, and to connect the smart mobile phone to a television or gaming console etc. Although it provides good connectivity, it has access to the appliances only within the reach of the wireless signal in the house [10]. (iii) The *GSM* can provide connectivity to the devices over the internet, from anywhere in the world [14]. (iv) *Near Field Communication* (NFC) is unique from the rest, since it is available only within a range of 10 cm and operates at a frequency of 13.56 GHz. NFC can be used where sensitive information such as passwords need to be exchanged between two parties, for example in a SHAS for door-lock access-codes or a secured safe. Here, a smart phone can be used as a remote controller device, at lower cost. NFC is also very reliable due to the option of a minimum 128-bit encryption.

In this paper, the HAT in the first category, i.e., voice-based control is implemented using a dedicated hardware module, instead of speech-to-text conversion methods, thus making the system more personal, versatile and robust.

III. Construction Details of the SHAS

In this paper, a prototype *voice-controlled SHAS* is developed. In the prototype, multiple functionalities in a home are controlled using voice-commands divided into five groups. A block diagram of the *prototype SHAS* along with the voice-command groups is shown in Figure 1.

A. Major Modules and Key Steps in the implementation:

(a) *Voice Recognition* using a Microphone and a Voice Recognition Module V3 [7].

(b) *Interpretation of voice commands* using a dedicated hardware Voice Recognition Module V3 and Arduino Uno micro-controller board [8].

(c) *Control* of various home appliances and their operation using the controller circuit connections, as shown in Figure 2.

The voice-commands are classified into 5 groups as per their functionality, as shown in Figure 1. Each voice-command group can have a maximum of seven voice-commands, which is a limitation of the voice recognition module used here.

B. Voice Commands and Voice Recognition Modules

Five groups of the voice-commands, demonstrated here, are: (i) Access, (ii) Fan, (iii) Light, (iv) Utility, and (v) Safety (Fig. 3). Each group includes minimum functions necessary for a smart home. Commands in each group are selected to ensure the basic needs of the residents. Few key functions that ensure few routine activities are automated in the prototype SHAS.

Once voice-commands are recognized, the corresponding controls are sent to the micro-controller (Arduino Uno), at a baud rate of 115,200 bps. First, *Voice Recognition* module and

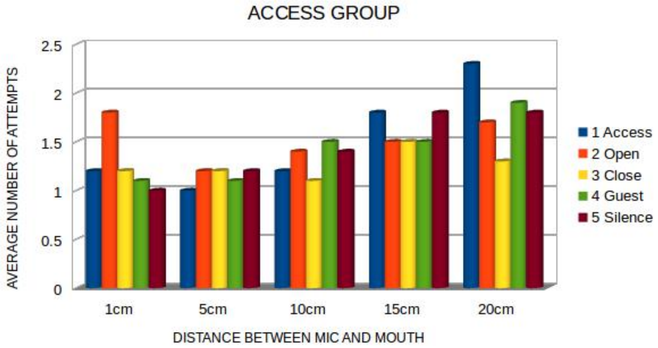

Fig. 4: Mean parameters for *Access* Group

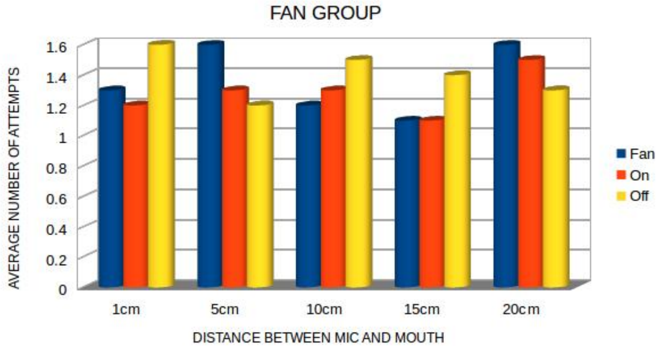

Fig. 5: Mean parameters for *Fan* Group

then Arduino micro-controller process the voice-commands for further actions. Commands received by the micro-controller are compared with the command templates previously loaded during the training process. If there is a match, then the micro-controller performs the desired home function or operates the corresponding appliance, as shown in Figure 2.

IV. Smart Home Functions

Two major aspects of a smart home function are *easy control* and *intelligent automation*. *Easy control* means the devices and appliances should be operable with minimum effort required on the user's part. This could be a simple gesture, or a simple voice-command. The control command may be given from anywhere and anytime. An *intelligently automated* smart home function implies that the smart home is tailored to the resident's lifestyle. It means that the smart home needs to monitor and respond automatically to events in and around the house, such as light intensity levels, weather conditions, security breaches and more. The smart home should know what to do, without the resident having to meddle in the routine operations. While the resident is out of the smart home, it should take care of keeping the temperature down by lowering the blinds, activating alarms in the event of fire or burglary, or switching-off electrical appliances to avoid unnecessary wastage of electricity etc.

The details of the five groups of voice-commands, shown in Figure 3, are as follows:

1. The *access group* controls the entry & exit to a house by the residents as well as guests. When a guest approaches the door, the voice command *'Guest'* rings a bell. This bell can be switched-off when the resident voices the command *'Silence'*. On the other hand, if a resident wants to enter or exit the home, one simply voices the command *'Open'* or *'Close'*.

2. The *fan group* controls the fan(s) in the house, providing commands for turning the *Fan-On* or *Off*.

3. The *light group* controls the multiple lights in different areas of the house, such as *Rooms*, *Kitchen* and *Hall*. Each *On* command has a corresponding *Off* command. For instance, to switch-on the lights in the Hall, the voice-command is *'Hall'* and to switch-off the lights the voice-command is *'H-Off'*.

4. The *utility group* consists of additional home functions such as curtains and garden sprinkler controls. To draw the curtains open, the voice-command is *'Curtain'*. To draw them close, the voice-command is *'Curt-Off'*. Similarly, for the sprinkler, the commands would be *'Sprinkler'* and *'S-Off'*. In future the SHAS may also include appliances such as microwave, washing machine and refrigerator etc.

5. The *safety group*, a very critical feature of the SHAS, is necessary for the security of its residents. A simple voice command *'Help'* would buzz a loud alarm in the smart home, to alert fellow residents and neighbours. The alarm can be silenced by voicing the command *'Silence'*.

To enter each voice command group, the group name needs to be spoken first, followed by the intended control command. For example, to switch-on the lights in the hall, the voice-command is *'Light'* followed by *'Room'*. A corresponding *off* command is simply *'Off'* or *'R-Off'*.

The concept of an adaptive system need not be limited to home appliances and it can be extended to other functionalities in the home. For example, the windows and blinds in the house windows provide a suitable temperature to the residents, apart from security and privacy. The windows can be shaded automatically when the temperature rises. When the sun goes down, the shades are automatically rolled up. The blinds can be configured to gently wake-up the resident with natural light, as the sun comes up, and close when the resident is out. Privacy could also be provided by varying the opacity of the glass windows, though at higher costs.

V. Voice-Commands Processing

The proposed system focuses on easy control in a smart home through voice, a *natural user interaction* HAT. The paper implements a *voice-controlled* SHAS for reduction of human effort and minimising any human movement. This is very helpful for the old and the disabled who may experience difficulties in the house just to turn their appliances ON or OFF. In a multi-purpose SHAS, one can switch-OFF and ON any electrical household appliance using voice-commands. The voice-controlled system can also help the visually-impaired in controlling their home appliances. The SHAS is designed such that it is easy to install and use.

TABLE I: Performance Results for all Voice Commands

Group	Voice-Command	Best Distance (cm)	Avg No. of Attempts
Group I: Access	Access	5	1
	Open	5	1.2
	Open	10	1
	Guest	5	1
	Silence	1	1
Group II: Fan	Fan	15	1.1
	On	15	1.1
	Off	5	1.2
Group III Light	Light	5	1.1
	Kitchen	5,15	1.4
	K-Off	1	1
	Hall	5,10	1.1
	H-Off	10	1
	Room	10	1
	R-Off	5,10	1
Group IV: Utility	Utility	1,15	1.2
	Curtain	10	1
	Curt-Off	5,10	1.1
	Sprinkler	5	1.1
	S-Off	5	1
Group V: Safety	Safety	10	1.25
	Help	10	1
	Silence	1	1.3

The prototype SHAS uses a *Voice Recognition Module V3* for voice-command recognition. It supports up to 80 voice-commands, each of maximum 1500 ms duration. The module can process up to 7 voice-commands at the same time. The module makes use of the *Voice Recognition Library V3* [15] of Arduino. There are two simple steps involved:

1. *Training:* the process of recording voice commands using microphone, stored in flash memory, numbered from 0 to 79.

2. *Loading:* i.e., copying the trained voice to the voice-command recognizer program.

Recognizer is container where the active voice-commands are loaded. It is a core part of the voice recognition module.

VI. Experiments and Results

Experiments are conducted involving different speakers, giving all the voice-commands, at different distances. Voice commands by 10 speakers (5 males and 5 females) were used to train the *Voice Recognition Module*. The distances between the speaker's mouth and the microphone as 1 cm, 5 cm, 10 cm, 15 cm and 20 cm were used. The performance evaluation results are presented as per different voice-command groups, in Table 1. Visual representation as bar charts, displaying the average number of attempts required by the *Voice Recognition Module* to successfully identify the voice-commands, is shown in figures Fig. 4 to Fig. 8.

In Table 1 and Figures 4 - 8, it is observed that the best distance for a voice command is in the range of 5 cm to 10 cm. This can be translated into the voice-level (in dB) required for the recognition of each voice-command. On average, the minimum number of attempts required is 1, while the maximum is 1.4 for the correct recognition of a voice-command. Out of 23 voice-commands, 11 have average # attempt of 1, 6 have an average # attempt of 1.1, 3 have an average # attempt of 1.2, while 3 others have an average # attempts of 1.25, 1.3 and

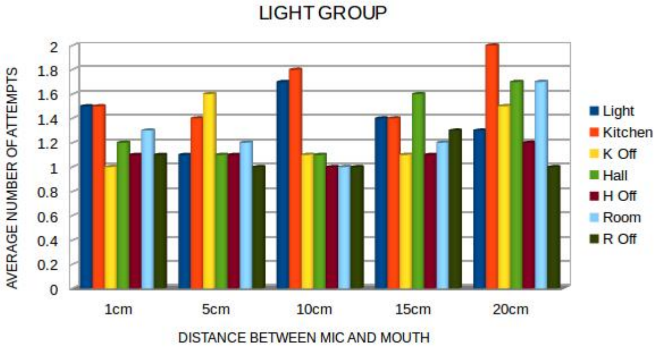

Fig. 6: Mean parameters for *Light* Group

1.4. The experiments demonstrate that the *Voice Recognition Module* used in the prototype SHAS requires only 1 to 1.4 # attempts to successfully identify and match a voice-command, for the corresponding control operation. The experiments also demonstrate that the prototype SHAS can recognize voice-commands, irrespective of the speaker, accent or linguistic dialect, as long as it has been trained before.

VII. Summary and Conclusion

The voice-controlled, multi-functional, smart home automation system (SHAS), proposed in this paper can receive voice-commands by a specific person and perform corresponding functions. The multiple functions could include controlling electrical *appliances* such as lights or fan, and electronic *gadgets* such as refrigerator or washing machines.

Though the proposed SHAS improves accessibility to appliances through a natural interface, i.e., human voice, it has few limitations. Voice recognition module needs to be placed at a common location in the room, or at a common place if the resident intends to use it from different locations inside the house. Another limitation is the need of training the system for every user or home resident, in the case of multiple residents. Testing also needs to be carried out further for effectiveness of the voice-commands' recognition with background noise or natural noise such as storm or rains etc.

In the prototype SHAS, the experiments are conducted to measure the effectiveness and range of voice-commands for each of the 5 voice-command groups. The results couldn't be compared with any similar study, as we haven't come across other similar applications. Comparing with voice/speaker recognition accuracy results would not be meaningful here. While the voice recognition technology makes people's lives easier, few other technologies may also help improve the living experience of the residents in a smart home. Developing specific mobile applications may aid in providing access to the SHAS from outside the home, and control the home appliances from remote locations. Examples are: switching-ON the geyser through voice-command on a mobile application while coming back from the office or asking the television to download the next episode of a SitCom from outside home.

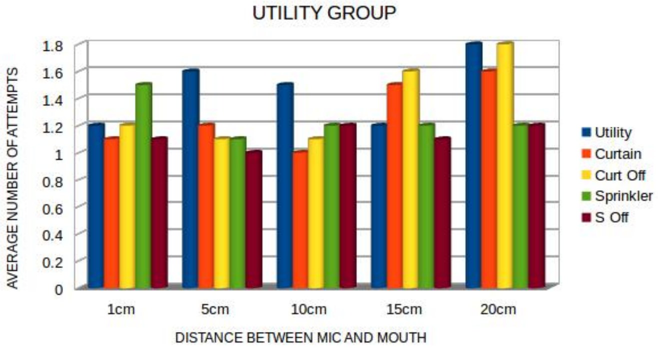

Fig. 7: Mean parameters for *Utility* Group

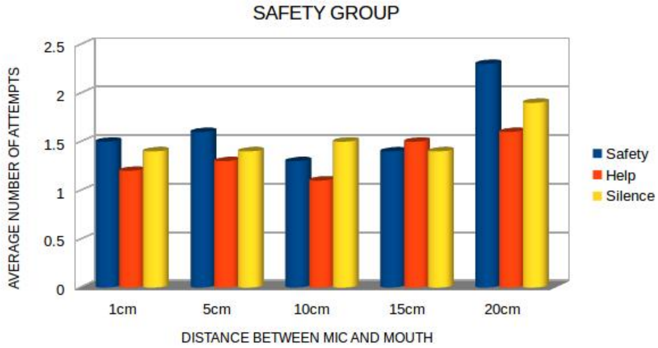

Fig. 8: Mean parameters for *Safety* Group

A future enhancement to the proposed voice-controlled SHAS would be the use of diverse sensors to aid the home automation [16]. Proximity and ambient light sensors could be used to detect motion in a specific area and thus control lights, fan and air-conditioners etc. when a human is in proximity. These could be coupled with a temperature sensor such as an InfraRed thermometer to measure temperature, humidity and moisture and change the air-conditioner temperature appropriately. The curtains could be automated to *draw* themselves *open* or *close* based on the time of the day. Security could be better implemented in a smart home, with the help of automatic alarms, and motion detectors attached to windows that would sound a siren if an intruder approaches the window from outside. Thus there is much scope for further exploration in the field of smart home automation.

The prototype SHAS developed in this paper may help developing the low cost voice-controlled smart home systems that could be installed in houses before/after construction. The demonstrated system can be directly scaled-up and implemented in a house with few basic steps. It also needs minimal training and maintenance overhead.

The proposed SHAS currently assumes that wiring is done all over the home. Wireless technology can further be used in SHAS, though at an extra cost [17], [18]. If these appliances can be made to *'talk'* to each other over the internet or a local area network, it would vastly reduce human effort. It would facilitate future lifestyle wherein the sole effort of the owner would be to give permission to the devices, while the devices perform most of the work themselves. Advances in signal processing may make it possible to even sense the mood and state of a resident through analysis of his or her voice, which could then help the home devices make smarter decisions.

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