AIR POLLUTION MONITORING USING LORA

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this project report **"AIR POLLUTION MONITORING USING LORA"** is the bonafide work of **"SANDHIYA S (111919106053), SARANYA M (111919106055), VARSHAA H (111919106066) "** who carried out the projectwork under my supervision.

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

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ABSTRACT:

Air pollution poses significant risk to environment and health. Air quality monitoring stations are often confined to a small number of locations due to the high cost of the monitoring equipment. They provide a low fidelity picture of the air quality in the city; local variations are overlooked. However, recent developments in low-cost sensor technology and wireless communication systems like Internet of Things (IoT) provide an opportunity to use arrayed sensor networks to measure air pollution, in real time, at a large number of locations. This article reports the development of a novel low-cost sensor node that utilizes cost-effective electrochemical sensors to measure carbon levels. The node can be powered by either solar-recharged battery or mains supply. It is capable of long-range, low power communication over public or private long-range wide area network IoT network and short-range high data rate communication over Wi-Fi. The developed sensor nodes were co-located with an accurate reference CO2 sensor for field calibration.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

In generally Air quality monitoring stations are often confined to a small number of locations due to the high cost of the monitoring equipment. They provide a low fidelity picture of the air quality in the city; local variations are overlooked.

1.2 SCOPE OF THE PROJECT

The scope of the project presents an prototype that reports the development of a novel low-cost sensor node that utilizes cost-effective electrochemical sensors to measure carbon levels.

1.3EXISTING SYSTEM

1. the homes or local area are not monitored continuously.
2. Increase in the pollution is not monitored properly these leads increase in pollution

1.3.1EXISTING SYSTEM DISADVANTAGES

Monitoring system with less communication

1.3.2LITERATURE SURVEY

TITLE 1: Convolution Recurrent Neural Networks Based Dynamic Transboundary Air Pollution Predictiona

AUTHOR Peijiang Zhao ,Koji Zettsu

YEAR: 2018

DESCRIPTION:

Trans boundary air pollution is one of the main sources of air pollution in island cities. However, the transboundary pollution confounded by local emission, meteorological conditions, and it is difficult to predict. Currently, most of urban airpollution prediction methods do not predict with transboundary air pollution. Therefore, we introduce a dynamic transboundary air pollution prediction approach based on convolutional recurrent neural networks(D-CRNN) which: (i) Divide the prediction inputs into prediction locations and transboundary air pollution sources; (ii) Use two different convolutional recurrent neural networks to solve the spatial-temporal feature of each inputs. (iii) Through a transboundary prediction network to integrate the spatial-temporal feature of prediction locations with the spatial-temporal feature of transboundary air pollution sources in a dynamic asynchronous method. Then use those mixed features to predict the air pollution.

We evaluate our DCRNN model with the local atmospheric monitoring data in Kyushu, Japan and the transboundary air pollution data from 33 coastal cities in eastern Asia from January 2015 to July 2017. The results show that our D-CRNN model have achieved 86.2%, 78.6% accuracy of total prediction and transboundary air pollution in next 6 hours..

TITLE 2: Air Purification System for Street Level Air Pollution and Roadside Air Pollution

AUTHOR: B.Ravi Subrahmanyam1 , Avanish Gautam Dr. Prabhakar Tiwari3

YEAR: 2018

DESCRIPTION:

Decreasing the pollution level is now the main aim for many. Pollution is in many forms; almost every natural thing is now affected by the term pollution. Not only land, water, air, but each and every thing belongs to the planet is now in danger levels of pollution. Already human civilizations woke up to reduce this danger but are not into many things one of such is air.

In this method the air is being purified by the use of distilled water only, without the use of any synthetic material and/or chemical substance. Here, the air is made passed through the water so by reaction with water, pollutants stay in it results in clean air. In this method air is being purified by polluting water, but the fact is cleaning water is easy and there are many methods for this but cleaning air needs some boost up in the technology level.

TITLE 3: Identifying Outdoor Context by Correlating Air and Noise Pollution Sensor log

AUTHOR: Biswajit Maity , Yashwant Polapragada , Arindam Ghosh , Sanghita Bhattacharjee, Subrata Nandi,

YEAR: 2020

DESCRIPTION:

In an urban area, the degree of ambient noise and air pollution play a vital role in determining the quality of human life. The impact of these two pollutants is increasing day-by-day due to rapid urbanization. Although, creating real-time pollution maps and forecasting of pollution levels have been studied extensively, the contextual, spatio-temporal correlation between air and noise pollution has not been investigated thoroughly. This correlation is important to identify the characteristics of an urban area.
this paper, we have highlighted some aspects that are useful to identify a context from different pollutant data. To collect the noise data, we have developed an android based application ”AudREC” that uses the inbuilt mobile micro-phone sensor. Moreover, for measuring air pollutants, we have used a ready-made ”Flow” device that senses PM2.5 and CO2, etc. The initial outdoor experiments show the feasibility of the platform for recognizing contexts from air and noise pollution information.

TITLE 4: Air Pollution Monitoring System using Internet of Vehicles and Pollution Sensors

AUTHOR: Kanpur Rani V, V allikanna A L

YEAR: 2020

DESCRIPTION:

The urban societies are running into fast growth, and an overriding portion of the realms population almost similar to be in built-up societies in the forthcoming generation. Besides a few built-up sectors, the automobile count also wrinkled. Motorized automobiles are ace of the primary causes of contamination in the atmosphere. Contamination released from the motorized automobiles is mostly the source of contamination is directly released in the atmosphere

Once the air is infected it is appropriately high, then it grades grave implications, it can even demise the result in a few cases. Additionally, this contamination distresses the public in heart and lung diseases. The work is proposed to monitor the air pollutants in the air and generates the advanced alerts by forecasting the pollution level in the city.

TITLE 5: Prediction and Monitoring of Air Pollution Using Internet of Things (IoT)

AUTHOR: Sarita Jiyal ,Rakesh Kumar Saini **YEAR**: 2020

DESCRIPTION:

In all developing countries such as India the main problem of premature death is air pollution which also effect the economy of country. When urbanization started then various problem occurs such as environmental pollution, traffic system etc. there is so much loss of resources in crowded cities due to urbanization.

The concept of smart sustainable city can be used to balance the resources. If we do loss of resources excessively than we will definitely create problems to our future generation and excessive use of resources causes air pollution.

Than it is necessary to predict air pollution timely by which it can be monitored. Using Internet of Things monitoring of air pollution is necessary to save our environment from all harmful pollutants. Vehicles are the main cause of air pollution.

1.4 PROPOSED SYSTEM

1. In proposed method, , the end house device are connected to the cloud using ESP8266 and also with the help of LORA.

2. The LORA provides broadcast communication for the locality to reduce the receiver nodes

1.4.1 PROPOSED SYSTEM ADVANTAGES

1. It is a real time monitoring system

CHAPTER 2

PROJECT DESCRIPTION

2.1 GENERAL

In generally Air quality monitoring stations are often confined to a small number of locations due to the high cost of the monitoring equipment. They provide a low fidelity picture of the air quality in the city; local variations are overlooked

2.2 PROBLEM DEFINITION

This article reports the development of a novel low-cost sensor node that utilizes cost-effective electrochemical sensors to measure carbon levels. The node can be powered by either solar-recharged battery or mains supply.

It is capable of long-range, low power communication over public or private long-range wide area network IoT network and short-range high data rate communication over Wi-Fi. The developed sensor nodes were co-located with an accurate reference CO2 sensor for field calibration.

The node can be powered by either solar-recharged battery or mains supply.And short-range high data rate communication over Wi-Fi.

BLOCK DIAGRAM

TRANSMITTER

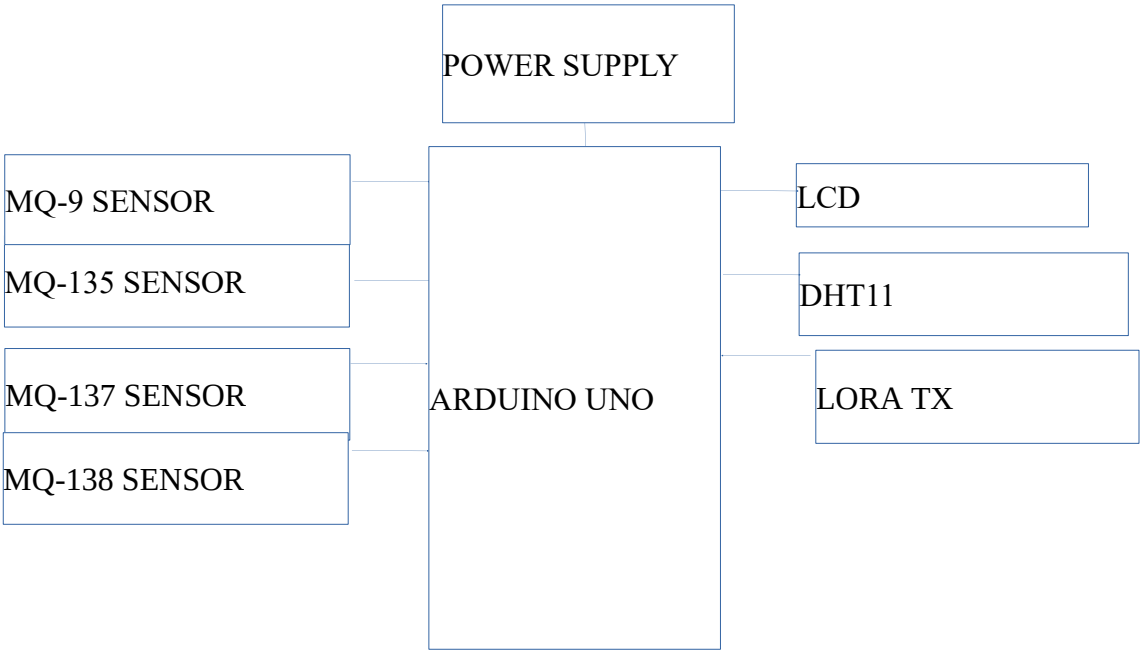


Fig 2.2 Transmitter

RECEIVER:

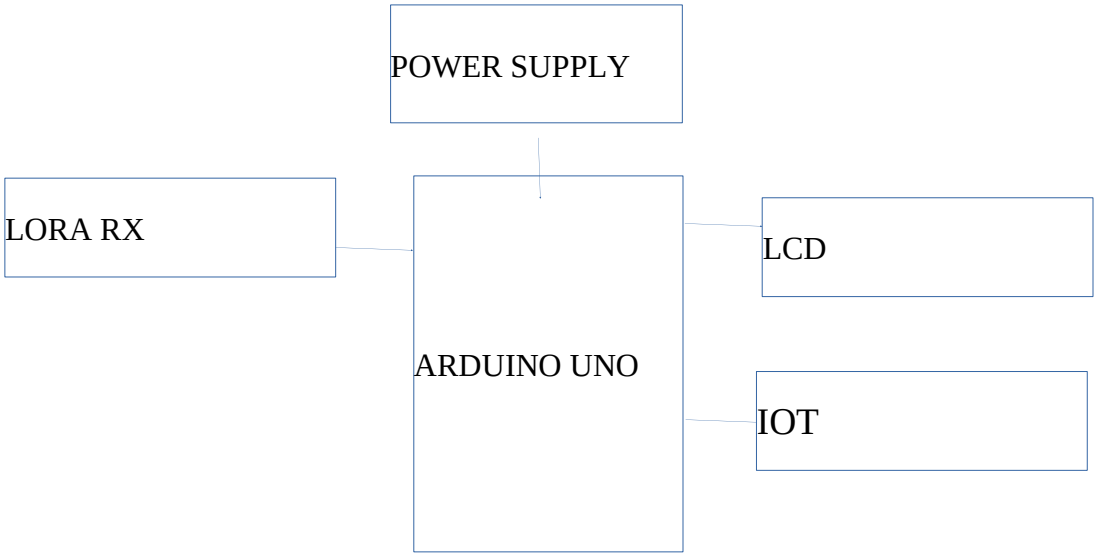


Fig 2.2 Receiver

2.3 MODULES NAME:

- ❖ **TRANSMITTER**
- ❖ **RECEIVER**

2.3.1 MODULE DESCRIPTION:

TRANSMITTER

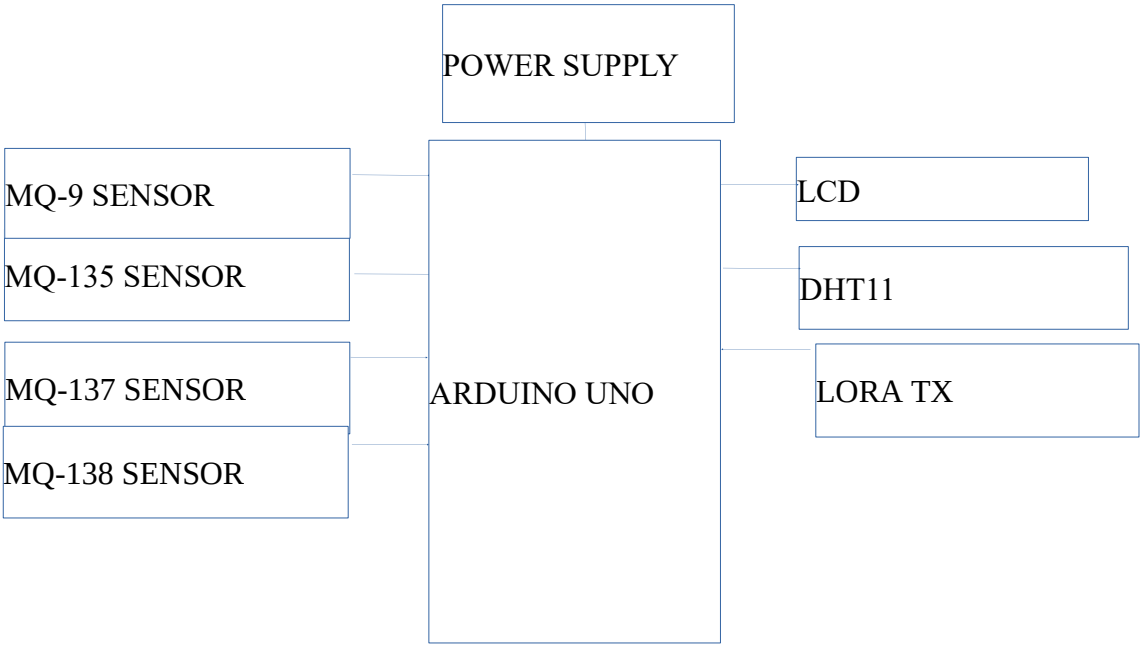


Fig 2.3.1 Transmitter

In this module, we get the gases value in the atmosphere using gas sensors series. The MQ-9 (Carbon Monoxide), MQ-135 (Air Quality, CO, Ammonia, Benzene, Alcohol, Smoke), MQ-137(Ammonia), MQ-138(Benzene, Toluene, Alcohol, Acetone, Propane, Formaldehyde gas, Hydrogen)provide the polluted the gas values. After getting the sensors value the LORAtx sends data with GPS to the LORArx. The LCD is used to show the corresponding gases value of the atmosphere

RECEIVER:

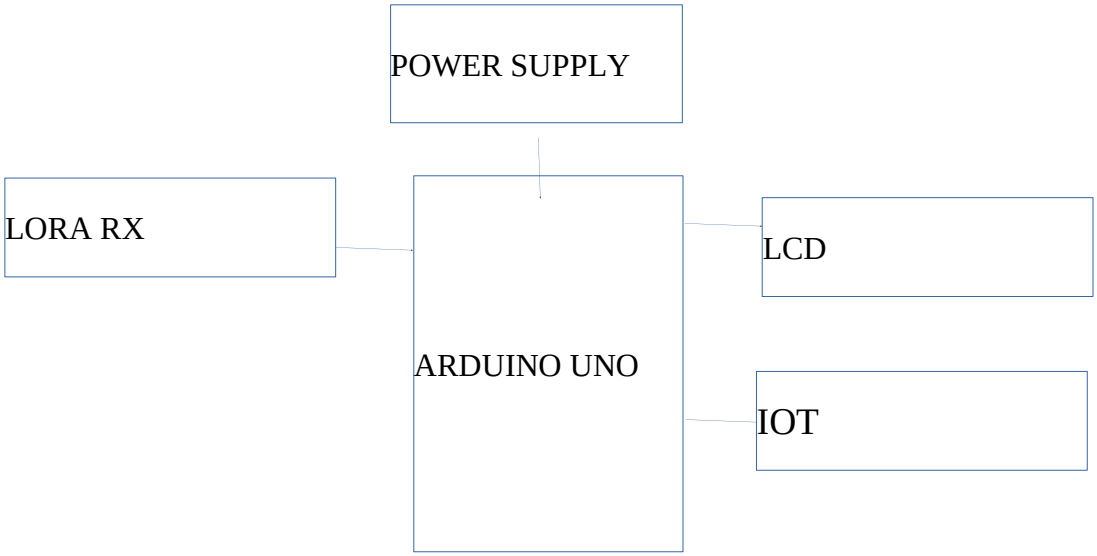


Fig 2.3.2 Receiver

In this module, the LORArx is used to get the gases value that LORAtx sends the IOT is used update the gases value in a webpage. The GSM is used to send the values of the corresponding location as SMS. The LCD is used to show the gases values

WORKING:

In this proposed method, Arduino UNO microcontroller is used to interface with the sensors and to the communication devices. The different types of MQ series sensors provide the accurate pollution toxic gases. The MQ-9 (Carbon Monoxide), MQ-135 (Air Quality, CO, Ammonia, Benzene, Alcohol, Smoke), MQ-137(Ammonia), MQ-138(Benzene, Toluene, Alcohol, Acetone, Propane, Formaldehyde gas, Hydrogen)provide the polluted the gas values.

The LCD is used to update the latest information in the LCD. The GPS is used to locate the polluted area and send the information through the LORA and the receiver end the GSM module used to update the polluted location through the message.

CHAPTER -3

HARDWARE AND SOFTWARE DESCRIPTION

3.1 HARDWARE DESCRIPTION:

3.1.1 ARDUINO UNO

The UNO is the best board to get started with electronics and coding. If this is your first experience tinkering with the platform, the UNO is the most robust board you can start playing with. The UNO is the most used and documented board of the whole Arduino family.

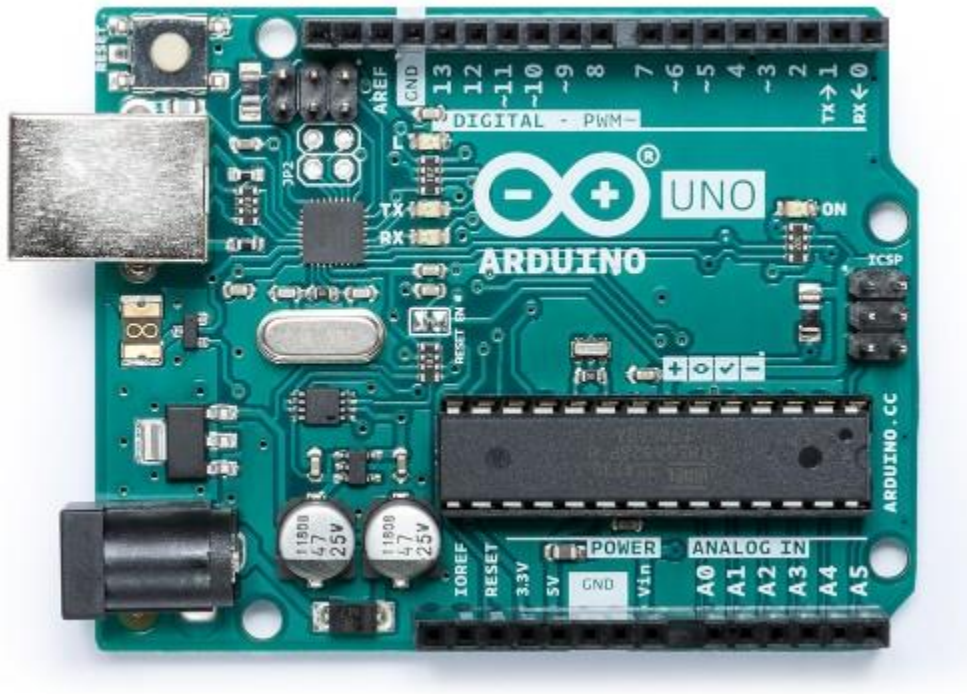


Fig 3.1.1 Arduino Uno

6 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a **Arduino Uno** is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 1omputer with a USB cable or power it with a AC-to-DC adapter or battery to get started. You can tinker with your UNO without worrying too much about doing something wrong, worst case scenario you can replace the chip for a few dollars and start over again.

TECHNICAL SPECIFICATIONS:

Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by boot loader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

TABLE 3.1.2 Technical Description

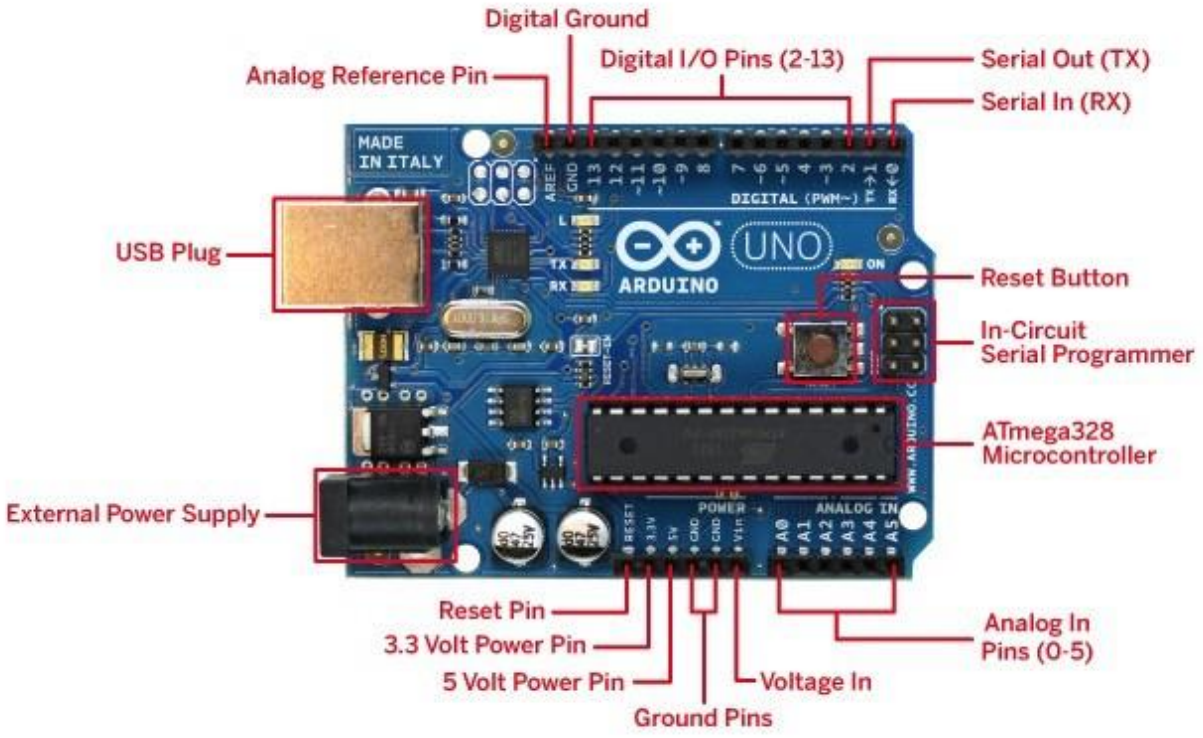


Fig 3.1.3 Arduino Pin

3.1.3 POWER SUPPLY

This section describes how to generate +5V DC power supply

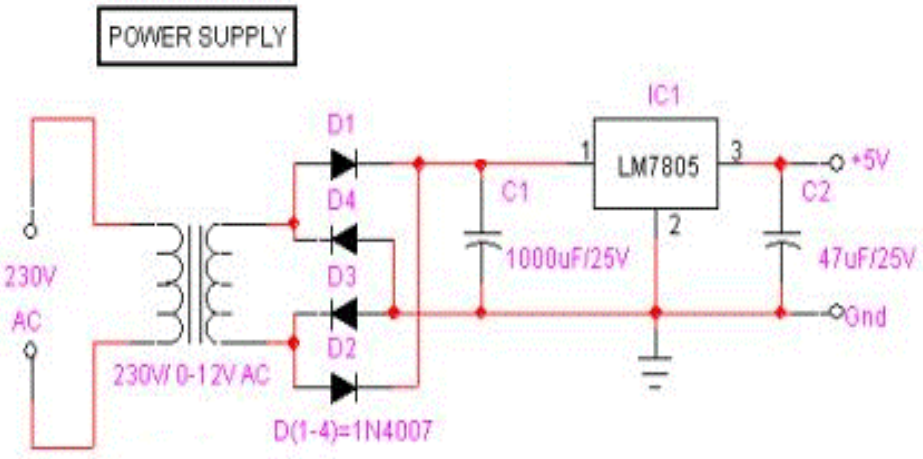


Fig 3.1.4 Power Supply

LIQUID CRYSTAL DISPLAY:

LCD screen is an electronic display module and find a wide range of applications. A 16x2 LCD display is very basic module and is very commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. The reasons being: LCDs are economical; easily programmable; have no limitation of displaying special & even custom characters (unlike in seven segments), animations and so on.

A **16x2 LCD** means it can display 16 characters per line and there are 2 such lines. In this LCD each character is displayed in 5x7 pixel matrix. This LCD has two registers, namely, Command and Data. The command register stores the command instructions given to the LCD. A command is an instruction given to LCD to do a predefined task like initializing it, clearing its screen, setting the cursor position, controlling display etc. The data register stores the data to be displayed on the LCD. The data is the ASCII value of the character to be displayed on the LCD. Click to learn more about internal structure of a LCD.

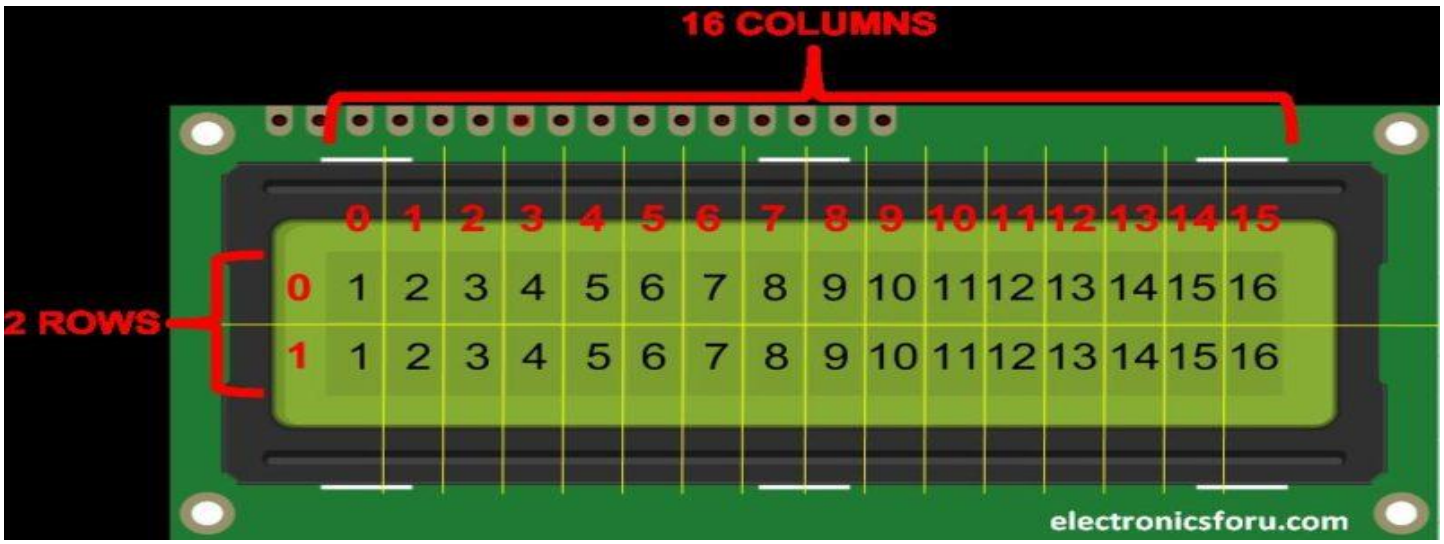


Fig 3.1.5 LCD Display

We come across LCD displays everywhere around us. Computers, calculators, television sets, mobile phones, digital watches use some kind of display to display the time. An LCD is an electronic display module which uses liquid crystal to produce a visible image. The 16×2 LCD display is a very basic module commonly used in projects. The 16×2 translates to a display 16 characters per line in 2 such lines. In this LCD each character is displayed in a 5×7 pixel matrix.

16X2 LCD PINOUT DIAGRAM:

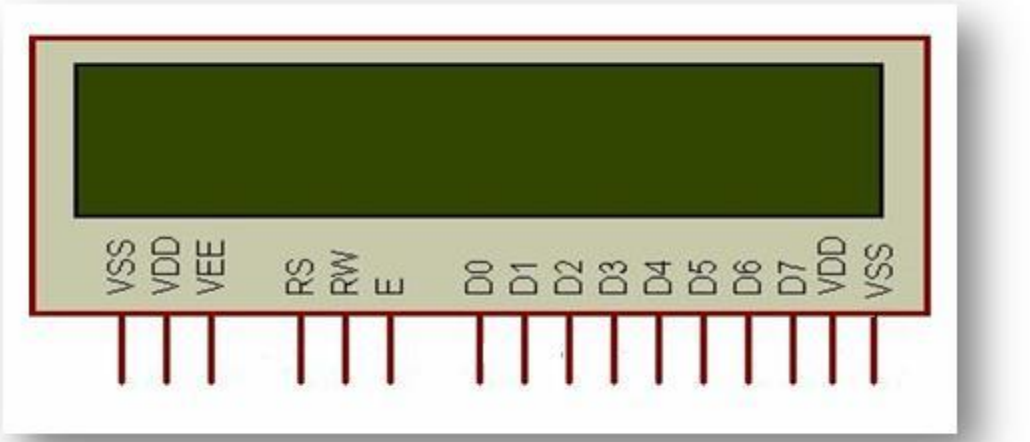


Fig 3.1.6. 16X2LCD Pinout

Generating custom characters on LCD is not very hard. It requires the knowledge about custom generated random access memory (CG-RAM) of LCD and the LCD chip controller. Most LCDs contain Hitachi HD4478 controller. CG-RAM is the main component in making custom characters. It stores the custom characters once declared in the code. CG-RAM size is 64 byte providing the option of creating eight characters at a time. Each character is eight byte in size.

CG-RAM address starts from 0x40 (Hexadecimal) or 64 in decimal. We can generate custom characters at these addresses. Once we generate our characters at these addresses, now we can print them on the LCD at any time by just sending simple commands to the LCD. Character addresses and printing commands are below.

In the table above you can see starting addresses for each character with their printing commands. The first character is generated at address 0x40 to 0x47 and is printed on LCD by just sending simple command 0 to the LCD. The second character is generated at address 0x48 to 0x55 and is printed by sending 1 to LCD.

CG-RAM is the main component in making custom characters. It stores the custom characters once declared in the code. CG-RAM size is 64 byte providing the option of creating eight characters at a time. Each character is eight byte in size.

MQ-9GAS SENSOR

FEATURES

1. High sensitivity to carbon monoxide and CH_4， LPG.
2. Stable and long life

APPLICATION

They are used in gas detecting equipment for carbon monoxide and CH_4， LPG in house and industry or car.

SPECIFICATIONS

A. Standard work condition

Symbol	Parameter name	technical condition	Remark
V_C	circuit voltage	5V±0.1	AC or DC
V_H (H)	Heating voltage (high)	5V±0.1	AC or DC
V_H (L)	Heating voltage (low)	1.4V±0.1	AC or DC
R_L	Load resistance	Can adjust	
R_H	Heating resistance	33Ω±5%	Room temperature
$T_{H\ (H)}$	Heating time (high)	60±1 seconds	
$T_{H\ (L)}$	Heating time (low)	90±1 seconds	
Ps	Heating consumption	Less than 340mw	

b. Environment conditions

Symbol	Parameters	Technical conditions	Remark
Tao	Using temperature	-20℃-50℃	
Tas	Storage temperature	-20℃-50℃	Advice using scope
RH	Relative humidity	Less than 95%RH	
O_2	Oxygen concentration	21%(stand condition) the oxygen concentration can affect the sensitivity characteristic	Minimum value is over 2%

C. **Structure and configuration, basic measuring circuit**

Structure and configuration of MQ-9 gas sensor is shown as Fig. 1 (Configuration A or B), sensor composed by micro AL_2O_3 ceramic tube, Tin Dioxide (SnO_2) sensitive layer, measuring electrode and heater are fixed into a crust made by plastic and stainless steel net. The heater provides necessary work conditions for work of sensitive components. The enveloped MQ-9 have

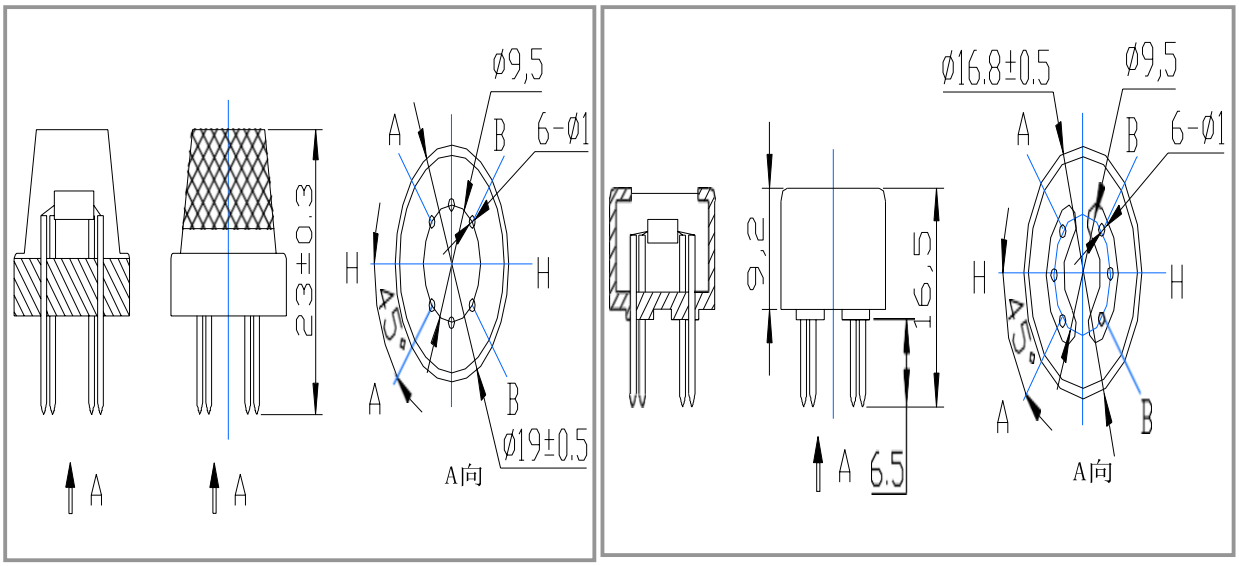


Fig 3.1.7.Basic circuit

OPERATION PRINCIPLE

. The surface resistance of the sensor Rs is obtained through effected voltage signal output of theload resistance RL which series-wound. The relationship between them is described:

Rs\RL = (Vc-VRL) / VRL

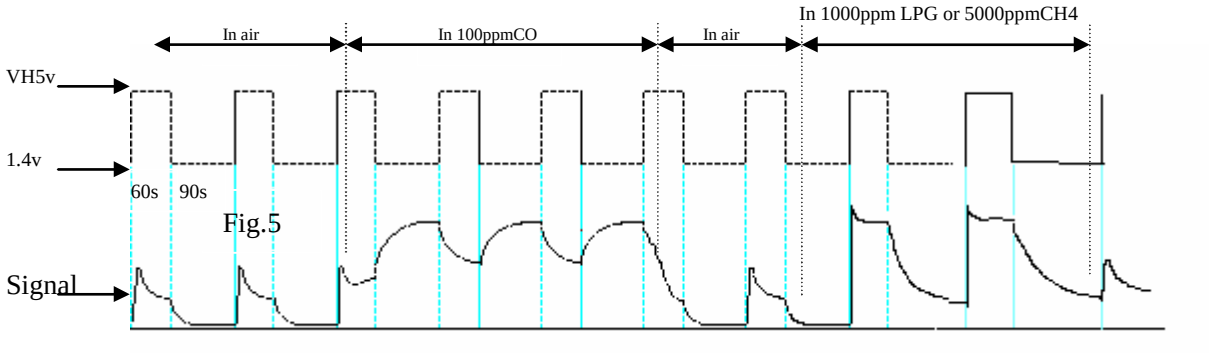


Fig.5

Fig. 5 shows alterable situation of RL signal output measured by using Fig. 2 circuit output signal when the sensor is shifted from clean air to carbon monoxide (CO) or CH_4, output signal measurement is made within one or two complete heating period (2.5 minute from high voltage to low voltage).

Sensitive layer of MQ-9 gas sensitive components is made of SnO2 with stability, So, it has excellent long term stability. Its service life can reach 5 years under using condition.

SENSITVITY ADJUSTMENT

Resistance value of MQ-9 is difference to various kinds and various concentration gases. So, Whenusing this components, sensitivity adjustment is very necessary. we recommend that you calibrate the detector for 200ppm and5000ppm CH_4 or 1000ppm LPG concentration in air and use value of Loadresistance that(R_L) about 20 KΩ(10KΩ to 47 KΩ).

When accurately measuring, the proper alarm point for the gas detector should be determined after considering the temperature and humidity influence.

The sensitivity adjusting program:

a. Connect the sensor to the application circuit.

b. Turn on the power, keep time of preheating through electricity is over 48 hours.

c. Adjust the load resistance RL until you get a signal value which is respond to a certaincarbon monoxide concentration at the end point of 90 seconds.

d. st the another load resistance RL until you get a signal value which is respond to a CH_4 or LPG concentration at the end point of 60 seconds .

Organic silicon steam cause sensors invalid, sensors must be avoid exposing to silicon bond, fixature, silicon latex, putty or plastic contain silicon environment

High Corrosive gas

If the sensors exposed to high concentration corrosive gas (such as H_2Sz, SO_X， Cl_2， HCl etc),

The sensors performance will be changed badly if sensors be sprayed polluted by alkali metals salt especially brine, or be exposed to halogen such as fluorin.

Sensitivity of the sensors will be reduced when spattered or dipped in water.

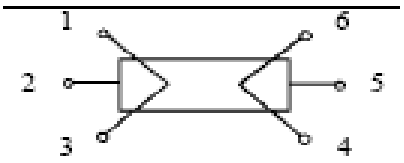
Do avoid icing on sensor'surface, otherwise sensor would lose sensitivity.

Applied voltage higher

Applied voltage on sensor should not be higher than stipulated value, otherwise it cause down-line or heater damaged, and bring on sensors' sensitivity characteristic changed badly.

Voltage on wrong pins

For 6 pins sensor, if apply voltage on 1、3 pins or 4、6 pins, itwill make lead broken, and without signal when apply on 2、4 pins



MQ135 Semiconductor Sensor for Air Quality

Profile

Sensitive material of MQ135 gas sensor is SnO_2, which with lower conductivity in clean air. When target pollution gas exists, the sensor's conductivity gets higher along with the gas concentration rising. Users can convert the change of conductivity to correspond output signal of gas concentration through a simple circuit.

MQ135 gas sensor has high sensitivity to ammonia gas, sulfide, benzene series steam, also can monitor smoke and other toxic gases well. It can detect kinds of toxic gases and is a kind of low-cost sensor for kinds of applications.

Features

It has good sensitivity to toxic gas in wide range, and has advantages such as long lifespan, low cost andsimple drive circuit &etc.

Main Applications

It is widely used in domestic gas alarm, industrial gas alarm and portable gas detector.

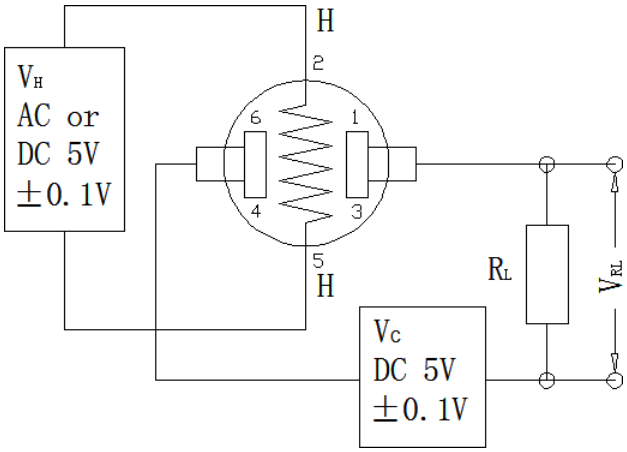
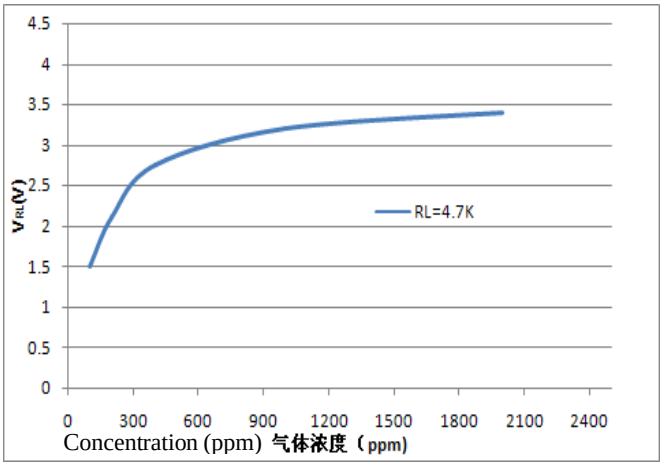


Fig 3.1.8.Basic circuit of MQ135

Instructions: The above fig is the basic test circuit of MQ135.The sensor requires two voltage inputs: heater voltage (V_H) and circuit voltage(V_C). V_H is used to supply standard working temperature to the sensor and it can adopt DC or AC power, while V_{RL} is the voltage of load resistance R_L which is in series with sensor. Vc supplies the detect voltage to load resistance R_L and it should adopts DC power



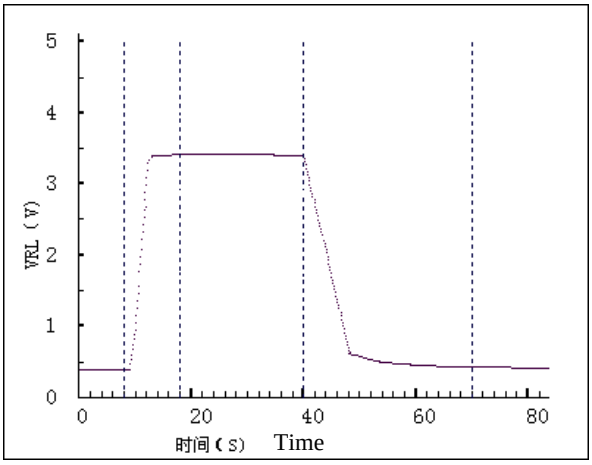


Fig3.1.9.Sensitity Curve

Fig6 shows the V_{RL} in H2 gas with different concentration. The resistance load R_L is 4.7 KΩ and the test is finished in standard test conditions.

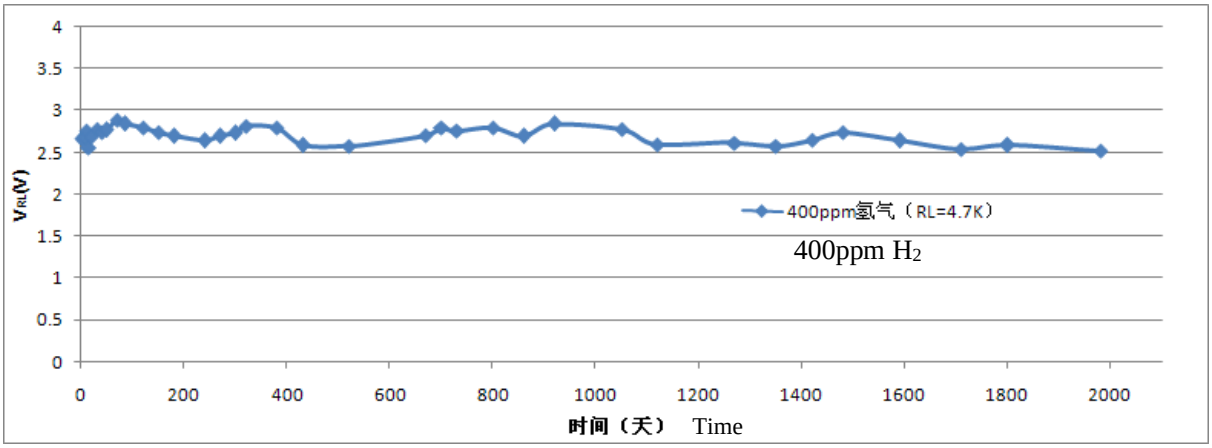


Fig3.2.0.long-term Stability

Cautions

1.Following conditions must be prohibited

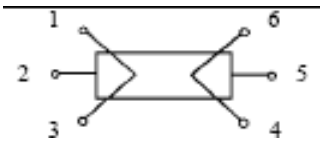
Sensing material will lose sensitivity and never recover if the sensor absorbs organic silicon steam. Sensors must avoid exposing to silicon bond, fixature, silicon latex, putty or plastic contain silicon environment.

If the sensors are exposed to high concentration corrosive gas (such as H_2S, SO_X, Cl_2, HCl etc.), it will not only result in corrosion of sensors structure, also it cause sincere sensitivity attenuation

The sensors performance will be changed badly if sensors be sprayed polluted by alkali metals salt especially brine, or be exposed to halogen such as fluorine.

Sensitivity of the sensors will be reduced when spattered or dipped in water.

Voltage on wrong pins
For 6 pins sensor, Pin 2&5 is heating electrodes, Pin (1,3)/(4,6) are testing electrodes (Pin 1 connects with Pin 3, while Pin 4 connects with Pin 6).If apply voltage on Pin 1&3 or 4&6, it will make lead broken; and no signal putout if apply on pins 2&4.



Lead sketch

MQ138 VOC Gas Sensor

Profile

Sensitive material of MQ138 gas sensor is SnO2, which with lower conductivity in clean air. When VOCgas exists, the sensor's conductivity gets higher along with the gas concentration rising. Users can convert the change of conductivity to correspond output signal of gas concentration through a simple circuit. MQ138 gas sensor has high sensitivity to toluene,acetone, alcohol, methanol, also can monitorhydrogen and other organic vapour well. It can detect kinds of organic gases and is a kind of low-cost sensor for kinds of applications.

Features

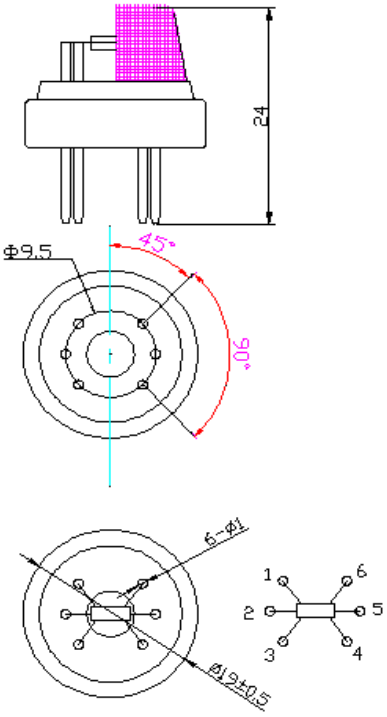
It has good sensitivity to organic vapour gas in wide range, and has advantages such as long lifespan, lowcost and simple drive circuit &etc.

Main Applications

It is widely used in domestic VOC gas alarm, industrial VOC gas leakage alarm and portable VOC gas detector.

Technical Parameters

Model			MQ138
Sensor Type			Semiconductor
Standard Circuit Conditions			
	Load Resistance	R_L	Adjustable
Sensor characterunder standard test conditions	Heater Resistance	R_H	29Ω±3Ω（ room tem.）
	Heater consumption	P_H	≤900mW
	Sensitivity	S	Rs(in air)/Rs(in 50ppm toluene)≥2
	Output Voltage	oVs	0.5V (in 50ppm toluene)
	Concentration Slope	α	≤0.6(R_{200ppm}/R_{50ppm} toluene)
Standard test conditions	Tem. Humidity		20℃±2℃；55%±5%RH
	Standard test circuit		Vc:5.0V±0.1V；V_H:5.0V±0.1V



Basic Circuit

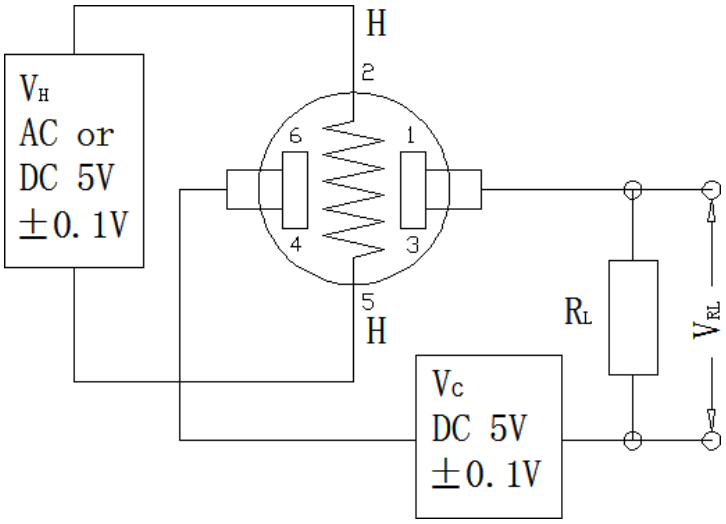


Fig3.2.1. MQ138 Test Circuit

Instructions: The above fig is the basic test circuit of MQ138.The sensor requires two voltage inputs: heater voltage (V_H) and circuit voltage(V_C). V_H is used to supply standard working temperature to the sensor and it can adopt DC or AC power, while V_{RL} is the voltage of load resistance R_L which is in series with sensor. Vc supplies the detect voltage to load resistance R_L and it should adopt DC power.

MQ138 VOC Gas Sensor

Profile

Sensitive material of MQ138 gas sensor is SnO2, which with lower conductivity in clean air. When VOCgas exists, the sensor's conductivity gets higher alongwith the gas concentration rising. Users can convert the change of conductivity to correspond output
signal of gas concentration through a simple circuit. MQ138 gas sensor has high sensitivity to toluene,acetone, alcohol, methanol, also can monitorhydrogen and other organic vapour well. It can detect kinds of organic gases and is a kind of low-cost sensor
for kinds of applications.

MQ138 gas sensor has high sensitivity to toluene,acetone, alcohol.It can convert the change of conductivity to correspond output

Features

It has good sensitivity to organic vapour gas in wide range, and has advantages such as long lifespan, lowcost and simple drive circuit &etc.

Main Applications

It is widely used in domestic VOC gas alarm, industrial VOC gas leakage alarm and portable VOC gasdetector.

Basic Circuit

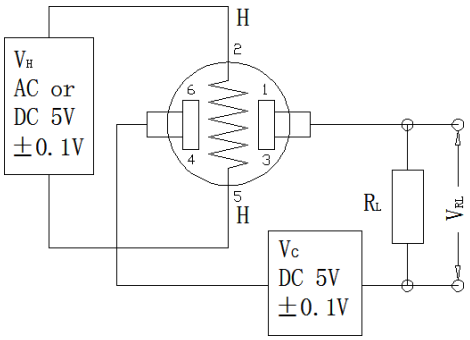


Fig3.2.2.. MQ138 Test Circuit

Instructions: The above fig is the basic test circuit of MQ138.The sensor requires two voltage inputs: heater voltage (V_H) and circuit voltage(V_C). V_H is used to supply standard working temperature to the sensor and it can adopt DC or AC power, while V_{RL} is the voltage of load resistance R_L which is in series withsensor. Vc supplies the detect voltage to load resistance R_L and it should adopt DC power.

Following conditions must be prohibited

Exposed to organic silicon steam

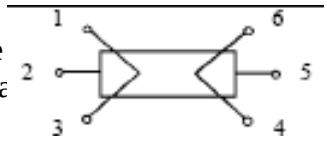
Sensing material will lose sensitivity and never recover if the sensor absorbs organic silicon steam. Sensors must avoid exposing to silicon bond, fixature, silicon latex, putty or plastic contain silicon environment.

High Corrosive gas

If the sensors are exposed to high concentration corrosive gas (such as H_2S, SO_X, Cl_2, HCl etc.), it will not only result in corrosion of sensors structure, also it cause sincere sensitivity attenuation.

Sensitivity of the sensors will be reduced when spattered or dipped in water.

Freezing
Do avoid icing on sensor's surface, otherwise sensing material will be broken and lost sensitivity.
Applied higher voltage
Applied voltage on sensor should not be higher than stipulated value, even if the sensor is not physically damaged or broken, it causes down-line or heater damaged, and bring on sensors' sensitivity characteristic changed badly.
Voltage on wrong pins
For 6 pins sensor, Pin 2&5 is heating electrodes, Pin (1,3)/(4,6) are connects with Pin 3, while Pin 4 connects with Pin 6).If apply volta it will make lead broken; and no signal putout if apply on pins 2&4.



MQ137 Ammonia Gas Sensor

Profile

Sensitive material of MQ137 gas sensor is SnO_2, which with lower conductivity in clean air. When NH_3 gas exists, the sensor's conductivity gets higher alongwith the gas concentration rising. Users can convert the change of conductivity to correspond output signal of gas concentration through a simple circuit. MQ137 gas sensor has high sensitivity to NH_3 gas,also can monitor organic amine such as trimethylamine, cholamine well. It can detect kindsof gases including ammonia and is a kind of low-cost sensor for kinds of applications.

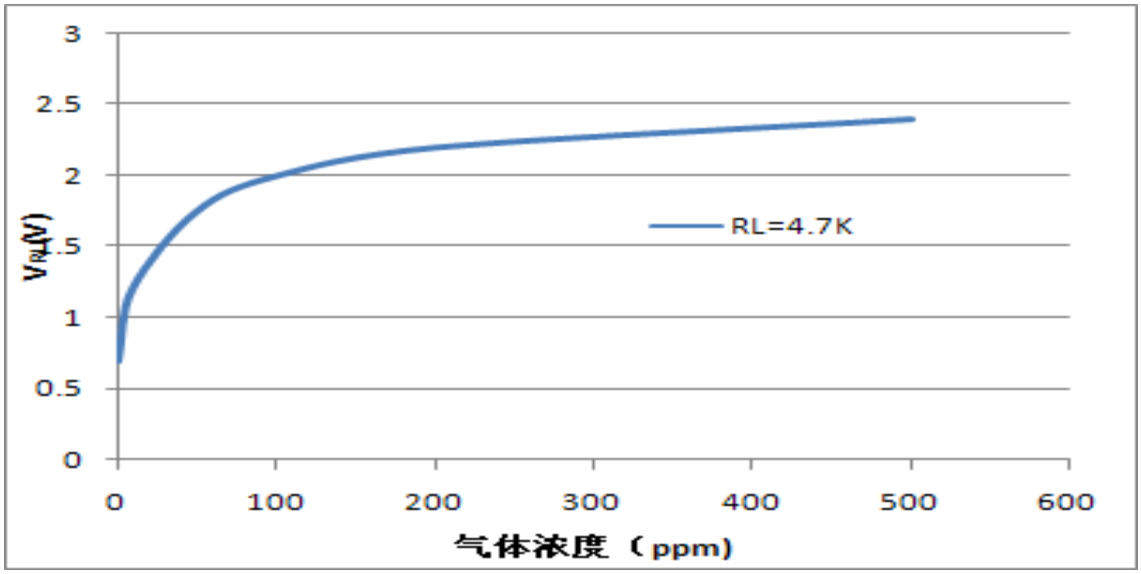
Features

It has good sensitivity to NH_3 gas in wide range, and has advantages such as long lifespan, low cost andsimple drive circuit &etc.

Main Applications

It is widely used in domestic NH_3 gas alarm, industrial NH_3 gas leakage alarm, portable NH_3 gas detector.

Instructions: The above fig is the basic test circuit of MQ137.The sensor requires two voltage inputs: heater voltage(V_H) and circuit voltage(V_C). V_H is used to supply standard working temperature to the sensor and it can adopts DC or AC power, while V_{RL} is the voltage of load resistance R_L which is in series with sensor. Vc supplies the detect voltage to load resistance R_L and it should adopts DC power.



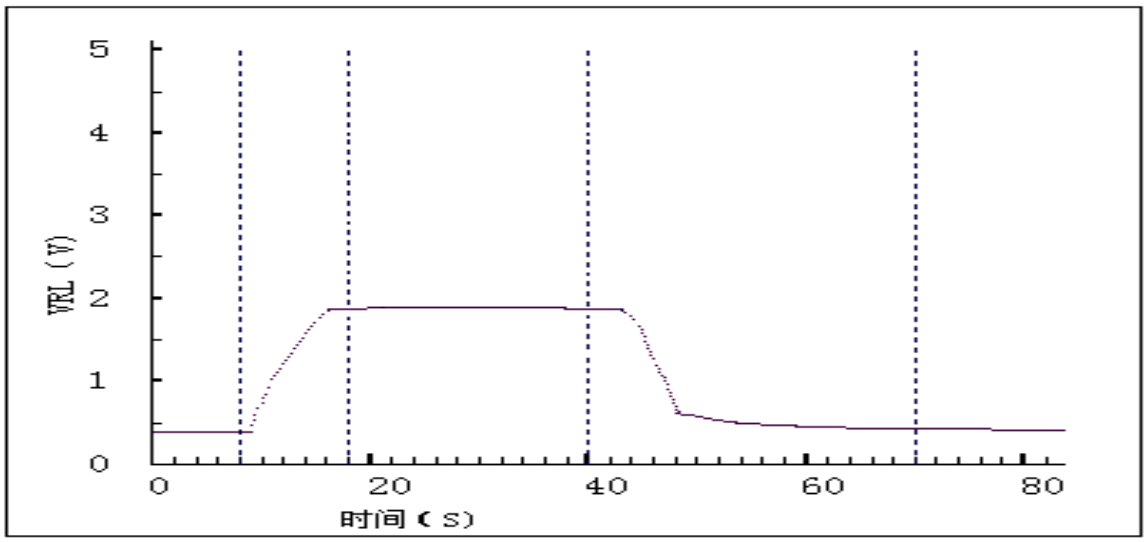


Fig3.2.3. Sensitivity curve

Cautions

1.Following conditions must be prohibited

Exposed to organic silicon steam

Sensing material will lose sensitivity and never recover if the sensor absorbs organic silicon steam. Sensors must be avoid exposing to silicon bond, fixature, silicon latex, putty or plastic contain silicon environment.

High Corrosive gas

If the sensors are exposed to high concentration corrosive gas (such as H_2S, SO_X, Cl_2, HCl etc.), it will not only result in corrosion of sensors structure, also it cause sincere sensitivity attenuation.

Alkali, Alkali metals salt, halogen pollution

The sensors performance will be changed badly if sensors be sprayed polluted by alkali metals salt especially brine, or be exposed to halogen such as fluorine.

Touch water

Sensitivity of the sensors will be reduced when spattered or dipped in water.

Freezing

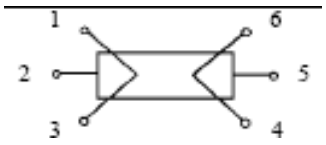
Do avoid icing on sensor's surface, otherwise sensing material will be broken and lost sensitivity.

Applied higher voltage

Applied voltage on sensor should not be higher than stipulated value, even if the sensor is not physically damaged or broken, it causes down-line or heater damaged, and bring on sensors' sensitivity characteristic changed badly.

Voltage on wrong pins

For 6 pins sensor, Pin 2&5 is heating electrodes, Pin (1,3)/(4,6) are testing electrodes (Pin 1 connects with Pin 3, while Pin 4 connects



GLOBAL POSITIONING SYSTEM

GPS or Global Positioning System is a satellite navigation system that furnishes location and time information in all climate conditions to the user. GPS is used for navigation in planes, ships, cars and trucks also. The system gives critical abilities to military and civilian users around the globe. GPS provides continuous real time, 3-dimensional positioning, navigation and timing worldwide.

The Global Positioning System (GPS) is a satellite-based navigation system made up of at least 24 satellites. GPS works in any weather conditions, anywhere in the world, 24 hours a day, with no subscription fees or setup charges. The U.S. Department of Defense (USDOD) originally put the satellites into orbit for military use, but they were made available for civilian use in the 1980s.

Fig 3.2.4.GPS

WORKING OF GPS:

GPS satellites circle the Earth twice a day in a precise orbit. Each satellite transmits a unique signal and orbital parameters that allow GPS devices to decode and compute the precise location of the satellite. GPS receivers use this information and trilateration to calculate a user's exact location. Essentially, the GPS receiver measures the distance to each satellite by the amount of time it takes to receive a transmitted signal. With distance measurements from a few more satellites, the receiver can determine a user's position and display it electronically to measure your running route, map a golf course, find a way home or adventure anywhere.

To calculate your 2-D position (latitude and longitude) and track movement, a GPS receiver must be locked on to the signal of at least 3 satellites. With 4 or more satellites in view, the receiver can determine your 3-D position (latitude, longitude and altitude). Generally, a GPS receiver will track 8 or more satellites, but that depends on the time of day and where you are on the earth. Some devices can do all of that from your wrist.

Once your position has been determined, the GPS unit can calculate other information, such as:

- Speed
- Bearing.
- Track.
- Trip distance.
- Distance to destination.
- Sunrise and sunset time.
- And more.

GPS SEGMENT:

The GPS system consists of three segments:

1) The space segment: the GPS satellites

2) The control system, operated by the U.S. military,

3) The user segment, which includes both military and civilian users and their GPS equipment.

SPACE SEGMENT:

The space segment is the number of satellites in the constellation. It comprises of 29 satellites circling the earth every 12 hours at 12,000 miles in altitude.

The function of the space segment is utilized to route/navigation signals and to store and retransmit the route/navigation message sent by the control segment.

These transmissions are controlled by highly stable atomic clocks on the satellites. The GPS Space ensure that the users will have, at least, 4 simultaneous satellites in view from any point at the Segment is formed by a satellite constellation with enough satellites toEarth surface at any time.

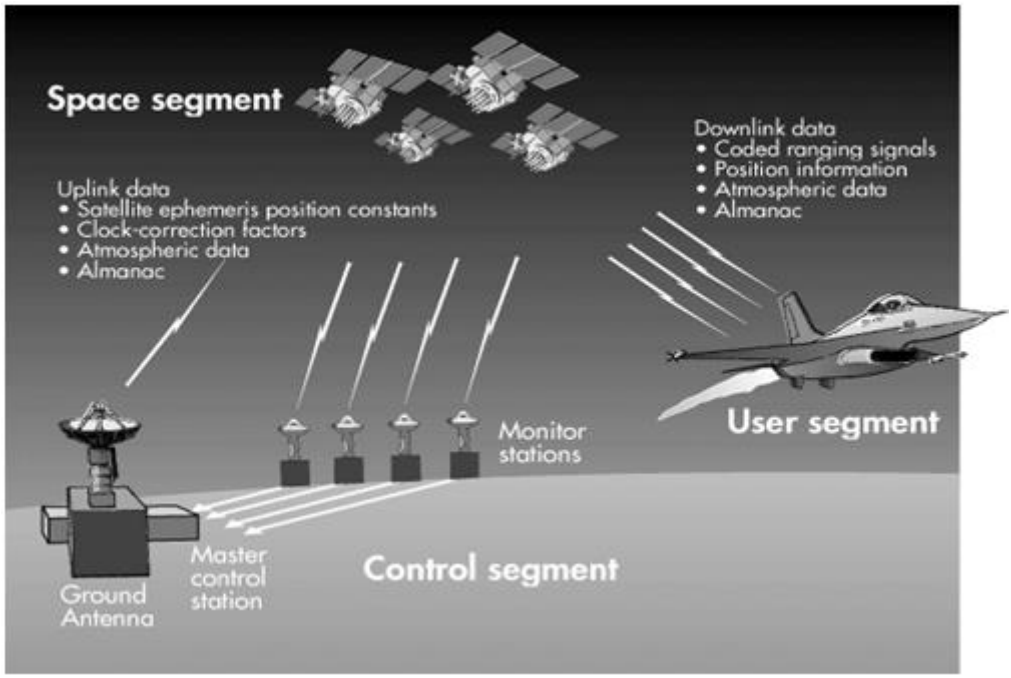


Fig 3.2.5.Space segment

CONTROL SEGMENT:

The control segment comprises of a master control station and five monitor stations outfitted with atomic clocks that are spread around the globe. The five monitor stations monitor the GPS satellite signals and then send that qualified information to the master control station where abnormalities are revised and sent back to the GPS satellites through ground antennas. Control segment also referred as monitor station.

USER SEGMENT:

The user segment comprises of the GPS receiver, which receives the signals from the GPS satellites and determine how far away it is from each satellite. Mainly this segment is used for the U.S military, missile guidance systems, civilian applications for GPS in almost every field. Most of the civilian uses this from survey to transportation to natural resources and from there to agriculture purpose and mapping too.

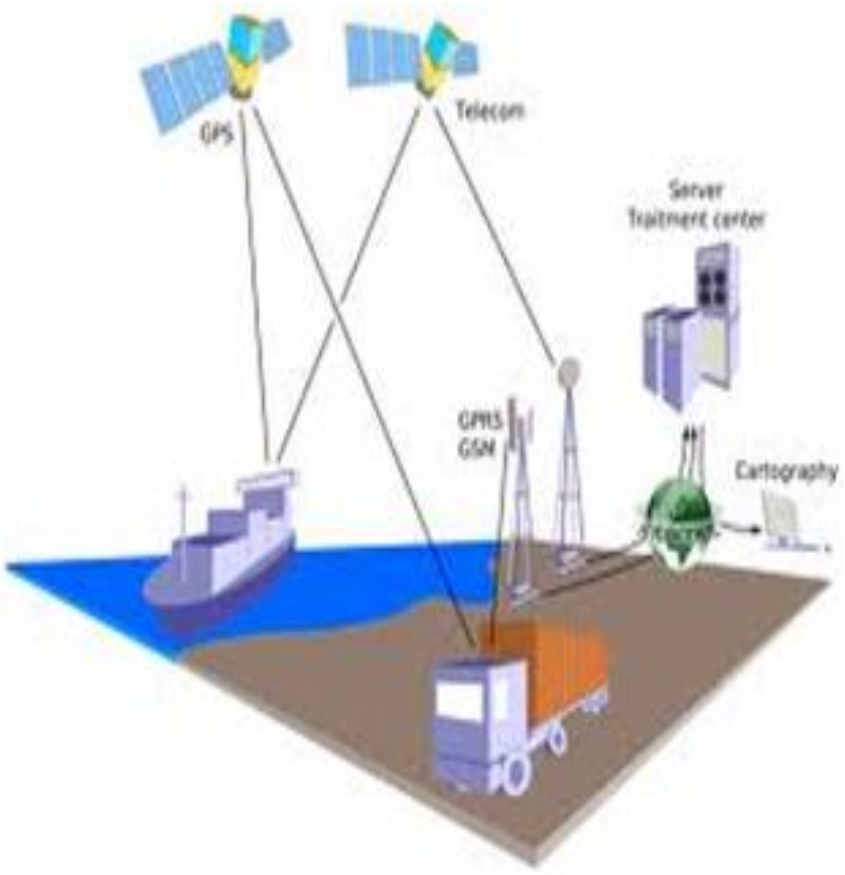


Fig 3.2.6. User Segment

3.3. INTERNET OF THINGS

The **internet of things** (**IoT**) is the network of physical devices, vehicles, buildings and other items embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to collect and exchange data. In 2013 the Global Standards Initiative on Internet of Things (IoT-GSI) defined the IoT as "the infrastructure of the information society. The IoT allows objects to be sensed and controlled remotely across existing network infrastructure, creating opportunities for more direct integration of the physical world into computer-based systems, and resulting in improved efficiency, accuracy and economic benefit. When IoT is augmented with sensors and actuators, the technology becomes an instance of the more general class of cyber-physical systems, which also encompasses technologies such as smart grids, smart homes, intelligent transportation and smart cities. Each thing is uniquely identifiable through its embedded computing system but is able to interoperate within the existing Internet infrastructure. Experts estimate that the IoT will consist of almost 50 billion objects by 2020.

INFRASTRUCTURE:

The Internet of Things will become part of the fabric of everyday life. It will become part of our overall infrastructure just like water, electricity, telephone, TV and most recently the Internet. Whereas the current Internet typically connects full-scale computers, the Internet of Things (as part of the Future Internet) will connect everyday objects with a strong integration into the physical world.

1. Plug and Play Integration

If we look at IoT-related technology available today, there is a huge heterogeneity. It is typically deployed for very specific purposes and the configuration requires significant technical knowledge and may be cumbersome. To achieve a true Internet of Things we need to move away from such small-scale, vertical application silos, towards a horizontal infrastructure on which a variety of applications can run simultaneously.

2. Infrastructure Functionality

The infrastructure needs to support applications in finding the things required. An application may run anywhere, including on the things themselves.

the status of things changes. The infrastructure has to support the monitoring of such changes and the adaptation that is required as a result of the changes.

3. Physical Location and Position

As the Internet of Things is strongly rooted in the physical world, the notion of physical location and position are very important, especially for finding things, but also for deriving knowledge. Therefore, the infrastructure has to support finding things according to location (e.g. geo-location based discovery). Taking mobility into account, localization technologies will play an important role for the Internet of Things and may become embedded into the infrastructure of the Internet of Things.

4. Security and Privacy

In addition, an infrastructure needs to provide support for security and privacy functions including identification, confidentiality, integrity, non-repudiation authentication and authorization. Here the heterogeneity and the need for interoperability among different ICT systems deployed in the infrastructure and the resource limitations of IoT devices (e.g., Nano sensors) have to be taken into account.

Data Management

Data management is a crucial aspect in the Internet of Things. When considering a world of objects interconnected and constantly exchanging all types of information, the volume of the generated data and the processes involved in the handling of those data become critical. A long-term opportunity for wireless communications chip makers is the rise of Machine-to-Machine (M2M) computing, which one of the enabling technologies for Internet of Things. This technology spans abroad range of applications. While there is consensus that M2M is a promising pocket of growth, analyst estimates on the size of the opportunity diverge by a factor of four [16]. Conservative estimates assume roughly 80 million to 90 million M2M units will be sold in 2014, whereas more optimistic projections forecast sales of 300 million units. Based on historical analyses of adoption curves for similar disruptive technologies, such as portable MP3 players and antilock braking systems for cars, it is believed that unit sales in M2M could rise by as much as a factor of ten over the next five years, see Figure 2.29 [16]. There are many technologies and factors involved in the “data management” within the IoT context.

Some of the most relevant concepts which enable us to understand the challenges and opportunities of data management are:

• Data Collection and Analysis

• Big Data

• Semantic Sensor Networking

• Virtual Sensors

• Complex Event Processing.

ESP-12E BASEDNODEMCU

The ESP8266 is the name of a micro controller designed by Espressif Systems. The ESP8266 itself is a self-contained Wi-Fi networking solution offering as a bridge from existing micro controller to Wi-Fi and is also capable of running self-contained applications. This module comes with a built in USB connector and a rich assortment of pin-outs. With a micro USB cable, you can connect NodeMCUdevkit to your laptop and flash it without any trouble, just like Arduino. It is also immediately breadboard friendly.

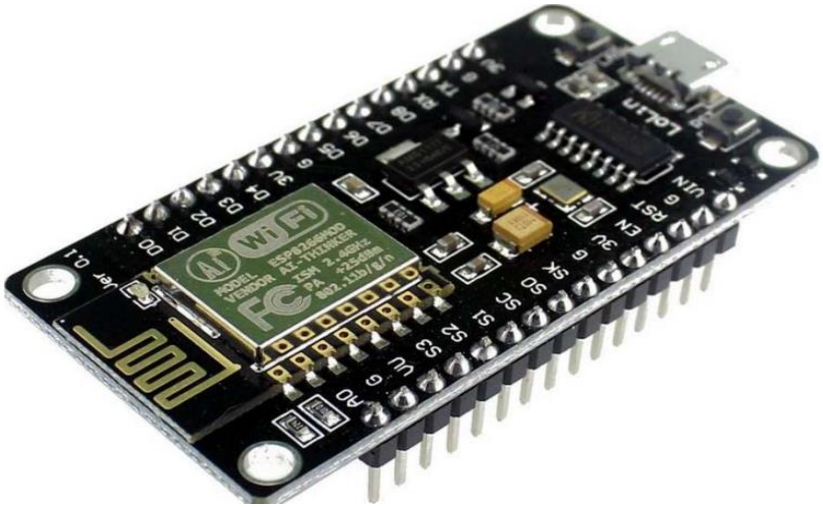
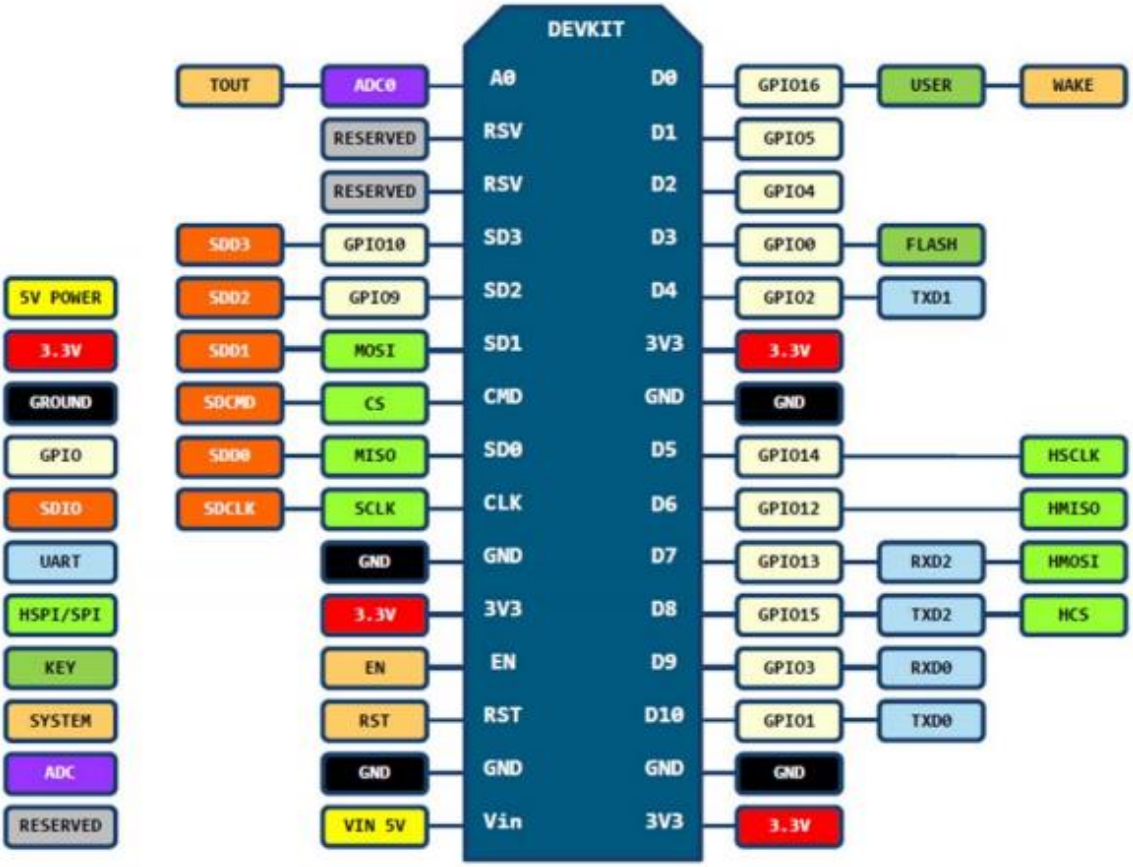


Fig 3.3.1.ESP-12E BASED NODE MCU

ESP-12E Wi-Fi module is developed by Ai-thinker Team. core processor ESP8266 in smaller sizes of the module encapsulates Tensilica L106 integrates industry-leading ultra-low power 32-bit MCU micro, with the 16-bit short mode, Clock speed support 80 MHz, 160 MHz, supports the RTOS, integrated Wi-Fi MAC/BB/RF/PA/LNA, on-board antenna. The module supports standard IEEE802.11 b/g/n agreement, complete TCP/IP protocol stack.

high integration wireless SOCs, designed for space and power constrained mobile platform designers. It provides unsurpassed ability to embed Wi-Fi capabilities within other systems, or to



function as a standalone application, with the lowest cost, and minimal space requirement.

Fig 3.3.2..NODEMCU PIN CONFIGURATION

ESP8266EX offers a complete and self-contained Wi-Fi networking solution; it can be used to host the application or to offload Wi-Fi networking functions from another application processor. When ESP8266EX hosts the application, it boots up directly from an external flash. In has integrated cache to improve the performance of the system in such applications. Alternately, serving as a Wi-Fi adapter, wireless internet access can be added to any micro controller based design with simple connectivity (SPI/SDIO or I2C/UART interface). ESP8266EX is among the most integrated Wi-Fi chip in the industry; it integrates the antenna switches, RF balun, power amplifier, low noise receive amplifier, filters, power management modules, it requires minimal external circuitry, and the entire solution, including front-end module, is designed to occupy minimal PCB area.

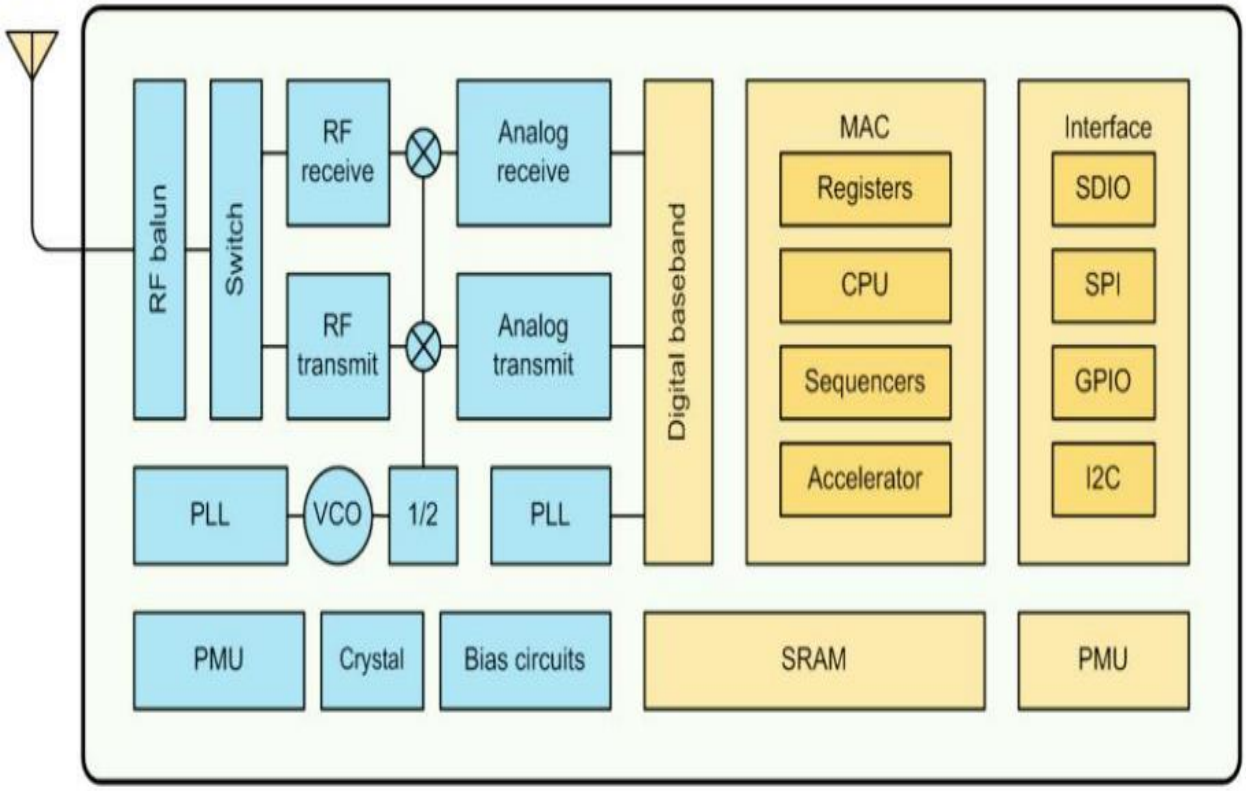


Fig 3.3.3. ESP8266EX

It also integrates an enhanced version of Tensilica's L106 Diamond series 32-bit processor, with on-chip SRAM, besides the Wi-Fi functionalities. ESP8266EX is often integrated with external sensors and other application specific devices through its GPIOs; codes for such applications are provided in examples in the SDK.

Espressif Systems' Smart Connectivity Platform (ESCP) demonstrates sophisticated system-level features include fast sleep/wake context switching for energy-efficient VoIP, adaptive radio biasing. For low-power operation, advance signal processing, and spur cancellation and radio co-existence features for common cellular, Bluetooth, DDR, LVDS, LCD interference mitigation.

GSM

In May 1987, the narrowband time division multiple access (TDMA) solution was chosen. A summary of GSM milestones is given in Table.

Throughout the evolution of cellular telecommunications, various systems have been developed without the benefit of standardized specifications. This presented many problems directly related to compatibility, especially with the development of digital radio technology. The GSM standard is intended to address these problems.

From 1982 to 1985 discussions were held to decide between building an analog or digital system. After multiple field tests, a digital system was adopted for GSM. The next task was to decide between a narrow or broadband solution.

THE GSMNETWORK:

GSM provides recommendations, not requirements. The GSM specifications define the functions and interface requirements in detail but do not address the hardware.

The reason for this is to limit the designers as little as possible but still to make it possible for the operators to buy equipment from different suppliers.

The GSM network is divided into three major systems: the switching system (SS), the base station system (BSS), and the operation and support system (OSS).

GSM NETWORK ELEMENTS:

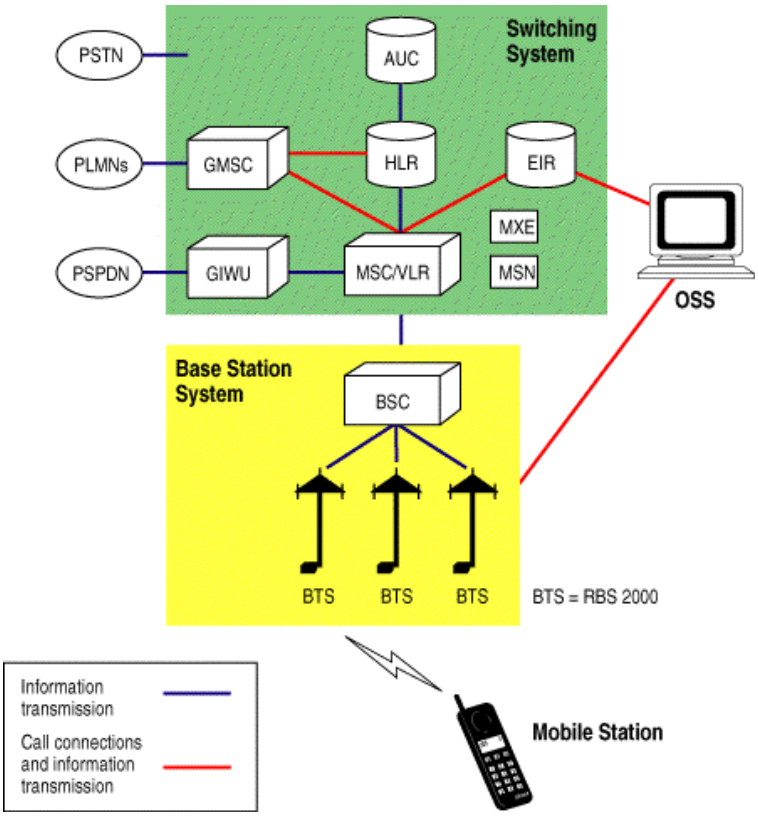


Fig 3.3.4.GSM Network Elements

THE SWITCHING SYSTEM:

The switching system (SS) is responsible for performing call processing and subscriber-related functions. The switching system includes the following functional units:

- **home location register (HLR)**—The HLR is a database used for storageandmanagementofsubscriptions.TheHLRisconsideredthe most important database, as it stores permanent data about subscribers, including a subscriber's service profile, location information, and activity status. When an individual buys a subscription from one of the PCS operators, he or she is registered in the HLR of thatoperator.

- **mobile services switching center (MSC)**—The MSC performs the telephony switching functions of the system. It controls calls to and from other telephone and data systems. It also performs such functions as toll ticketing, network interfacing, common channel signaling, and others.

- **visitor location register (VLR)**—The VLR is a database that contains temporary information about subscribers that is needed by the MSC in order to service visiting subscribers. The VLR is always integrated with the MSC. When a mobile station roams into a newMSC area, the VLR connected to that MSC will request data about the mobile station from the HLR. Later, if the mobile station makes a call, the VLR will have the information needed for call setup without having to interrogate the HLR eachtime.

- **authentication center (AUC)**—A unit called the AUC provides authentication and encryption parameters that verify the user's identity and ensure the confidentiality of each call. The AUC protects network operators from different types of fraud found in today's cellularworld.

- **equipment identity register (EIR)**—The EIR is a database that contains information about the identity of mobile equipment that prevents calls from stolen, unauthorized, or defective mobilestations. The AUC and EIR are implemented as stand-alone nodes or as a combined AUC/EIRnode.

THE BASE STATION SYSTEM (BSS):

All radio-related functions are performed in the BSS, which consists of base station controllers (BSCs) and the base transceiver stations (BTSs).

- **BSC**—The BSC provides all the control functions and physical links between the MSC and BTS.

- It is a high-capacity switch thatprovides functions such as handover, cell configuration data, and control of radio frequency (RF) power levels in base transceiver stations. A number of BSCs are served by anMSC.
- **BTS**—the BTS handles the radio interface to the mobile station.The BTS is the radio equipment (transceivers and antennas) needed to service each cell in the network. A group of BTSs are controlled by a BSC.

THE OPERATION AND SUPPORT SYSTEM:

The operations and maintenance center (OMC) is connected to all equipment in the switching system and to the BSC. The implementation of OMC is called the operation and support system (OSS). The OSS is the functional entity from which the network operator monitors and controls the system. The purpose of OSS is to offer the customer cost-effective support for centralized, regional, and local operational and maintenance activities that are required for a GSM network. An important function of OSS is to provide a network overview and support the maintenance activities of different operation and maintenance organization*s*.

ADDITIONAL FUNCTIONAL ELEMENTS*:*

- **message center (MXE)**—The MXE is a node that provides integrated voice, fax, and data messaging. Specifically, the MXE handles short message service, cell broadcast, voice mail, fax mail,e- mail, and notification.
- **mobile service node (MSN)**—The MSN is the node that handlesthe mobile intelligent network (IN)services.
- **gateway mobile services switching center (GMSC)**—A gateway is a node used to interconnect two networks. The gateway is often implemented in an MSC. The MSC is then referred to as theGMSC.
- **GSM interworking unit (GIWU)**—The GIWU consists of both hardware and software that provides an interface to various networks for data communications. Through the GIWU, users can alternate between speech and data during the same call. The GIWU hardware equipment is physically Slocated at theMSC/VLR.

LORA 204GHZ TI CC2530 – RSSI

GENERAL DESCRIPTION

The LORA (cc2530) is a true system on chip (SoC) solution for IEEE 802.15.4 applications. It combines the excellent performance of a leading RF transreceiver with an industry-standard enhanced 8051 MCU, in system programmable flash memory, 8 kB RAM, and many other powerful features. Received Signal Strength Indicator (RSSI) is a measurement of power present in a received radio signal. . In an IEEE 802.11 system, RSSI is an indication of the power level being received by the receive radio after the antenna and possible cable loss. Therefore, the higher the RSSI number, the stronger the signal.

PRODUCT DESCRIPTION:

The CC2530 comes in four different flash versions: CC2530F32/64/128/256, with 32/64/128/256 KB of flash memory, respectively. The CC2530 has various operating modes, making it highly suited for systems where ultralow power consumption is required. Short transition times between operating modes further ensure low energy consumption.

RSSI is usually invisible to a user of a receiving device. However, because signal strength can vary greatly and affect functionality in wireless networking, often make the measurement available to users. RSSI is often done in the intermediate frequency (IF) stage before the IF amplifier.

In zero-IF systems, it is done in the baseband signal chain, before the baseband amplifier.

RSSI output is often a DC analog level. It can also be sampled by an internal ADC and the resulting codes available directly or through peripheral or internal processor bus. RSSI can be used internally in a wireless networking card to determine when the amount of radio energy in the channel is below a certain threshold at which point the network card is clear to send (CTS). Once the card is clear to send, a packet of information can be sent.

Fig 3.3.5. Lora 204 GHZ

FEATURES

- Supply voltage: 5v DC
- RS232 output
- Output power: up to 4.5dBm–
- Detection range: (10-20) m
- Frequency: 2.4GHz
- Ultra-low power consumption

APPLICATIONS

- Remote control systems
- Home/building automation

3.4 SOFTWARE REQUIREMENTS:

3.4.1.EMBEDDED C

EMBEDDED SYSTEMS:

Embedded System is a system composed of hardware, application software and real time operating system. It can be small independent system or large combinational system.

Our Embedded System tutorial includes all topics of Embedded System such as characteristics, designing, processors, microcontrollers, tools, addressing modes, assembly language, interrupts, embedded c programming, led blinking, serial communication, lcd programming, keyboard programming, project implementation etc.

SYSTEM:

System is a way of working, organizing or performing one or many tasks according to a fixed set of rules, program or plan.

It is an arrangement in which all the unit combined to perform a work together by following certain set of rules in real time computation. It can also be defined as a way of working, organizing or doing one or many tasks according to a fixed plan.

An Embedded System is a system that has software embedded into computer-hardware, which makes a system dedicated for a variety of application or specific part of an application or product or part of a larger system.

An embedded system can be a small independent system or a large combinational system. It is a microcontroller-based control system used to perform a specific task of operation.

An embedded system is a combination of three major components:

- **Hardware:** Hardware is physically used component that is physically connected with an embedded system. It comprises of microcontroller based integrated circuit, power supply, LCD display etc.
- **Application software:** Application software allows the user to perform varieties of application to be run on an embedded system by changing the code installed in an embedded system.
- **Real Time Operating system (RTOS):** RTOS supervises the way an embedded system work. It act as an interface between hardware and application software which supervises the application software and provide mechanism to let the processor run on the basis of scheduling for controlling the effect of latencies.

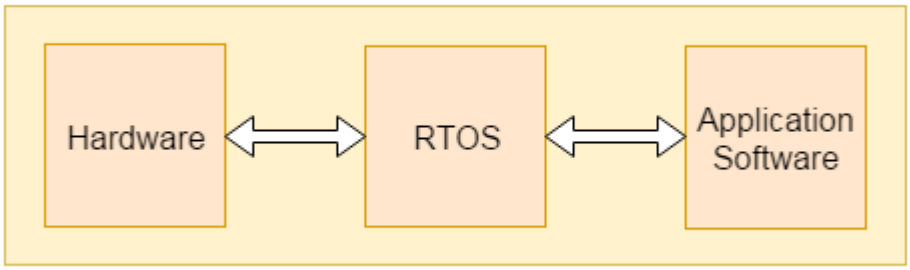


Fig 3.4.2. RTOS

CHARACTERISTICS OF EMBEDDED SYSTEM:

- An embedded system is software embedded into computer hardware that makes a system dedicated to be used for variety of application.
- Embedded system generally used for do specific task that provide real-time output on the basis of various characteristics of an embedded

- Embedded system may contain a smaller part within a larger device that used for serving the more specific application to perform variety of task using hardware-software intermixing configuration.
- It provides high reliability and real-time computation ability.

Advantages:

- Same hardware can be used in variety of application.
- Lesser power requirement
- Lower operational cost of system
- Provide high performance and efficiency

Disadvantages:

- Developing a system required more time. Due to functional complexity.
- Skilled engineers required because one mistake may result in destroying of complete project.

Designing of an embedded system

BASIC STRUCTURE OF AN EMBEDDED SYSTEM:

Let's see the block diagram shows the basic structure of an embedded system.

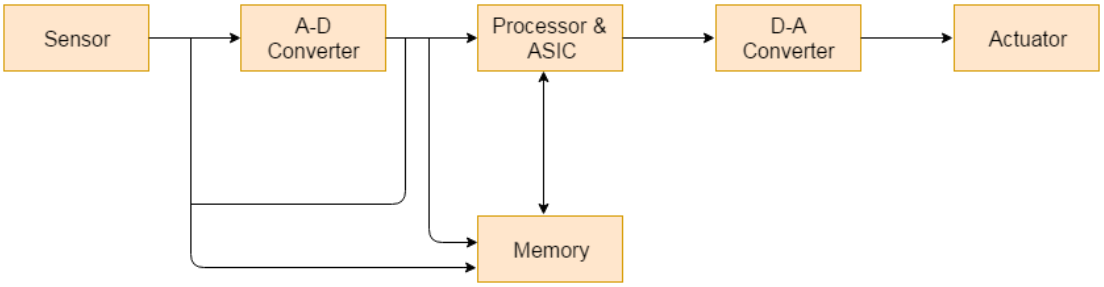
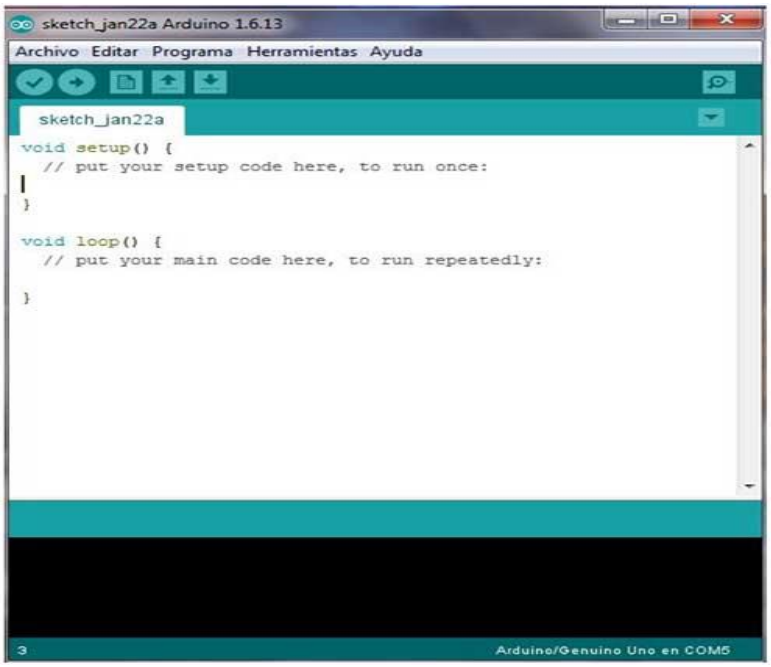


Fig 3.4.5 .Basic Structure of an Embedded System.

- **Sensor**: Sensor used for sensing the change in environment condition and it generate the electric signal on the basis of change in environment condition. Therefore it is also called as transducers for providing electric input signal on the basis of change in environment condition.
- **A-D Converter**: An analog-to-digital converter is a device that converts analog electric input signal into its equivalent digital signal for further processing in an embedded system.
- **Processor & ASICs**: Processor used for processing the signal and data to execute desired set of instructions with high-speed of operation.Application specific integrated circuit (ASIC) is an integrated circuit designed to perform task specific operation inside an embedded system.
- **D-A Converter**: A digital-to-analog converter is a device that converts digital electric input signal into its equivalent analog signal for further processing in an embedded system.
- **Actuators**: Actuators is a comparator used for comparing the analog input signal level to desired output signal level.

3.5.ARDUINO SOFTWARE IDE

The Arduino Integrated Development Environment - or Arduino Software (IDE) - contains a text editor for writing code, a message area, a text console, a toolbar with buttons for common functions and a series of menus. It connects to the Arduino and Genuino hardware to upload programs and communicate with them.



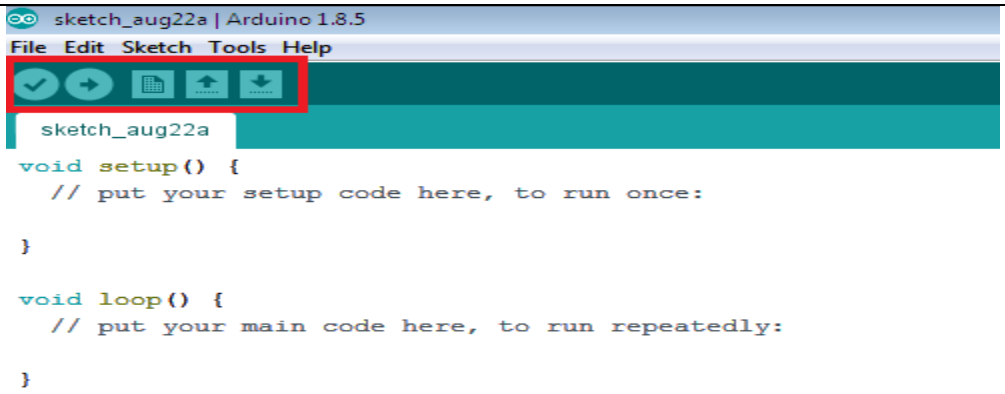
WRITING SKETCHES:

Programs written using Arduino Software (IDE) are called **sketches**. These sketches are written in the text editor and are saved with the file extension **.ino**. The editor has features for cutting/pasting and for searching/replacing text. The message area gives feedback while saving and exporting and also displays errors. The console displays text output by the Arduino Software (IDE), including complete error messages and other information. The bottom right hand corner of the window displays the configured board and serial port. The toolbar buttons allow you to verify and upload programs, create, open, and save sketches, and open the serial monitor.

NB: Versions of the Arduino Software (IDE) prior to 1.0 saved sketches with the extension .pde. It is possible to open these files with version 1.0, you will be prompted to save the sketch with the .ino extension on save.

	**Verify** Checks your code for errors compiling it.
	**Upload** Compiles your code and uploads it to the configured board. See uploading below for details. Note: If you are using an external programmer with your board, you can hold down the "shift" key on your computer when using this icon. The text will change to "Upload using Programmer"
	**New** Creates a new sketch.
	**Open** Presents a menu of all the sketches in your sketchbook. Clicking one will open it within the current window overwriting its content.

	Note: due to a bug in Java, this menu doesn't scroll; if you need to open a sketch late in the list, use the **File | Sketchbook**menu instead**.**
	**Save** Saves your sketch.
	**SerialMonitor** Opens the serial monitor**.**



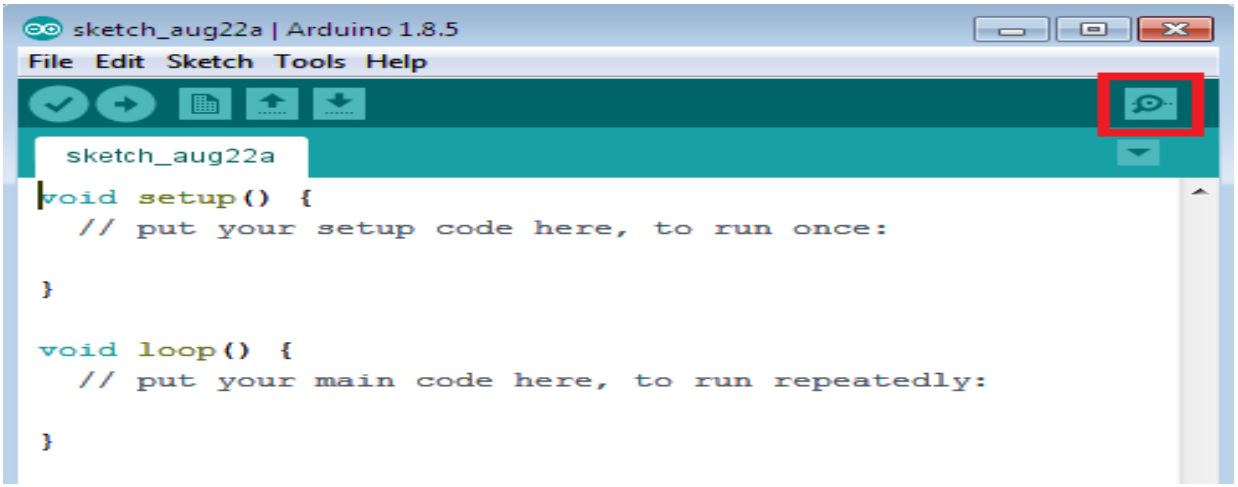
Additional commands are found within the five menus: **File**, **Edit**, **Sketch**, **Tools**, and help. The menus are context sensitive, which means only those items relevant to the work currently being carried out are available.

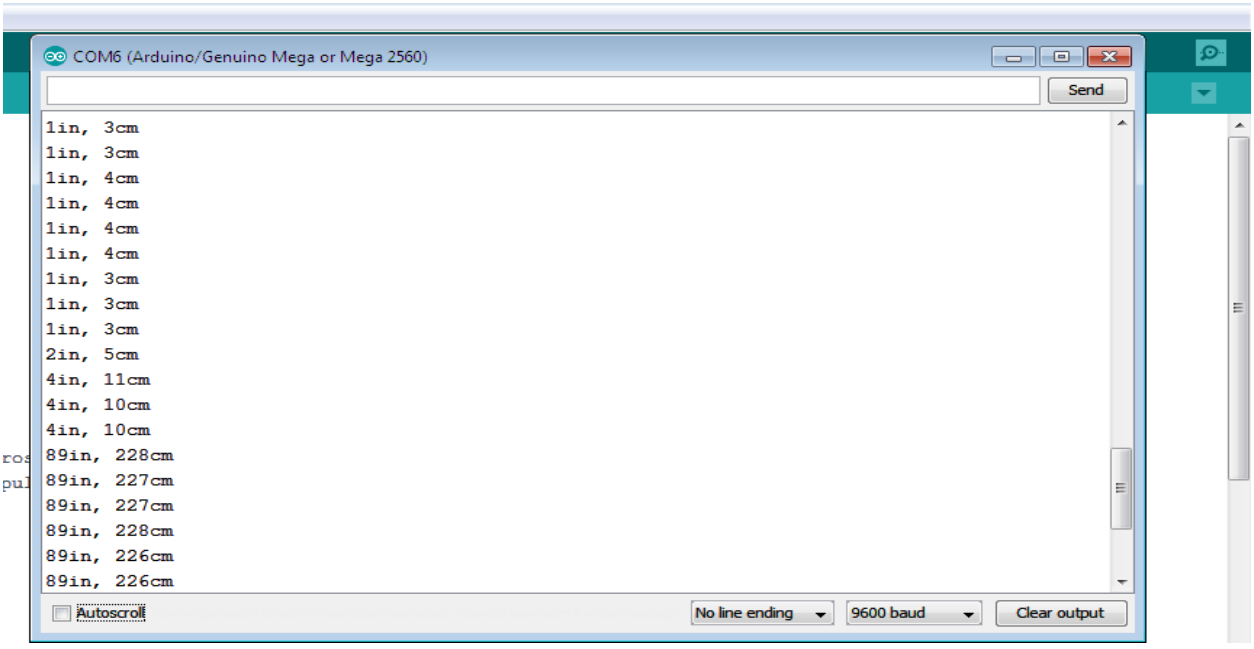
SERIAL MONITOR:

This displays serial sent from the Arduino or Genuino board over USB or serial connector. To send data to the board, enter text and click on the "send" button or press enter. Choose the baud rate from the drop-down menu that matches the rate passed to **Serial.begin** in your sketch.

if your sketch needs a complete management of the serial communication with control characters, you can use an external terminal program and connect it to the COM port assigned to your Arduino board.

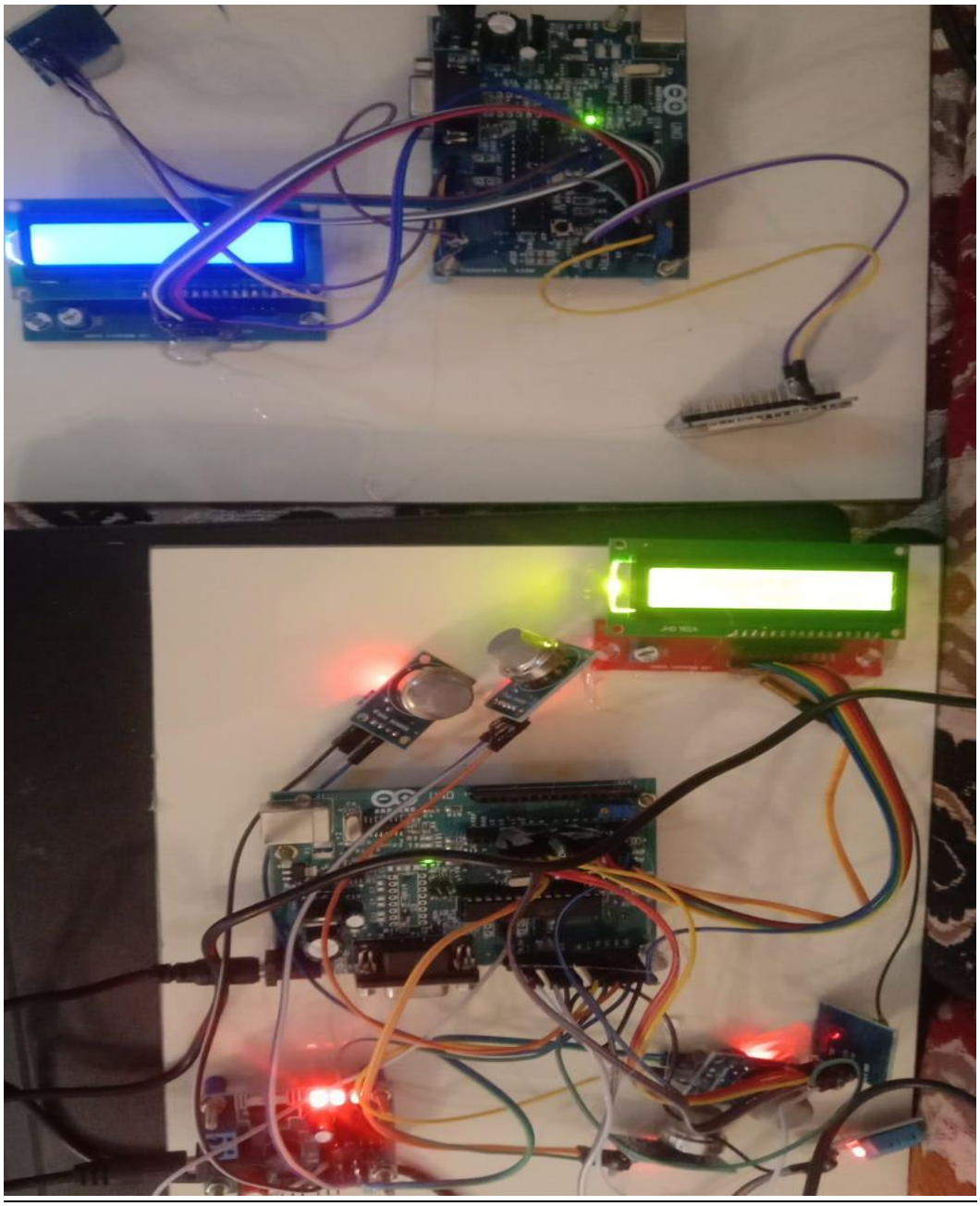
You can also talk to the board from Processing, Flash, MaxMSP, etc (see the interfacing page for details).





CHAPTER: 4 - OUTPUT

4.1.OUTPUT:



CHAPTER: 5 -FUTURE ENHANCEMENT

5.1 APPLICATIONS

This system is used to monitor the air quality system in the high polluted places to measures the world pollution control.

5.2 FUTURE ENHANCEMENT:

- ❖ In future we can upgrade the accuracy of the data collecting faster.
- ❖ We can also get more gases value in future.

5.3 ADVANTAGES:

- Real time monitoring system
- Real time alert system

5.4 CONCLUSION:

The model proposed in this paper serves automatic detection of potholes and humps and alerting vehicle drivers to evade potential accidents. This article reports the development of a novel low-cost sensor node that utilizes cost-effective electrochemical sensors to measure carbon levels. The node can be powered by either solar-recharged battery or mains supply. It is capable of long-range, low power communication over public or private long-range wide area network IoT network and short-range high data rate communication over Wi-Fi. The developed sensor nodes were co-located with an accurate reference CO2 sensor for field calibration.

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