PROJECT

Cloud Connected Sensors Using Arduino
+
Fuzzy Inference System

Project Area: Internet-of-Things(IoT) & Fuzzy Logic

Abstract: In this project, different types of available sensors and the data acquired from them will be publish to a cloud service using Arduino as the microcontroller board and Esp8266 12E as the wifi module.The wifi module will enable the Arduino board to be connected to the internet , thereby facilitating web data transfer . The uploaded sensor data will be interpretted and displayed in the form of graphs. Uploaded sensor data is also inputted into a fuzzy inference engine whose output is used in the creation of a response system to create alerts incase of fire/gas leaks enabling more functionality in this IoT based prototype. Finally we look at some real life applications where this type of a project could be scaled up and used in different ways.

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CHAPTER 1

Arduino Microcontroller

1.1 Introduction

Arduino is an open source company that manufactures microcontrollers, hardware components, hardware modules, sensors etc. It also provides hardware kits and special purpose microcontrollers for projects ranging from embedded systems to IoT. Being open-source it has a large community of users thereby making debugging and error handling an easy task. It is the most popular platform for hardware projects and is widely used in prototyping. It also provides an integrated development environment called Arduino IDE for developing embedded applications.

1.2 Microcontroller

A microcontroller (or MCU for microcontroller unit) is a mini-computing device built on a single integrated circuit. A microcontroller can be single or multi-core processor system along with random access memory (RAM) and ports for input/output devices. Program memory for a microcontroller may be implemented as FRAM or NOR flash. It is mainly designed for embedded systems applications/projects as they are low powered devices and easily programmable and interfaced with different devices, sensors, modules etc.

1.3 Arduino MEGA 2560 & MSP430FR6989

This project uses two microcontrollers – the Arduino MEGA 2560, which is the main MCU and will be used for all the processing, whereas the other MCU, the TI launchpad MSP430FR6989 will be used to provide voltage stability , which is mainly required by the wi-fi module.

Figure 1- Arduino Mega 2560

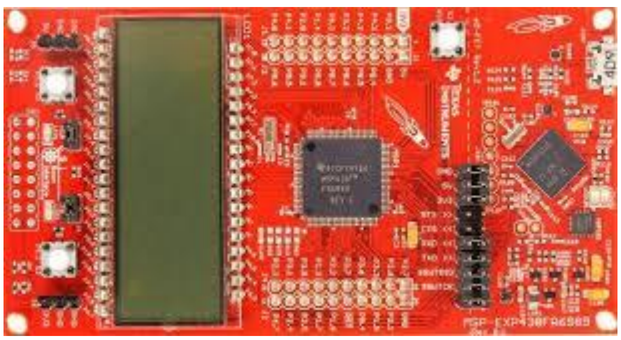


Figure 2- MSP430FR6989 launchpad

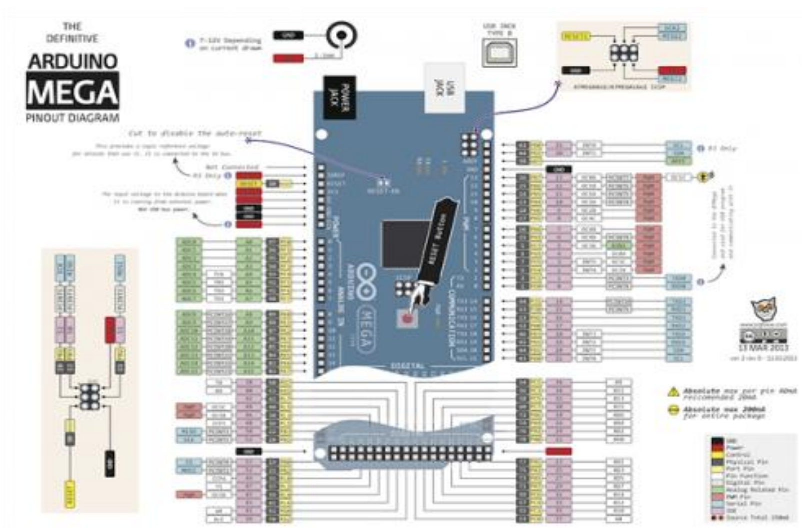


Figure 3- Arduino Mega 2560 pinout

Chapter 2

Wi-Fi Module

2.1 The ESP8266

The esp8266 is a Wi-Fi module, 3.3 volt powered, compatible with a range of microcontrollers like Arduino,MSP launchpad,NodemCU etc.
It is mainly used for adding Wi-Fi functionality to any hardware project and used almost every where, when working on Internet-of-things projects.

Some of its features are:

- Can be used as Wi-Fi client ,server or both
- Cheap and efficient
- Operation @ 2.4 Ghz
- Integrated TCP/IP stack
- Native support for encryption like WPA/WPA2

Esp comes in many different form factors and also from different vendors like Espressif, AI Thinker etc.

Figure 4- Esp8266 Form Factors

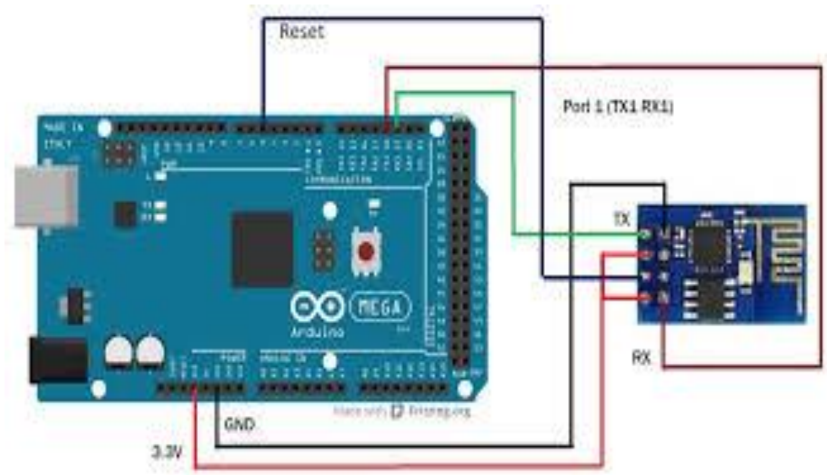


Figure 5-Circuit diagram

2.2 Communication between Arduino and ESP8266

The Arduino MEGA 2560 provides multiple serial ports, so one set of of **TX/RX** pins are used for reading and writing to the serial ports to send commands and receive responses. ESPs come preloaded with a firmware using which Arduino commands can be received, processed and responses transmitted. The set of serial ports will be used to display values to the user on the serial monitor of Arduino IDE. Also the ESP operates at 3.3V, so the 3v3 Arduino VCC is used.

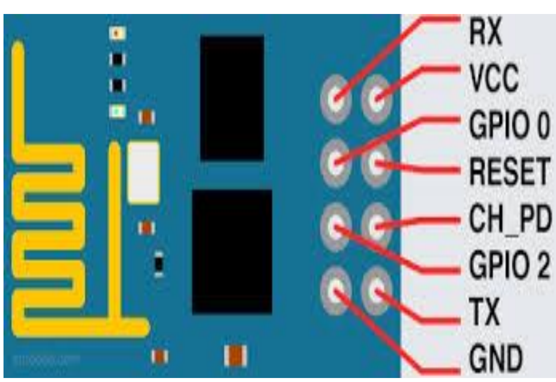


Figure 6a- Esp8266 01 pinout

Figure 6b- AT command set

CHAPTER 3

Sensors

3.1 Why use sensors?

A sensor is a small-sized,low powered electronic component that is used to capture, monitor and detect environmental conditions or variables like temperature,humidity, pressure,light etc. Sensors can be analog or digital, and there is a sensor for almost any environment variable that would like to be measured. A typical smartphone can have more than a dozen sensors. Sensors are extensively used in IoT application as well as for monitoring environment in real time,hence sensors have huge industrial applications. The following sensors have been used in this project.

3.2 Temperature Sensor – TMP36

Fig 7a.

3.3 Digital Light Sensor – LM393

Fig 7b.

3.4 Digital Sound Sensor – LM393

Fig 7c.

3.5 Gas Sensor – MQ-09

Fig 7d.

3.6 Ultrasonic Sensor – HC-SR04

Fig 7e.

CHAPTER 4

Cloud Service

After acquiring data from sensors, now we would like to upload as well as store these data points on an online cloud service, which forms the other part of any IoT application. Cloud computing is the term used to refer to the ubiquitous access of shared resources that can be maintained and analyzed over a network such as the internet.Thingspeak and IBM Bluemix are two popular examples that provide these services

4.1 **ThingSpeak**

ThingSpeak is an API service that is popularly used for IoT analytics.Using ThingSpeak users can upload ,store ,analyze and visualize data such as those coming from sensors . ThingSpeak also provides a range of online apps and analysis/visualization tools for free thereby enabling quick addition of features as well as additional functionality to any IoT project, small or big,personal or enterprise level.

Figure 8a – ThingSpeak Cloud Service

Figure 8b – ThingSpeak cloud communication

4.2 Features of ThingSpeak API

- Open source.
- Allows uploads every 15 seconds with free account and per second with premium.
- Comes with online Matlab tools for Matlab analysis and visualizations.
- Uses HTTP protocol, hence easy to work with.
- Provides read and write API keys which can be shared to easily read/update sensor fields. Also it allows for exporting logged data.
- Comes with a range of ThingSpeak apps like TimeControl , React and TalkBack providing easy to use features and flexibility to add more functionality to a project.

CHAPTER 5

5.1 Circuit Diagram (PHASE I)

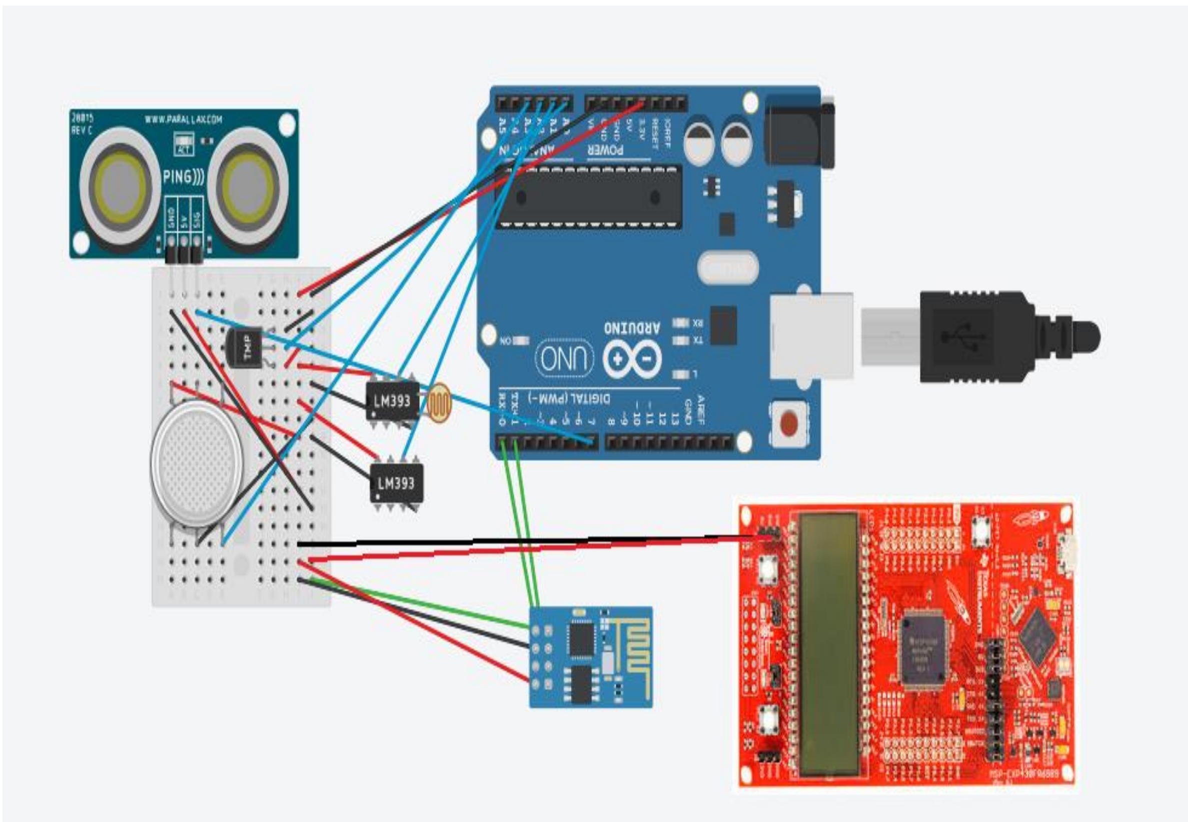


Figure 9 – Phase 1 circuit setup

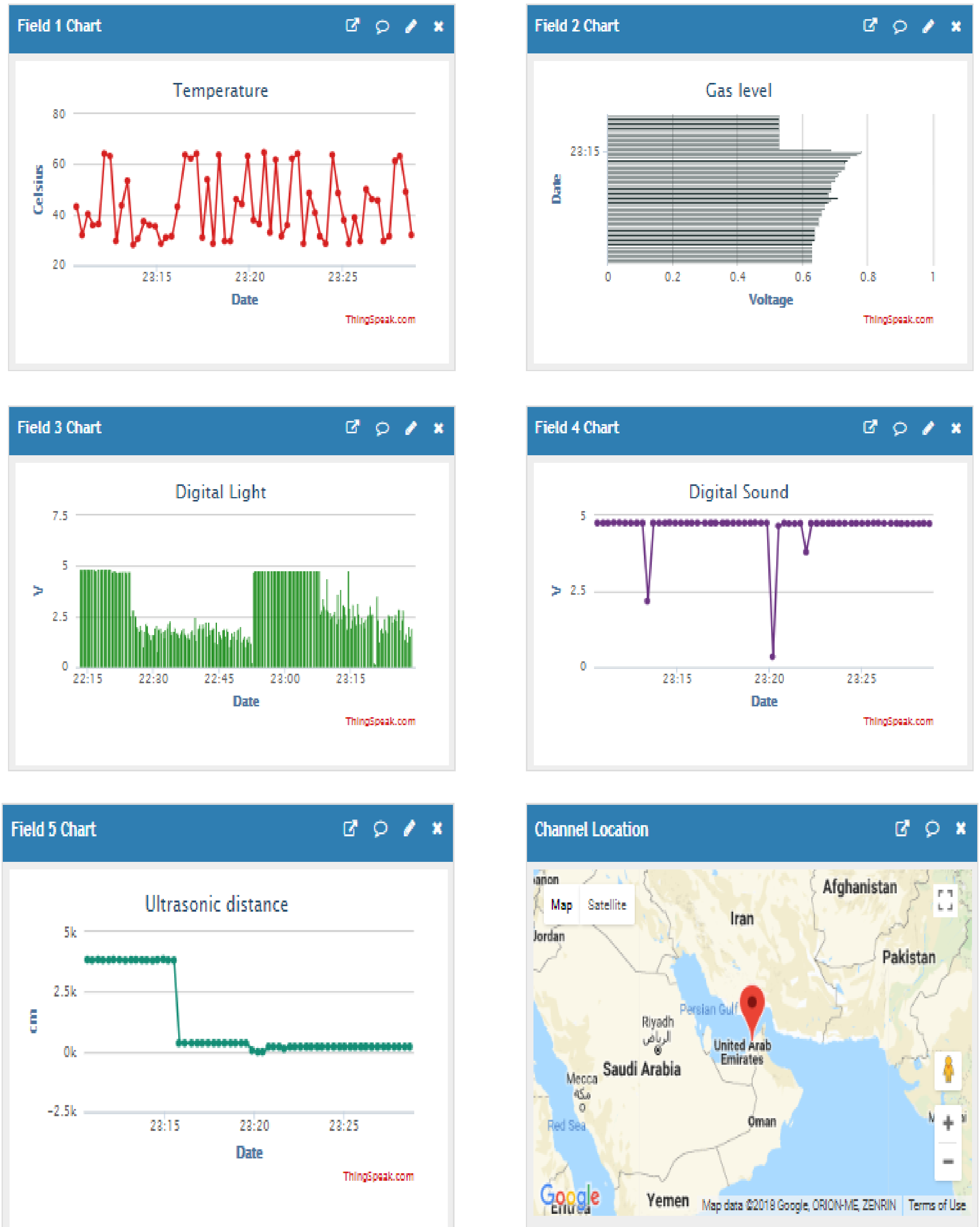


Fig 10 – ThingSpeak channel fields showing sensor data uploaded by Arduino and Esp8266

5.2 Response System Overview

Since we now have the IoT system ready and uploading data in real time, we can analyze the uploaded data in numerous ways and use it for applications like monitoring environment conditions, intrusion detection systems, emergency response systems etc.

For this project, a basic response system has been implemented for fire/gas leak detection which is especially useful in industrial monitoring such as for factories, power plants, nuclear reactor stations where temperatures and gas concentration levels need to be constantly monitored and maintained at normal levels. Also, detection of abnormally high or low values of these environment variables are crucial to prevent deadly gas leaks or explosive fires.

For the scope of this project we will use a piezo speaker as an alarm whose beep frequency can be controlled which draws inspiration from BIOS beep codes used for computer motherboard troubleshooting as well as a pair of LEDs which light up based on conditions and since we have 2 LEDs, they can be used in 4 different combinations – 00 ,01 ,10 ,11 - to represent four different environmental conditions similar to state machines*. Additionally, a mobile SMS will be sent to a user to alert them in case of immediate action to be taken such as cooling, turning off a machine etc. in case there is a gas leak or possible fire.*

Figure 11 – LED combinations and buzzing piezo speaker

Chapter 6

6.1 FUZZY LOGIC

Fuzzy logic is a type of logic in which truth values are represented as degrees of membership or degree of belongingness to a particular attribute,feature,property etc in a range from 0 to 1. Prof.Lofti Zadeh in 1965 proposed this new system of logic and coined the term ‘fuzzy logic’.

Fuzzy logic differs from boolean logic in which truth values are either 1 or 0. It is used to represent the concept of partial truth, where the value of truth ranges between the values **0** and **1**, where 0 is complete false and 1 is complete truth.

Due to the nature of fuzzy logic which can take into account multiple factors and their corresponding membership as well as variances in computing a value it has immense applications in areas like control theory, artificial intelligence PLC/PID controllers , electronic appliances like washing machines etc. Notable companies like Siemens,Hitachi,Honeywell etc. make extensive use of fuzzy logic for their products and appliances. Fuzzy logic is especially useful in automation processes as well.

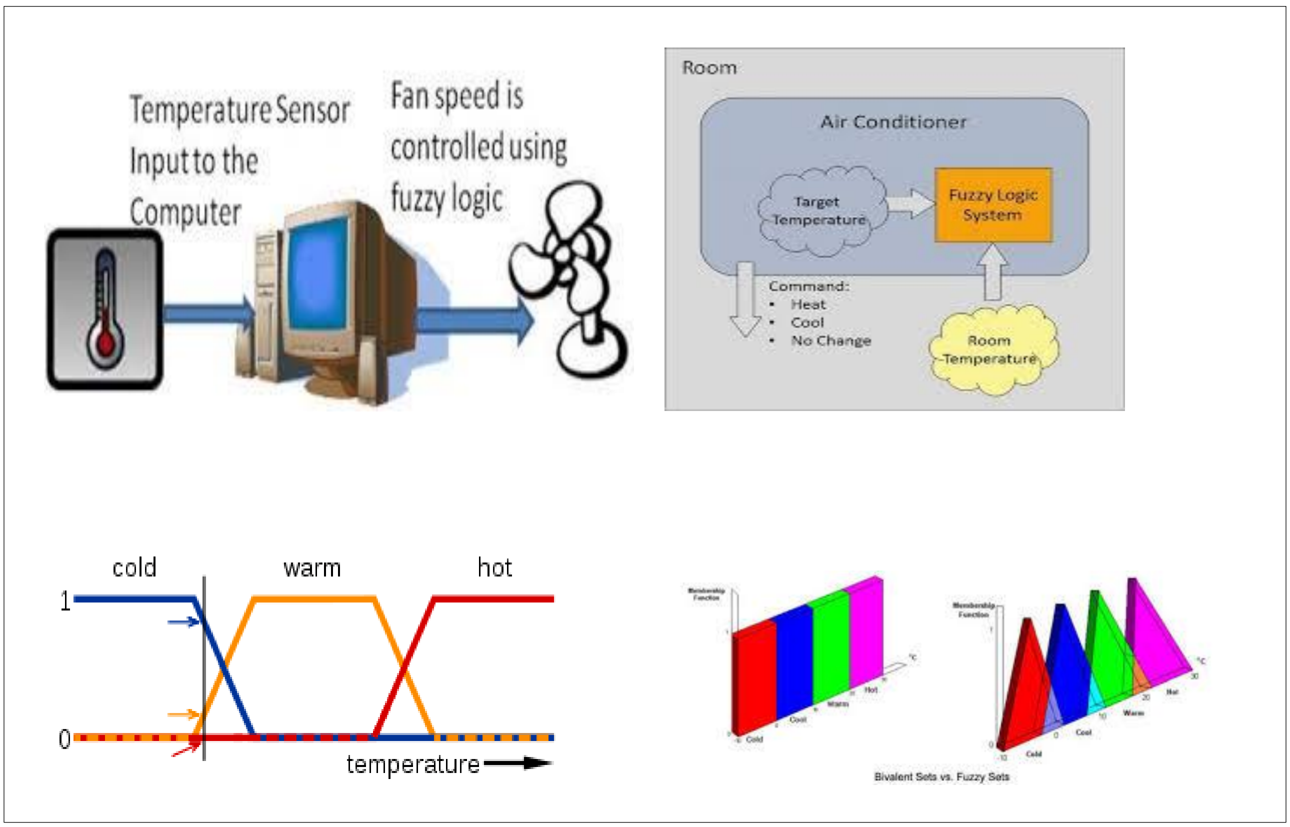


Figure 12 – Fuzzy logic applications

6.2 FUZZY INFERENCE SYSTEM

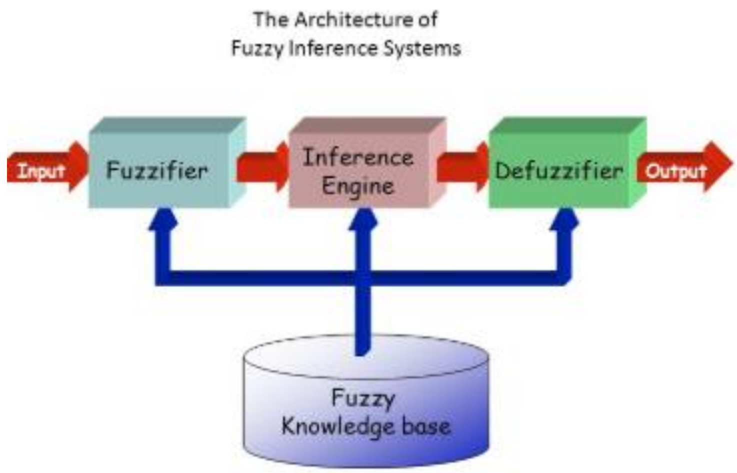


Fig13

Fuzzy Inference System is the key unit of a fuzzy logic system having decision making as its primary work. It uses the "IF…THEN" rules along with connectors "OR" or "AND" for drawing essential decision rules.

Functional blocks of a FIS:

a) **FUZZY KNOWLEDGE BASE**- The rule base and the database are jointly referred to as the knowledge base. •a rule base containing a number of fuzzy IF-THEN rules; •a database which defines the membership functions of the fuzzy sets used in the fuzzy rules

b) **FUZZIFIER** - Converts the crisp input to a linguistic variable using the membership functions stored in the fuzzy knowledge base.

c) **FUZZY INFERENCE ENGINE -** Using If-Then type fuzzy rules converts the fuzzy input to the fuzzy output.

d) **DEFUZZIFER** - Converts the fuzzy output of the inference engine to crisp using membership functions analogous to the ones used by the fuzzifier.

6.3 FUZZY LOGIC IN PYTHON WITH SKFUZZY

Fuzzy logic systems can be created using software and there are a variety of scientific/mathematical softwares such as Matlab, GNU Octave, SciLab to create robust fuzzy inference systems

Python which is a powerful general purpose programming language extensively used in machine learning,scientific and mathematical applications and features a rich collection of libraries suited to a wide range of problems and applications.

Python provides ‘Scikit-Fuzzy’, which is a fuzzy logic toolbox intended for use in the SciPy stack which is an ecosystem of open source software for mathematics and engineering . *Due to the portability and ease of use of python as well as additional features like web data handling we use the interactive Jupyter Python Notebook to create a fuzzy inference system which forms the heart of the response system for our IoT setup.*

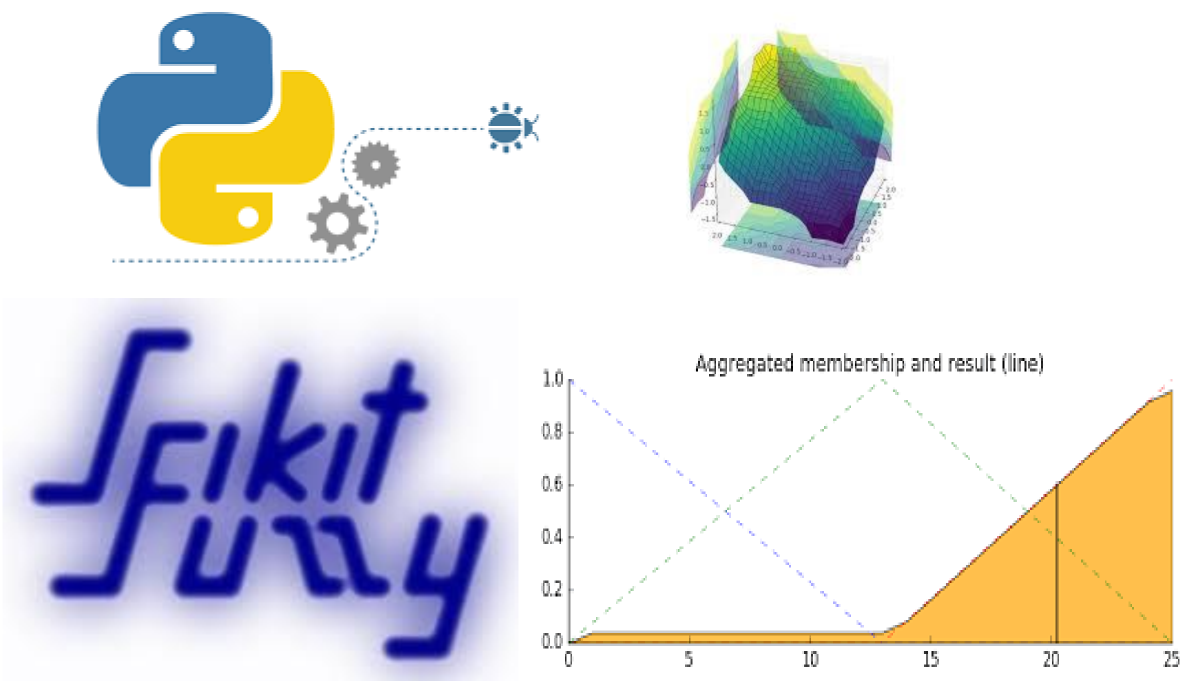


Figure 14- Python and Skfuzzy package along with some plots

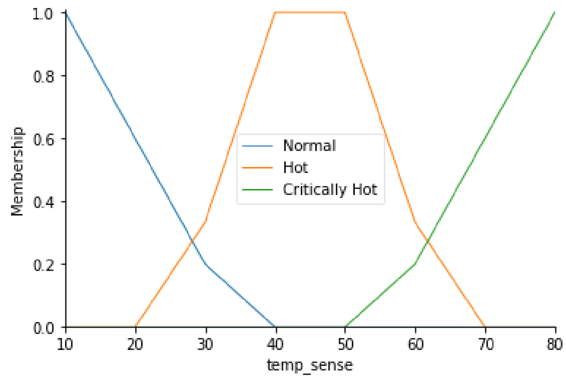


Fig 15a - Temp_sense i/p fuzzy set

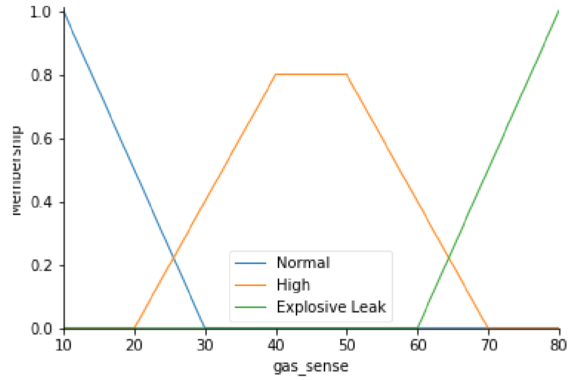


Fig 15b - Gas_sense i/p fuzzy set

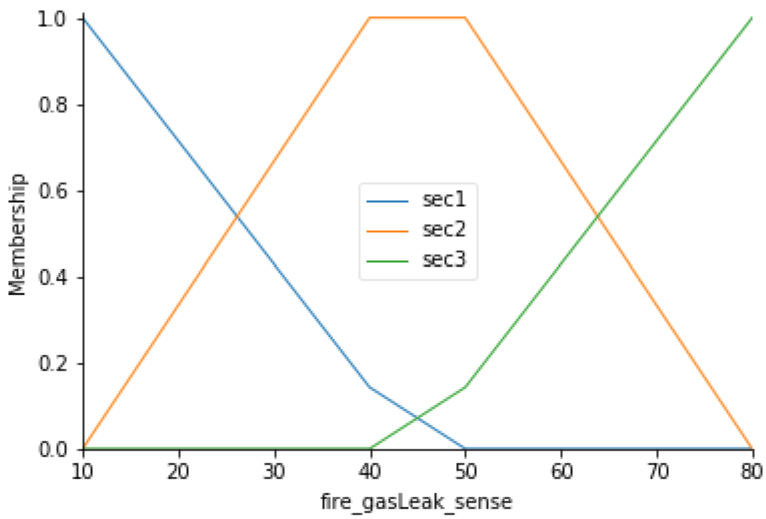


Fig 15c – Fire_gasLeak_sense o/p fuzzy set

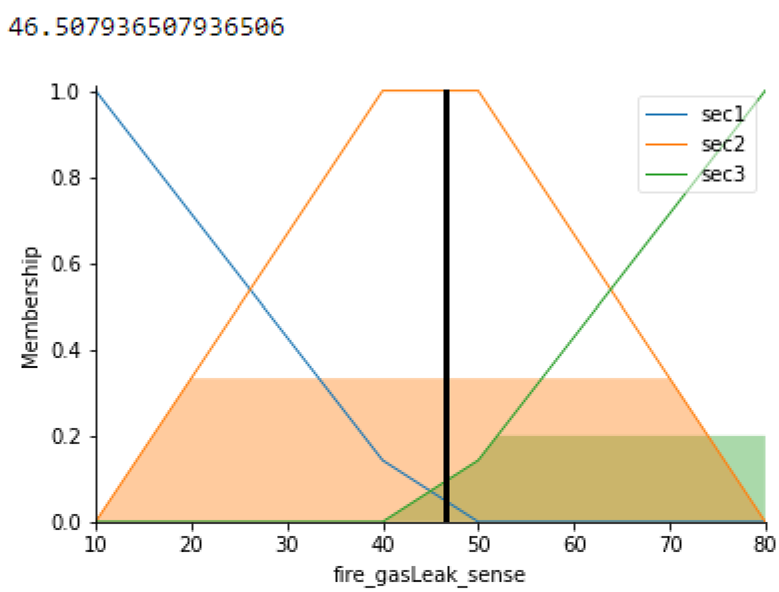


Fig 15d – Crisp o/p value plotted with membership grades highlighted

<u>**Chapter 7**</u>

7.1 <u>SMS API</u>

The second part of out IoT response system is to alert a user via mobile sms in case of possible fire or gas leak. In order to do so, we need to use an SMS API and a programming language to use the API. An API(Application Programming Interface) is a set of tools for designing software applications with a specific use or purpose. So a Short Message Service API or SMS API is used to send/receive sms' with applications.

*The programming language used for implementing this functionality is **Python** and the SMS API used is **Nexmo**.*

7.1 <u>Nexmo</u>

Nexmo SMS API is an API service, using which SMS functionality can be integrated into applications to send and receive messages between users and generate messages directly from applications. Nexmo also provides various other APIs for voice, messaging and authentication these are used by commercial business and enterprises.

Figure 16 – Nexmo API

Chapter 8

Using Fuzzy Inference System and Nexmo with IoT System (Phase II)

8.1 The complete system:

i) Creating fuzzy inference system with skfuzzy in jupyter python notebook and linking it with the Thingspeak cloud.
ii) Setting up the Nexmo SMS API using python and a phone.
iii) Making our hardware circuit with MSP430FR6989, Arduino MEGA 2560, ESP8266 – 01 , TMP36 temperature sensor , MQ-9 gas sensor and piezo speaker.
iv) Coding the Arduino sketch in Arduino IDE.

The system is now ready to run.

8.2 Implementation details of the fuzzy inference system:

The FIS defined by us takes two inputs namely temperature sensor data in Celsius and gas sensor data as voltage which are retrieved from the ThingSpeak cloud. The fuzzy inference engine produces a crisp output which is then analyzed and uploaded to a ThingSpeak channel. Based on the crisp output from this FIS, the environment we are monitoring can be in 1 of 4 different states, and we use LEDs to represent these 4 states which is done after Arduino retrieves the crisp output uploaded to the Thingspeak channel.

Automation – *The value of the crisp output generated by the FIS is also used by Arduino to turn on/off as well as set the frequency of the piezo speaker which emulates the response.* ***By doing so we are emulating an automation proof-of-concept as our crisp output based on environment conditions is used to automatically tune or adjust the response, in this case the piezo speaker, instead of we having to manually do it . In an industrial/controlled set-up the speaker can be thought of as an actuator.***

At the same time an sms is also sent via Nexmo API to alert the user if required based on the environment state.

8.3 Environment States Representation:

led0 led1

State 00 -- System OFF/ Unmonitored

Fig 17a

led0 led1

State 01 -- Normal

Fig 17b

led0 led1

State 10 -- Gas Leak / High Temperature

Fig 17c

led0 led1

State 11-- Critical Leak/Explosive Fire

Fig 17d

8.4 SMS Screenshots

Image by **picapp.net**

Image by **picapp.net**

Figure 18a,Figure 18b – Screenshots of SMS

8.5 Circuit Diagram (PHASE II)

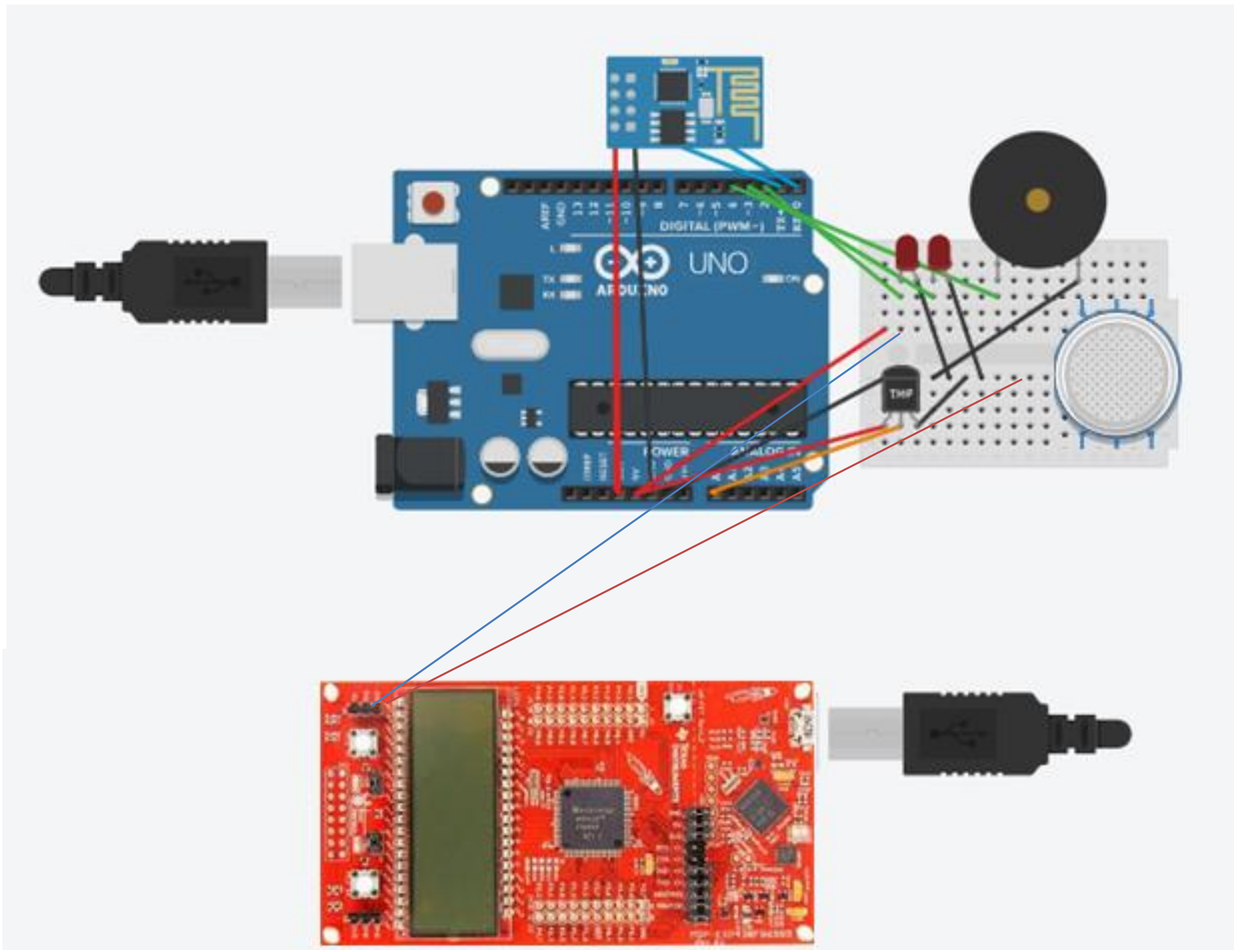
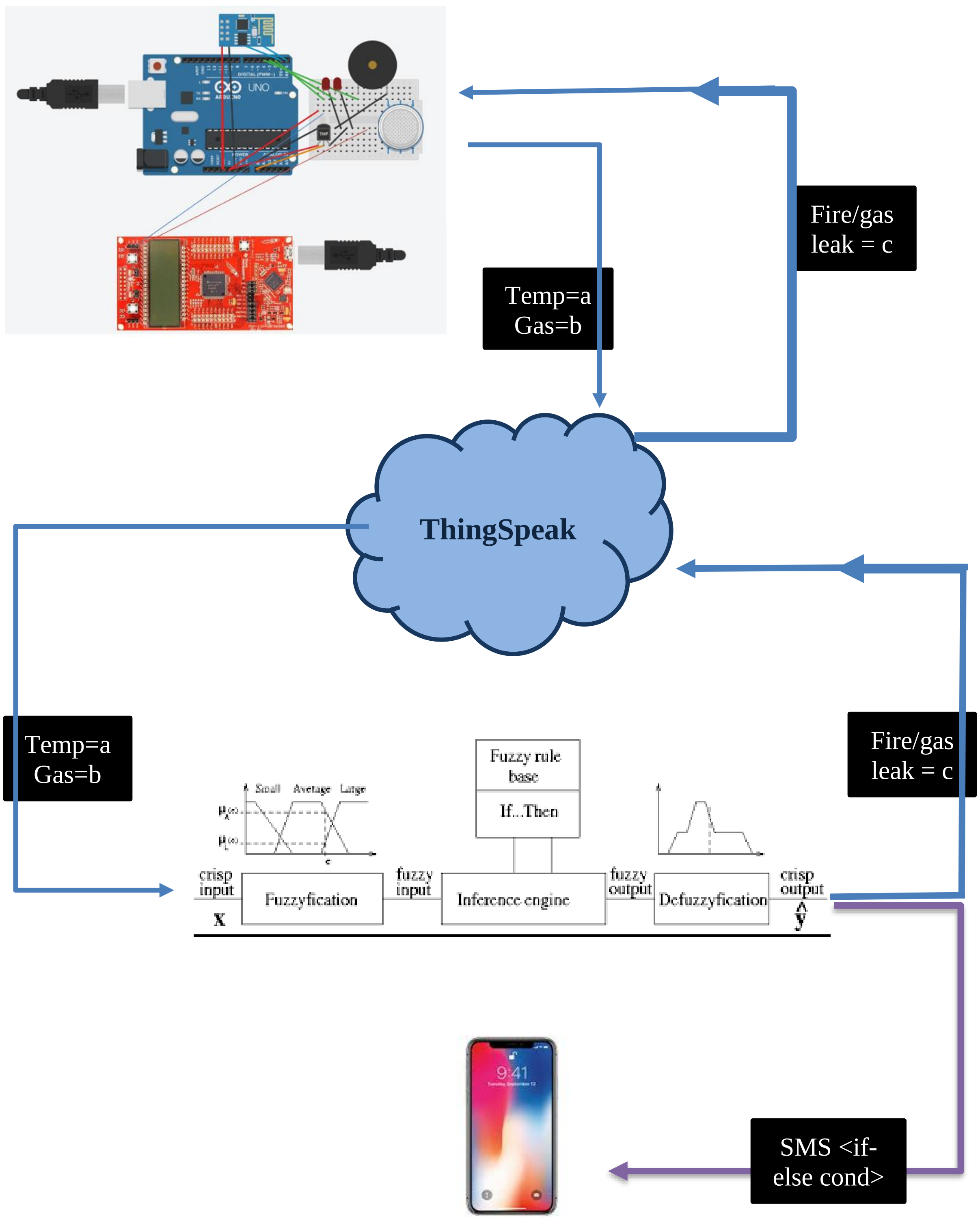


Figure 19 – Circuit Diagram

8.6 Graphical Representation of Working System



8.7 Sequence of Operations

1. Arduino Sketch is run and Esp8266 is connected to a Wi-Fi hotspot as a station.

2. Data from sensors is uploaded to ThingSpeak channel fields via Esp8266.

3. Python script from Jupyter notebook retrieves the latest data uploads,in our case temperature and gas values,and feeds them as input to the fuzzy inference system.

4. FIS outputs a crisp value which is ;
   i) uploaded via python to the fire/gas leak field in the same ThingSpeak channel.
   ii) used to check if it falls within a range and if this condition is true an SMS is sent to phone via python and Nexmo API.

5. Esp8266 retrieves the crisp output ,which is processed by Arduino to ;
   i) determine the environment state to consequently light up the LEDs to represent the state.
   ii) set the piezo buzzer to buzz with a particular frequency as an alarm.

6. Loop back to step 2

Chapter 9

Applications and Scalability

9.1 Latest Trends

With the growing number of inter-connected devices and advancements in networking technologies like IPV6 , IoT will soon be the future of computing, AI , automation , industry level systems etc. in which every device as small as sensors and as large as washing machines will be able to communicate with each other and take actions without human intervention. Combined with the power of fuzzy logic especially for controllers and end-to-end automation, this will lead to robust, intelligent, scalable and self-sustained systems which will require very little maintenance.

9.2 Home and Industry

Some areas/projects/research based on IoT/fuzzy logic:

- Industrial IoT
- Intelligent transport system
- IoT based cargo monitoring system
- IoT based health monitoring systems
- Sensitive information protection of power IoT based on fuzzy control logic.
- IoFClime – smart system to control indoor temperatures

9.3 Advantages and Scopes

1. Intelligent systems
2. Can easily be combined with other technologies like AI,machine learning etc.
3. Enables easy addition of automation techniques.
4. Data collected from systems can be stored and used for analysis.
5. Easily scalable.
6. Makes use of existing network infrastructure.