Device Control System for a Smart Home using Voice Commands: A Practical Case

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ABSTRACT
The development of new voice-controlled home assistant devices such as Amazon Echo and Google Home has allowed the interaction between users and devices in a more human and familiar way. With this background, this project aims to use Amazon Echo, Alexa, and complementary technologies to implement a smart home environment by controlling external devices using voice commands. After designing and implementing the voice controlled smart home solution, we proceeded to measure the response time of commands to verify their applicability in different uses. The implemented solution reached the expected goals allowing an effective control of different devices from an LED light to commonly used household appliances through voice commands with a reasonable delay.

CCS Concepts
• Human-centered computing → Human computer interaction (HCI) → Interaction devices

Keywords
Voice recognition; home automation; smart home; IoT; Alexa.

1. INTRODUCTION
In recent years, more people are interacting with digital technology devices connected to the Internet in their homes using home automation technologies [1]. Among the different definitions, home automation can be defined as the introduction of technology within the home to improve the quality of life of its occupants, through the provision of different services such as health, multimedia, entertainment and energy related applications [2-4]. The standard X10, developed in 1975 for communication between electronic devices, could be considered as one of the oldest standards that initiate the home automation trend. X10 provided limited control over household devices through household power lines [5]. Currently, standards have evolved in a gigantic way and the market gives us different device options using such standards for home automation. Among different options, those that allow interaction through voice commands are becoming very popular; among this kind of devices are the Google Home [6], Apple HomePod [7] and Amazon Echo [8], being the latter the most pioneering and popular.

Amazon Echo which is connected to Amazon's intelligent personal assistant called Alexa was launched in 2016. Alexa is a cloud system that converts the voice of users into text and interpret the text to respond verbally, musically or passing commands to other intelligent devices such as a Wi-Fi compatible light bulb [9]. In the following, we list some of the features of Amazon Echo [8]:

- Amazon Echo uses the Alexa Voice Service to play music, provide information, read news, set alarms, and control smart home devices.
- Amazon Echo allows to play music from different services providers such as Prime Music, Spotify, Pandora, iHeartRadio and TuneIn.
- Amazon Echo can control different smart devices such as lights, switches and thermostats from different brands such as WeMo, Philips, Samsung, Nest, and others.

Despite the mentioned benefits, there are still not many works that document in an organized way the design and implementation of home automation solutions based on Amazon Echo. Faced with this situation, this paper aims to share our experience in the design

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and implementation of a practical case of home automation device control through the voice where Amazon Echo participates as one of its key components. The proceedings are the records of the conference. ACM hopes to give these conference by-products a single, high-quality appearance. To do this, we ask that authors follow some simple guidelines. In essence, we ask you to make your paper look exactly like this document. The easiest way to do this is simply to download a template from [2], and replace the content with your own material.

2. RELATED CONCEPTS

In the following, some concepts used throughout this work are explained.

2.1 Home Automation

Home Automation can be defined as the adoption, integration and application of new information and communication technologies to the home environment. It mainly includes the use of electricity/electronic devices, computer systems and different telecommunications devices including mobile telephony and Internet. Some of its main characteristics are: interaction, interrelation, ease of use, remote management, reliability, and ability to be programmed and updated. Its architecture can be centralized or distributed; however, the decentralized one is the most used due to its advantages of intercommunication and fault tolerance. The protocols used in home automation solution can be an open standard or proprietary [10, 11].

2.2 Smart Speaker

A smart speaker is a type of speaker which integrates a voice command device and a virtual assistant that offers interactive actions with the user. The virtual assistant allows smart speakers to respond users' requests such as playing music, responding questions, ordering food, and so on. Most of smart speakers can extend their functionality to control home automation devices such as smart bulbs, smart locks and smart thermostats. Many manufactures have released their own smart speakers; for example Amazon has launched the Amazon Echo while Google and Apple have created the Google Home and Apple HomePod, respectively. In addition to the ad-vantage of being easy to use, voice controls used in Smart Speakers are becoming very popular as they have great potential to facilitate daily tasks for all users inclusive for fragile groups (e.g. elderly and disabled people) [12]. Many studies have been conducted in the field of voice interfaces and 95% of people said they would continue to use the system, even though this technology is not perfect yet and fail many times in understanding user commands [13].

3. PROPOSED SYSTEM

As mentioned previously, the intention of this work is to design and implement a practical case of home automation device control through the voice where Amazon Echo participates as one of its key components. The proposed system uses the services provided by Amazon Echo and Amazon Services in combination with other devices and services. Figure 1 shows the implemented architecture which is composed of different elements organized in three sections i.e. Smart Home, Amazon Services and Tunnel to Localhost.

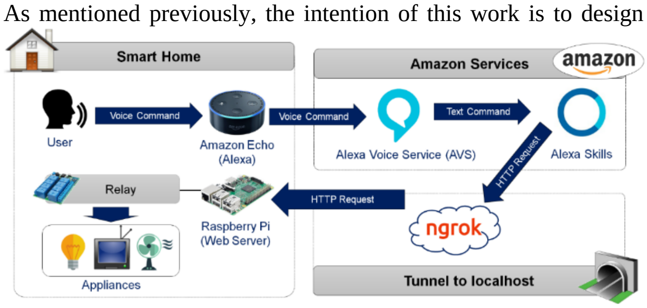

Figure 1. Architecture of the Implemented System

3.1 Components of the Implemented Solution

3.1.1 Smart Home

This group of components includes the different elements installed inside user's home. In other words, we consider all the devices that integrate an intelligent system that could be used in the daily life of users. In our architecture, the components used this section are: Amazon Echo, Raspberry Pi with Relay and the different external devices that are going to be controlled (e.g. fan, TV, lights, among others).

- User: User is the person who will use the implemented system. The user will use his/her voice to control the different devices located in the Smart Home.
- Amazon Echo: It is the smart speaker which will receive the voice commands of the user. Amazon Echo incorporates seven microphones that allow it to hear and recognize user's voice. The noise cancellation technology allows to hear effectively the voice commands indicated by the user from relatively far distances. Amazon Echo also has a new spatial perception technology that allows Alexa to respond appropriately from the device that is closest [14].
- Raspberry Pi: It is a computer developed by the Raspberry Pi foundation in the United Kingdom which can be connected to different devices. It is a development board that allow people of all ages to explore the world of computing systems and programming languages using languages such as Scratch and Python [15] and create prototype of computing systems. For the present work, Raspberry Pi was used as a web server that receives the interpretation different commands and sends electrical signals to control the Household appliances installed in the Smart Home. The specific model of Raspberry Pi used for this work was Raspberry Pi 3 Model B.
- Relay: It is an electromagnetic switch which will allow to translate the signal coming from Raspberry Pi into the 110v/220v electricity connection used by the household appliances [17]. The relay is activated or deactivated when the electromagnet is energized by the Raspberry Pi.
- Appliances: These are the household appliances which will be controlled by the implemented system.

3.1.2 Amazon Services

This section includes the cloud services provided by Amazon for the development of applications based on Alexa i.e. Alexa Voice Service (AVS) and Alexa Skills.

- Amazon Voice Service: The Alexa Voice Service allows developers to enable voice-connected products. It consists of interfaces used by clients to execute different actions such as voice recognition, audio playback, and volume control. [18].
- Alexa Skills: Skills are the capabilities that a developer can add to Alexa [19].

3.1.3 Tunnel to localhost

Since the commands interpreted by Amazon Services cannot reach directly to the server (Raspberry Pi) installed in the Smart

Home, it is necessary to have an intermediary i.e. tunnel to localhost. The functionality of the tunnel to localhost is delivered by Ngrok.

- Ngrok allows a user to access a server with a private IP address through the ngrok cloud service [20]. When a user needs to access to the server with the private IP address, such request is sent to the ngrok cloud service which accepts traffic on a public address and relays that traffic through to the ngrok process running on the private IP server (in our case, Raspberry Pi).

3.2 Execution Process of the Implemented Solution

The components mentioned in the previous sub-section interacts each other as follows. First, the user delivers the voice command to the Amazon Echo. Amazon Echo understands that the received voice sound corresponds to a command and transfer it to the Amazon Voice Service (AVS). The data in sound format is interpreted by AVS and transformed into a text format data and redirected to Alexa Skills. Making use the Alexa Skill features that allows developers to create their own functionalities, the proposed solution implemented its own Skill. The implemented Alexa Skill was called "control GPIO" and it allows to control a specific household appliance located in the Smart Home e.g. radio or television (see Figure. 2 and 3).

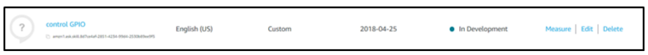

Figure 2. Developed Alexa Skill

The implemented Skill sends the JSON data to a URL configured by the developer. Such URL corresponds to the one provided by the Ngrok Cloud Service. In other word, the text received from AVS is interpreted by the "control GPIO" skill and if the text corresponds to the command implemented in the Skill, it delivers the defined JSON data to Ngrok.

```
Intent Schema
{
  "intents": [
   { "slots": [
      {"name": "status",
        "type": "GPIO_CONTROL" },
      {  "name": "location",
        "type": "LOCATION"   }
     ],
     "intent": "LocationControlIntent" }  ]
}
Sample Utterances
LocationControlIntent {status} {location}
LocationControlIntent cambiar {location} a {status}
```

Figure 3. JSON Code of the Implemented Alexa Skill

Later, the JSON data received by the Ngrok Cloud Service is transferred to the server (which was implemented in a Raspberry Pi) located inside the Smart Home. Once the Raspberry Pi receives the JSON data, it executes the device control script. Figure.4 shows a sample code that allows the turn on/off of a household appliance.

```
from flask import Flask
from flask_ask import Ask, statement, convert_errors
import RPi.GPIO as GPIO
import logging

GPIO.setmode(GPIO.BCM)
app = Flask(__name__)
ask = Ask(app, '/')
logging.getLogger("flask_ask").setLevel(logging.DEBUG)
@ask.intent('LocationControlIntent',           mapping={'status':
'status', 'location': 'location'})
def location_control(status, location):
locationDict = {
   'One' : 18,
   'Two' : 14,
   'radio' : 23
}
targetPin =  locationDict[location]
GPIO.setup(targetPin, GPIO.OUT)
if status in ['on', 'high']:    GPIO.output(targetPin, GPIO.HIGH)
if status in ['off', 'low']:    GPIO.output(targetPin, GPIO.LOW)
```

Figure 4. Sample Code Implemented in Raspberry Pi

Depending on the requested command, it is translated into the outputs of the Rasp-berry which contains the server that allows controlling the relay which connects to the Raspberry pins and allows the control of different devices.

4. EXPERIMENTAL RESULTS

Once implemented the proposed solution, delay measurement was executed to understand its performance feasibility in real-time services. For the exact delay evaluation, control of simple devices was selected i.e. turn on/off of leds and simple house-hold appliance i.e. a fan.

The delay results are detailed in Table 1. Such table shows the response time in con-trolling the external device (led or household appliance), latency from Smart Home to Ngrok Cloud Service, and the percentage that latency to Ngrok covers in the command response time. Finally, the latency to google.com server is also presented to deliver the level of congestion of the Internet connection when the command was executed.

As shown in Table 1, the type of device (i.e. led or household appliance) is not an important variable for the performance of the implemented solution. It is because the additional functionality that could generate the control of complex household appliances is executed by the local computing system in the Smart Home (i.e. Raspberry System). If a complex process were required, a more powerful device could be used (e.g. a real computer) to increase the performance of the system. As shown in the same Table, the most important issue that affects to the performance of the system is the latency of different services located on Internet. As you can see, the Latency to Ngrok takes as low as 16% and as high as 52% of the Command Response Time. This data let us to understand that a more powerful service of tunneling to localhost is required if a real-time service were required. On the other hand, in terms of the correctness of the execution of requested command, all of the test was executed without problem.

After the tests, it can be said that the system worked as we expected and responded to the commands within a few seconds and the sound-based responses returned by Alexa were clear. Even though, it was not possible to create a real-time response be-cause of the delay of Amazon Services and Ngrok, we believe that the present solution will not be a problem in most of services required in a Smart Home.

5. CONCLUSIONS

In this work, we have shared our experience in designing and implementing a practical case of home automation device control through the voice where Amazon Echo participates as one of its key components. Through the experiments, we could show how the implemented prototype was possible to control different types of devices in an effective manner. Same experiments, let us know that, because of the delays existent in Amazon Services and Ngrok, it is not possible to implement a totally real-time services. However, the response time of the prototype was acceptable for the most of the services that users require. For the future works, we will experiment different designs and technologies to reduce the delay for trying to make a real-time service controlled by voice.

Table 1. Delay Evaluation (seconds)

Device Type	Res-ponse Time	Latency to Ngrok	Percentage of Ngrok Latency in Total Response Time	Average Latency to Google.com
Appliance	2.03	0.48	24%	0.10
Appliance	2.06	0.50	25%	0.10
Appliance	2.96	0.48	16%	0.11
LED	2.25	0.50	22%	0.10
LED	2.02	0.48	24%	0.11
LED	2.08	0.48	23%	0.10
Appliance	4.32	1.43	33%	0.32
Appliance	5.49	1.05	19%	0.32
Appliance	3.82	1.62	42%	0.32
LED	5.14	2.02	39%	0.32
LED	8.33	2.45	29%	0.32
LED	5.48	2.84	52%	0.32

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