Intelligent Instruction-Based IoT Framework for Smart Home Applications using Speech Recognition

Yao Ge
Glasgow College UESTC
University of Glasgow
Glasgow, UK
2288980G@student.gla.ac.uk

Shuja Ansari
James Watt School of Engineering
University of Glagow
Glasgow, UK
Shuja.Ansari@glasgow.ac.uk

Amir Abdulghani
James Watt School of Engineering
University of Glagow
Glasgow, UK
Sultan Qaboos University
Muscat, Oman
AmirMohamed.Abdulghani@glasgow.ac.uk

Muhammad Ali Imran
James Watt School of Engineering
University of Glagow
Glasgow, UK
Muhammad.Imran@glasgow.ac.uk

Qammer H. Abbasi
James Watt School of Engineering
University of Glagow
Glasgow, UK
Qammer.Abbasi@glasgow.ac.uk

***Abstract*—Design of a smart home using Internet of Things (IoT) and Machine Learning technology has been presented in this paper. This design is primarily based on LoRaWAN protocol and the main objective of this work was to establish an IoT network that is based on integration of sensors, gateway, network server and data visualization system. More importantly, intelligent speech recognition system is designed and presented here in detail as part of this work to achieve a novel futuristic smart home system design framework with intelligent instruction-based operation mechanism. In the case of low noise, the success rate of speaker recognition is above 90% based on THCHS-30 dataset.**

***Index Terms*—Smart Home, Internet of Things (IoT), LoRaWAN, Speech Recognition, Maichine Learning**

I. Introduction

Rationale behind using the IoT technology in smart homes is to address the smart living aspect of future smart homes. In residential circumstances, information from various sensors is gathered at the server consistently through the internet. This provides home appliance control, such as music, automatic lighting, curtain control, air-conditioning control, security systems, video feeds, etc. Compared with ordinary household, smart home not only has the traditional living function, both buildings, network communication, information appliances, equipment automation, provide a full range of information interaction function, and even save money for a variety of energy costs. [1]. Smart lighting and temperature controlling system can recognize what the residents need at different times. For an ordinary customer, suitable temperature for sleeping and daily exercise must be different. Less heating results in reduced energy consumption, allowing other electrical equipment to utilize the saved energy if needed, so that the rest electrical energy can be utilized to supply other equipment more efficiently. Looking at safety and security, smart home system has the capacity to detect switch status through sensors placed on doors and windows, as well as the temperature and smoke environment through sensors in door. The main contribution of this work is also to establish a set of IoT visualization platform. Through this platform, user can easily obtain real-time status of events at any time using their smart phone or computer. Meanwhile, system will execute programmed tasks such as alarm and message to inform owner of the house. [2].

Most of the literature in the field covers research of LoRaWAN application in smart farms, cities and other such fields instead of smart homes. LoRa indeed plays a prominent role in the direction of long-distance transmission. However, smart home will not be a single part in our daily life as the development of LoRaWAN. Smart city can be combined with smart home, smart traffic which wide transmission range of LoRa can provide this integration. [3]. On the other hand, LoRaWAN has the potential to meet the requirements in case of large number of sensors are deployed. [4], [5].

In [6], the number of gateways will influence the performance of communication. The author has systemically proved that the packet success rate can be influenced by number and layout of gateways and nodes. Generally, multiple gateways will support the higher performance of packet transmission.

In [7], the paper has researched the maximum tolerated number of nodes for a single gateway based on LoRaWAN protocol. The experiment proved that for 1500 nodes matched with one LoRaWAN gateway will keep the packet success rate above 99%. In [8], the LoRa network can be extended successfully, with a packet success rate of more than 95% in the case of 10,000 terminal devices.

Mel Frequency Central Coefficient (MFCC) is general method to be considered for voice recognition [9], especially in Speech Recognition and Speaker Recognition. Besides, Linear Prediction Coefficient (LPC), Linear Prediction Cepstrum Coefficient (LPCC), Linear Spectrum Frequency (LSF) and Discrete Wavelet Transform (DWT) have been broadly used in speech recognition. Among them, compared with other methods based on human vocal tract, MFCC is a model based on human auditory system, which represents the low frequency region more efficiently than the high frequency region. So, it has the ability to calculate formant and describe channel resonance in the low frequency range. Therefore, MFCC is a typical technology of speaker recognition front-end application, reducing the vulnerability of noise interference with small session consistency, which is easy to be mined. [10].

In [11], Microsoft speech API was implemented by the voice recognition application. The system compares incoming speech with an obtainable predefined dictionary to judge the result. The use of API provides more powerful natural language processing capabilities than the individual training model.

II. Background

A. Internet of Things

The Internet of things is defined as a network that connects any item to the Internet for information exchange and communication according to the agreed protocol through various information sensing devices such as infrared sensors, global positioning system (GPS), laser scanner and other information sensing devices to realize intelligent identification, positioning, tracking, monitoring and management of items. The applications can touch on aspects of production and living of human being. It is predicted that nearly 28 billion devices will be connected to IoT due to efficiency and functionality. [12].

B. LPWAN and LoRaWAN

Generally, IoT protocols are classified into wired and wireless types. Wired means that the controller and intelligent device needs to be connected by a physical wire to form a path to achieve the control purpose. This is relatively complex with time-consuming and laborious installation, which means inflexible and relatively costly. Due to above mentioned reasons, wireless communication protocols are better choice.

Traditional common wireless protocols such as WIFI, Bluetooth, Cellular and Zigbee standards have their distinct advantages. However, above protocols fail in Power consumption and system scalability in comparison with LPWAN (Low Power, Wide Area Networks). The advantages and disadvantages of some protocols are listed below.

Effective transmission distance of Bluetooth protocol is relatively short, around 80-100 meters. [13]. Meanwhile, it cannot support a large number of devices connected at the same time. Thirdly, Bluetooth cannot work all consistently after it is turned on, but only operates when data needs to be transmitted. Device must be in a low-power sleep state when it is not needed. Due to the requirement of sleep, Bluetooth is not suitable for long time transmission, only for short time transmission scenarios.

WIFI and TD-LTE communication technologies have better performance in higher data rate traffic to adapt large-volume transmission application like intelligent monitoring. In order to maintain transmission performance, a limited number of devices can be joined to the network. In other respects, IoT application requires wider transmission distance and distributed sensor nodes rather than the system with large volume of transmitted data and limited range . Last but not the least, the cost of Wi-Fi and LTE nodes can be much more expressive than LPWAN.

ZigBee uses the same 2.4Ghz band as Bluetooth, which is used for small amount of data transmission over short distances and low power consumption. With few competitors, ZigBee was adopted by many products in the early days of the smart home. However, power consumption of LoRa device, which is one of the LPWAN communication technologies, accounts a third of Zigbee devices, as well as higher scalability.

As a result, LPWAN has become one of the most widely used protocols in the field of smart home at present, with the advantage of large number of connections, which can fully meet the needs of all devices in a home or a building.

Generally, the signal's short transmission distance, weak wall penetration and system instability are the bottleneck of wireless intelligent household industry. LoRa is an ultra-long distance [14] wireless transmission scheme based on spread spectrum technology adopted and promoted by SEMTECH. This scheme changes the traditional contradiction between longer transmission distance and lower power consumption and provides users with a simple system that can realize long distance, long battery life and large capacity. At present, LoRa mainly operates in the global free frequency band, including 433/868/915MHz and so on.

In comparison with the above short-distance transmission protocols, LoRa, as a kind of long transmission distance communication protocol, efforts will be more promising with better penetration ability, system stability and strong anti-interference ability. Villa, house of large family such as double entry building only need a central host can control the whole house intelligent wireless products. Without installation problems, difficult maintenance cost, LoRaWAN is a simple solution to solve traditional wireless smart home signal transmission short distance and high-power loss.

LoRaWAN is an open standard that defines the communication protocol of LPWAN technology based on LoRa chip. Fundamental LoRaWAN network structure shows in Figure 1 [15] :

Network architecture contains four parts: sensors (LoRa nodes), LoRa Gateway, Network Server (NS) and application server. Star network topology is applied between the Gateway and sensors. Attribute to the long-distance characteristics of LoRa, single-hop transmission can be used between them. Terminal nodes can send messages to multiple gateways at the same time. The gateway forwards the LoRaWAN protocol

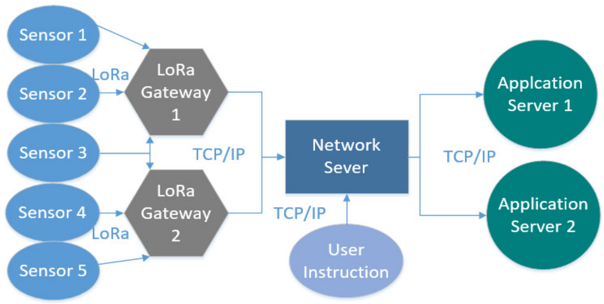

Fig. 1. Typical LoRaWAN network topology

data between NS and terminal and carries the LoRaWAN data on the LoRa RF transmission and TCP/IP respectively

Specifically, there are three types of node devices in the agreement, Class A/B/C, which basically cover all the application scenarios of the Internet of things.

Before formally sending and receiving data, the terminal must first add network. There are two ways to join in the network: Over-the-air-Activation (OTAA) and Activation by Personalization (ABP). Because of the flexibility and security of OTAA, more products choose this way to access LoRaWAN network [16]. This approach needs preparation of LoRaWAN Device EUI, Application EUI, and Application Key parameters. After the terminal initiates the join process of adding network, it issues the adding network command. After NS confirms and reply to the terminal with assigned Device Address.

Last but not the least, for capacity expansion of LoRaWAN, ADR (LoRa Adaptive Data Rate) mechanism was designed on the protocol. This allows devices with different transmission distances to use the fastest data rate possible depending on the transmission conditions, improving the overall data rate as well.

LoRa technology, as a new generation of wireless communication protocol, has not been widely used in Smart Home field, which means the online resources and hardware dependency is relatively difficult to find. However, as introduction has explained, LoRaWAN owns its unique advantage of wide sensor IoT network.

C. Automatic Speech Recognition (ASR)

In traditional household appliances in smart home control, there are only two kinds of control modes: manual or remote control. However, along with the increase in household appliances, more and more switches and remote control, use very convenient. At this time, ASR system can be adopted, to achieve automatic speech controlling in modern Smart Home.

If the hardware part of the smart home is compared to the shell of the system, then the smart instructions form part of its kernel. Speech recognition is one of the most popular methods for construction of intelligent interface of Smart Home.

Process of recognition refers to the ability of interfaces to receive the speech signal, recognize the speaker in the signal, and finally transfer to the command from voice. ASR performs tasks similar to those performed by the human brain. Generally speaking, the speaker recognition process is mainly divided into three steps: Sound Processing, Feature Extraction and Recognition.

The purpose of Pre-processing aims to denoise the original signal for the feature extraction section. Residual noise feature can decrease the accuracy in training steps. Feature Extraction is realized by converting speech signal into parameter at a relatively small data rate for subsequent processing and analysis.

MFCC was adopted as the speech characteristic parameter in a large number of experiments. [17]. Because low-frequency sounds tend to mask high-pitched sounds, while high-pitched sounds tend to mask high-pitched sounds, the critical bandwidth of sound masking at low frequencies is smaller than at high frequency. Therefore, a set of bandpass filters is arranged in the band from low frequency to high frequency according to the critical bandwidth from dense to sparse to filter the input signal, which is the theory of MFCC algorithm [18]:

$$Mel(f) = 2595 \times \log(1 + f/700) \tag{1}$$

This kind of parameter has better robustness, matches to auditory characteristics of the human ear, and still has better recognition performance when the SNR is reduced.

III. Experimental Setup

A. Hardware

The testbed is the prototype of a whole system for Smart Home. For hardware, IoT development devices contain single sensor board and LoRaWAN gateway. Sensor board will be integrated with temperature sensor, humidity sensor and atmospheric pressure sensor to test the instantaneous value of living parameters indoor.

Since 2017, Chinese 470MHz spectrum has been added to the V4.3.1 version of the LoRaWAN stack. Compared with other giant companies in China, Alibaba is the only one that regards the IoT as a main track for strategic development, which has launched IoT platform based on LoRaWAN protocol since then. Meanwhile, the platform has ability to share data with Ali-cloud service for large volume of information processing. So, gateway of RAK7258 (Ali-Cloud version) and node board of RAK5205 were chosen to start with the construction of IoT testbed. Boards and antenna were equipped with 470MHz protocol.

To equip gateway and node boards, setting firmware and changing parameters is necessary. The LoRa Concentrator is the basic unit of the LoRa gateway, and the gateway will be selected according to the actual usage scenarios in practical applications. Each LoRa Concentrator can simultaneously monitor 8 multi-rate LoRa channels, 1 Standard LoRa Channel and 1 FSK Channel, a total of 10 channels. At the same time LoRa Concentrator contains two Radio units: Radio 0 and Radio 1. Radio 0 can be used to receive and send signal, with Radio 1 is used to receive radio frequency signals. Each Radio unit can listen to up to 5 channels (including Multi-SF channel, LoRa Std channel, and FSK channel). Following task need to be done.

- Set the central band of the Radio
  Each Radio is allocated 8 multi-rate LoRa channels, channel 1-4 belonging to Radio 0, and the central frequency is 472.3MHz. Channel 5-8 belong to Radio 1 and the central frequency is 473.1MHz
- Set the transmission frequency
  It is necessary to ensure that all frequency points of the downlink channel are included in the Radio segment, so Radio 0 Tx Min is set to 485MHz. Radio 1 Tx Max is set to 487MHz. The minimum gap should be more than 500KHz
- Set the channel
  Multi-SF 0-3 Radio is set to Radio0, and frequency offset is set to -0.4M/-0.2M/0/0.2M respectively, which is identical to Multi-SF 4-7.

RAK5205 node board is equipped with LoRa antenna and BME680 environment sensor (Gas, Atmosphere pressure, Humidity and Temperature). With the help of firmware, information collected by sensor can be transmitted through USB to experimental laptop. Although the general LoRa nodes have been proved that own long-range transmission capability, indoor tests should be done due to the difference of hardware.

Fig. 2. Nodes placement in the apartment (40m×30m)

In order to establish the testbed platform of Smart Home, five sensors were placed in distinct region of the house for environmental data collection as shown in 2: kitchen, two bedrooms, living room and balcony. In every 30 seconds, the detected result will be updated to the NS by the system.

B. IoT Platform

With the set-up of hardware, the interface of the upper network should be established to build a system. It's necessary to create products and devices, define the model of things, and write and submit data analysis scripts for LoRa devices on the platform. Product should be defined by custom type with LoRaWAN standard communication protocol. It's simple to login the platform with devices. However, the terminal devices are embedded board with very few available electricity, and the device side usually uses binary communication protocols-Message Queuing Telemetry Transport (MQTT) for IoT system. [19]. MQTT not only can reduce the device side in the process of protocol consumption of resources, including ROM, RAM, battery, traffic, etc, but also bring the volume of payload down. [20]. The communication protocol is usually HTTP or HTTPS protocol, the data format is usually JSON, which requires a conversion, to transfer binary message of the device side into JSON protocol of the NS side. The process of converting binary into text is called decoding, and the process of converting text into binary is called encoding, which is contained by Alink JSON protocol, which was provided by Alibaba cloud. To apply Alink JSON, there are several steps:

1) Defining object model: In the platform, defining the model of things is to define product functions (including attributes, events, and services). After completing the function definition, the system will automatically generate the physical model of the product. The equipment reports temperature, humidity, air pressure and gas resistance and Battery Remaining Capacity. Therefore, on the Internet of things platform, the data model is defined with above information, which is shown in Table I

TABLE I
OBJECT MODEL DEFINITION

Property	**Tag**	**Range**	**Step size**	**Unit**
Temperature	Temperature	99-100	0.01	°C
Humidity	Humidity	1-100	0.01	%
Atmosphere pressure	Atmosphere	550-1060	0.1	hPa
Gas	Gas_resistance	10000-10000	0.01	NULL
Residual voltage	Battery_voltage	0-10000	0.01	mV

2) Write a data parsing script: The data reported by LoRa equipment is in binary format, the script interface got a 16-bit number at the specified byte offset whose starting position is counted at byte.

3) Testing: Select the simulation type to upload status. Fill in simulated input binary message, click operate and find the if JSON results worked successfully. Meanwhile, platform provided a simple data display in the decoded JSON format. Data of sensors were shown directly in the form of a list, which is the symbol of success of message upload.

C. Establish interfaces for user

As a Smart home product, easy access to the IoT system is an essential part for user. In order to satisfy various kinds of requirement of monitoring and processing the information, user server, web interface and mobile program are necessary for the system.

1) Web visual development: IoT Studio provides a series of convenient development tools, such as Web visual development, service development and device development, to solve the problems of long development link, complex technology stack, high collaborative cost and difficult solution migration in the development field of Internet of things.

2) Mobile Applcation: On mobile devices, WeChat applets are more appropriate as a development platform than official apps. First of all, whether it is IOS APP or Android APP, the development cost is relatively high, Secondly, from the perspective of users, most people are reluctant to install new apps. Small program development fast, no need to install the new APP, there is no problem of different mobile phone adaptation. After searching WeChat built-in applet, customer can import the secret key and login their IoT platform. Interface will give feedback of parameters that had been tested by LoRa nodes to the mobile phone.

3) User server: Under some practical situation, users want to store some information on their own computer or somewhere. However, the log generally will be hold only in seven days online, which proves the local server is meaningful. On the other hand, the computation ability of general computer cannot be replaced by terminal development boards. So, the local server is useful for other function like local video and voice recognize, making system smart.

To realize the foundational function, transmitting the JSON data of object model to the local server, the laptop workstation with Ubuntu 18.04 environment was established. Message queue (MQ) is an application-to-application communication method. The application communicates by writing and retrieving application-specific messages in and out of the queue, without requiring a dedicated connection to link them. This asynchronous communication method is simpler and more flexible. The platform provides two kinds of MQ methods for the link with application server: Message Notification Service (MNS) and Advanced Message Queueing Protocol (AMQP). [21]. In comparison with MNS, AMQP supports for open-source RabbitMQ services, as well as message queuing services for open source clients in various languages, so that the AMQP method was chosen in this step.

Through service subscription, the product can be linked to a consumer group which stores the data stream of uplink and downlink with its Consumer Group ID. After that, with the help of example, receiver program based on python successfully operates on the local server. Data stream can be received and stored in excel lists.

D. ASR system

To realize the local server instruction part, the system consists of two main parts in the system: Speaker Recognition and Speech Recognition.

1) Speaker Recognition: This system applies MFCC feature to train the speaker recognition network based on Gaussian Mixture Model (GMM) model. The MFCC feature is based on the theory of human ear hearing cepstrum coefficient, of which response to the sensitivity of different frequency signals are different, with logarithmic relationship as depicted in Figure 3.Procedures of MFCC feature extraction needs several steps as Figure 4.In Figure 5, with the help of calculation and MFCC library, the input voice can be transformed to energy spectrum image.

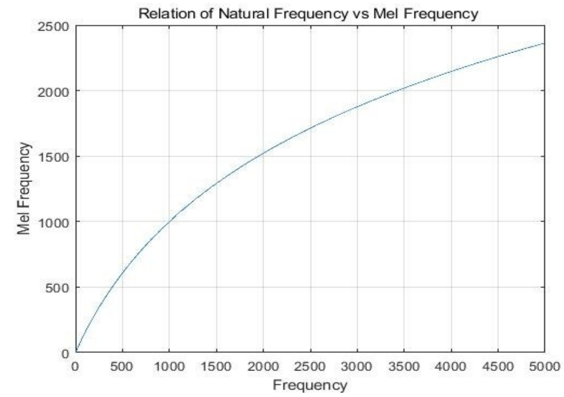

Fig. 3. Natural Frequency vs Mel Frequency

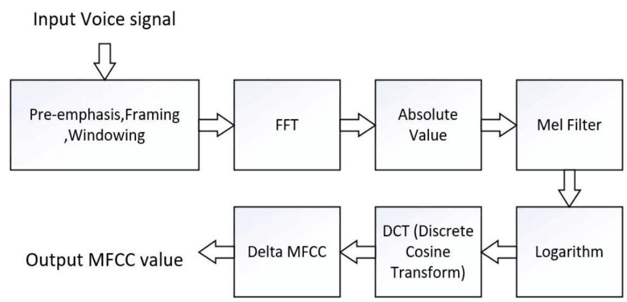

Fig. 4. MFCC Procedure block diagram

After short-time Fourier transform (STFT) or cepstrum is taken, the original speech data will become feature sequence. Under the condition of ignoring the timing information, GMM is very suitable for fitting such speech feature.

The speaker recognition system based on GMM can be divided into training stage and recognition stage. The speaker model training block diagram is shown in Figure 6. GMM module has been packaged in Scikit-learn library for application development.

Firstly, training data set consisted of recordings from five students, with the same words. Due to relatively small training resources, the training time is around 97 seconds. However, five kinds of speaker recordings cannot establish reliable performance quantification of network, larger volume of dataset

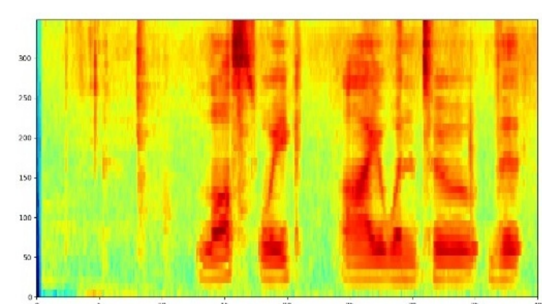

Fig. 5. Energy spectrum after Pre-Process

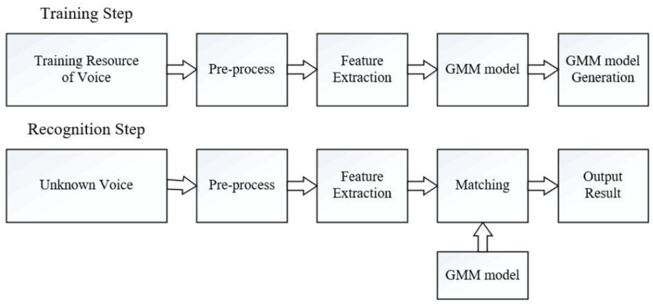

Fig. 6. Speaker recognition system based on GMM block diagram

TABLE II
TEST RESULT IN TOTAL SETS

Noise Type	Test Numbers	Success Rate In total (%)
Cafe	590	43.95
Car	590	84.28
White noise	590	12.65

is required for training and testing. Therefore, THCHS-30, a free Chinese speech corpus released by Center for Speech and Language Technologies (CSLT) of Tsinghua University, was applied to test the accuracy of speaker recognition model.

With 22 different sets of recordings from individuals, firstly, the whole dataset was divided into two parts – 70% for training and 30% for testing. In this step, all recordings have been denoised. The accuracy shows more than 90% success rate of classification. But in fact, the noise must be considered. Another set of test data with 0 dB noise was tested. In the first test, the set was combined with all different experiment groups of speakers with average rate, shown in Table II.

The results in Table II prove that the noise will affect the performance of the system and degrade the performance. However, the reason for fluctuations of success rate should be explained. Therefore, the whole experiment test object were divided completely based on identity of speakers.

After noise tests, the results in Table III have proved that this model cannot adapt to noisy surrounding, which means the robustness of feature extraction method based entirely on MFCC is poor. Among 3 types of noise, especially in white noise tests, 'D8' almost replace each right results and gain the highest GMM score. From the results, it can be seen that effective denoise method is necessary for a well-performance speaker recognition system based GMM and MFCC.

TABLE III
TEST RESULT OF SPEAKERS SEPARATELY

Noise Types	Success Rate of Different Speaker (%)							
	D4	D6	D7	D8	D11	D12	D13	D21
Cafe	99.6	100	100	100	1.3	0	0	52.1
Car	100	100	98.6	100	0	93.2	82.4	100
White noise	1.2	0	12.6	100	0	0	0	0

2) Speech Recognition with Interface: Speech Recognition of Smart Home must be real-time interaction type to get living of people more comfortable. To achieve this goal, the trained GMM model for speaker recognition is not enough.

At first, to apply speech recognition technology, general short-words Artificial Neural Network (ANN) training method with Keras was chosen. The training recording files all last for 1 second long, with 16000 frames. By training different types of words on a large scale with constant length and rate, recognition result can reach 90% and higher.

Nevertheless, taking living environment into consideration, this short-word recognition cannot be applied. At first, noise factor must exist, short word recognition may cause much error during operation. Secondly, the system should know the contents of speech as much as possible. Therefore, CMUSphinx Open Source Speech Recognition [22] project and Voice Activity Detection API are selected by me to realize the real-time Speech recognition.

CMUsphinx is the general name of a series of speech recognition systems developed by Carnegie Mellon university. Available resources include acoustic model training software, language model editing software and speech dictionary CMU-dict. It provides open source large vocabulary set and Open source speaker-independent continuous speech recognition program for English (US) speech recognition.

The final ASR system integrated the speaker recognition based on GMM and MFCC, speech recognition based on CMUsphinx Model and VAD API. The structure of whole system is shown in Figure 7

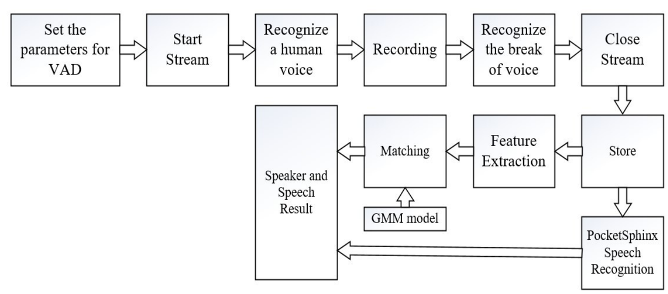

Fig. 7. ASR system block diagram

IV. EXPERIMENTAL RESULT

A. IoT Testbed

Through the display interface from Web application, WeChat applet and local server, the data can be transmitted successfully. The Web interface is shown in Figure 8.

From web and local server, the data can also be recorded and plotted by line chart for user as Figure 9. The temperature change caused by the air-conditioner has been reflected on the panel as Figure 9. With the help of a large number of sensors, users can simply judge the state of their living environment from the data.

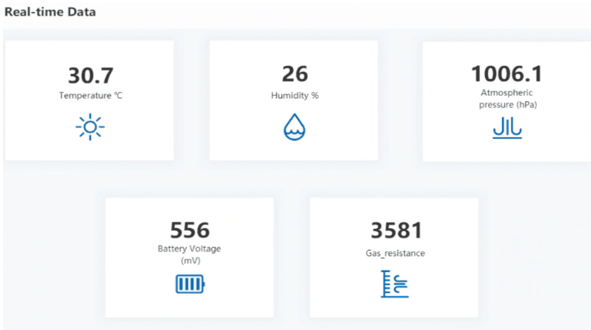

Fig. 8. Web interface performance

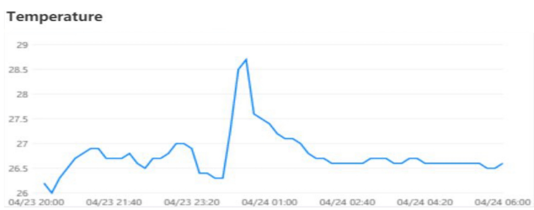

Fig. 9. Temperature monitor on web page

B. ASR system

In speaker recognition part, test signal can be recognized for about 0.5 second, without pre-process steps. However, in VAD part, the voice should be processed by denoising, frequency shift and feature extraction steps and so on. These procedure delayed the recognition period. From voice input to the result output, 3 seconds – 4 seconds is needed for the period.

For Speaker Recognition, in the first test with few dataset from five students proved that the speaker recognition system was able to work. In the next, LibriSpeech ASR corpus library was added. However, for Smart Home system, limited word list is acceptable for controlling instruction, which means the simple instruction like "turn the light on" and "turn the light down" can be trained in the data set. Therefore, the speaker of instruction can be recognized with high accuracy.

For Speech Recognition, the open source model consists of large number of words list, including the words that system needs, such as "open", "on", "off", "light" and so on. Use conditional execution algorithm, when extraction of recognized words is matched with one of instruction of Smart Home, the message will be sent to the corresponding terminal.

V. Conclusion and Future Perspectives

This work resulted in successful implementation and completion of the structure of a smart home based on LoRaWAN, including LoRa nodes, LoRa Gateway, IoT platform, user server and mobile application. Meanwhile, a type of ASR system, based on GMM and MFCC speaker recognition techniques with open source CMUsphinx model for speech recognition, has been developed in this project.

In IoT system establishment section, major tasks in developing and deploying IoT system were the selection and debugging of nodes and gateway, testing of useful platform, learning and writing the Parsing Scripts to transfer the binary message to JSON format data, constructing user server and writing the scripts to receive the message with AMQP message protocol and finally completion of small WeChat program. In ASR system design process, major challenges were selection of model for speaker and speech recognition, collection of voice database, testing trained model in large-volume datasets and testing the whole system in real-time.

In the next step over hundreds different sensor should be placed around the Smart Home to obtain detailed living information, without invasion of privacy, such as Radar behavior detection system, infrared anti-theft and so on. On the other hand, due to the long-range and low-power characteristic, commercial residential-oriented LoRaWAN Smart Home is economically more viable. In ASR system part, as the results can be easily influenced by noise, a well-performing denoising method should be worked out and applied.

Acknowledgment

The author would like to thank the Glasgow College UESTC for its assistance during the research. Meanwhile, the author is very grateful to those who dedicates himself to saving lives and restoring social order during the COVID-19 outbreak.

References

[1] C. Coelho, D. Coelho and M. Wolf. "An IoT Smart Home Architecture for Long-term Care of People with Special Needs." 2015 IEEE 2nd World Forum on Internet of Things (WF-IoT) (2015): 626-27.

[2] H. Yu-Liang, C. Po-Huan , C. Hsing-Cheng, L. Shyan-Lung , Y. Shih-Chin, S. Heng-Yi, C. Chih-Chien, C. Yuan-Sheng and K. Yu-Chen, "Design and Implementation of a Smart Home System Using Multisensor Data Fusion Technology," Sensors, 2017

[3] P. Fraga-Lamas, M. Celaya-Echarri, P. Lopez-Iturri, T.M. Fernández-Caramés, L. Azpilicueta, E. Aguirre, M. Suárez-Albela, F. Falcone, L. Castedo, Analysis, "Design and Empirical Validation of a Smart Campus based on LoRaWAN." In Proceedings of the 5th International Electronic Conference on Sensors and Applications,15–30 November 2018

[4] P.J. Basford, F.M.J. Bulot, M. Apetroaie-Cristea, S.J. Cox, S.J.Ossont, "LoRaWAN for Smart City IoT Deployments: A Long Term Evaluation." Sensors 2020, 20, 648.

[5] G. Suciu, et al. "Low-Power IoT Devices for Measuring Environmental Values." 2018 IEEE 24th International Symposium for Design and Technology in Electronic Packaging (SIITME) IEEE, 2018.

[6] P. Gianni, et al. "Smart City Pilot Projects Using LoRa and IEEE802.15.4 Technologies." Sensors 18.4(2018):1118-.

[7] A. Lavric, "LoRa (Long-Range) High-Density Sensors for Internet of Things." Journal of Sensors 2019(2019):1-9.

[8] L. Vangelista, M. Centenaro, D. Magrin, (2017). "Performance Evaluation of LoRa Networks in a Smart City Scenario." 10.1109/ICC.2017.7996384.

[9] N. Gangatharan, T.S. Arulananth, T. Jayasingh, M. Baskar,. (2015). "SMARTPHONE BASEDFACE AND VOICE AUTHENTICATION IN MOBILE DEVICESBY USING MFCC ALGORITHM." International Journal OF Engineering Sciences & Management Research. 2. 7-13.

[10] R. Charan, and K. Ravichandran . "A text-independent speaker verification model: A comparative analysis." I2C2 2018.

[11] Krishna, Y. Bala , and S. Nagendram . "ZIGBEE BASED VOICE CONTROL SYSTEM FOR SMART HOME." International Journal of Computer Technology Applications 03.01(2012).

[12] G. Sachs, "The Internet of Things-What is Making S-E-N-S-E of." 2014. [Online]. Available: https://www.goldmansachs.com/insights/pages/internet-of-things/iot-report.pdf.

[13] H. Jun-Ho, and S. Kyungryong . "An Indoor Location-Based Control System Using Bluetooth Beacons for IoT Systems," Sensors 17.12(2017):2917-.

[14] P. Jörke, S. Böcker, F. Liedmann and C. Wietfeld, “Urban channel models for smart city IoT-networks based on empirical measurements of LoRa-links at 433 and 868 MHz,” 2017 IEEE 28th Annual International Symposium on Personal, Indoor, and Mobile Radio Communications (PIMRC), Montreal, QC, 2017, pp. 1-6.
[15] L. Alexandru, “LoRa (Long-Range) High-Density Sensors for Internet of Things,” Journal of Sensors Volume 2019, Article ID 3502987, 9 pages, 2019
[16] Z. Qihao, Z. Kan, H. Lu, X. Jinyu, X. Rongtao, “Design and Implementation of Open LoRa for IoT,” IEEE Access, vol. 7, pp. 100659-100657, 2019
[17] L. Juvela, et al. “Speech Waveform Synthesis from MFCC Sequences with Generative Adversarial Networks.” ICASSP 2018 - 2018 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP) IEEE, 2018.
[18] W. Han, et al. “An efficient MFCC extraction method in speech recognition.” 2006 IEEE International Symposium on Circuits and Systems IEEE, 2006.
[19] K. Fysarakis, O. Soultatos, I. Askoxylakis, H. Manifavas, I. Papaefstathiou, V. Katos, (2016). “Which IoT Protocol? Comparing Standardized Approaches over a Common M2M Application.” 10.1109/GLOCOM.2016.7842383.
[20] Z. Tianxin , et al. “Insulation Condition Monitoring in Distribution Power Grid via IoT-Based Sensing Network.” IEEE Transactions on Power Delivery PP.99(2019):1-1.
[21] Yassein, B. Muneer, et al. “Internet of Things: Survey and open issues of MQTT protocol.” International Conference on Engineering Mis IEEE, 2018
[22] D. Huggins-Daines, et al. “Pocketsphinx: A Free, Real-Time Continuous Speech Recognition System for Hand-Held Devices.” Acoustics, Speech and Signal Processing, 2006. ICASSP 2006 Proceedings. 2006 IEEE International Conference on IEEE, 2006.