International Journal of Scientific Research and Engineering Development-– Volume 7 Issue 5, Sep-Oct 2024

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

Design and Implementation of a Low-Cost Spirometer for Predicting Respiratory Diseases

Manasvi Raj*, Anshul**

* (Department of Electronics and Communication Engineering, Netaji Subhas University of Technology,
Dwarka, New Delhi 110078, India
Email: manasvi.raj.ug22@nsut.ac.in)

** (Department of Electronics and Communication Engineering, Netaji Subhas University of Technology,
Dwarka, New Delhi 110078, India
Email: anshul.ug22@nsut.ac.in)

--************************----------------------------------

Abstract:

Spirometry is an essential diagnostic tool for assessing lung function and detecting respiratory diseases. However, commercially available spirometers are often prohibitively expensive, with prices ranging from INR 15,000 to INR 70,000, depending on the brand and features. Hospital-grade spirometry machines, which are usually the most advanced and PC-based, cost between INR 50,000 to INR 100,000 or even higher. Additionally, the cost of a single spirometry test can range from INR 1,000 to INR 2,000. Despite their high cost, these spirometers do not always provide accurate results, comprehensive data, or precise disease indications.

To address these limitations, we have developed a low-cost spirometer with a total production cost of only INR 800. This device is capable of detecting and predicting a total of 26 diseases related to the lungs and heart with high accuracy. In this paper, we will discuss the materials, methodology, techniques, design, data acquisition, and report generation processes involved in the development of this spirometer. Our aim is to provide an affordable yet reliable alternative to existing spirometry solutions, making respiratory health monitoring accessible to a broader population.

Keywords — **Spirometry, Microcontroller, Respiratory Diseases MQ-135 Sensor.**

--************************----------------------------------

I. INTRODUCTION

Millions of adults live with chronic respiratory issues and suffer from various lung and heart conditions [1]. These issues primarily affect the respiratory and cardiovascular systems, leading to symptoms such as shortness of breath, chronic cough, and chest tightness [2]. These conditions can be triggered by various factors, including environmental pollutants, smoking, respiratory infections, and genetic predisposition. Timely diagnosis and management of these issues are crucial as they can significantly impair an individual's quality of life and lead to severe complications if left untreated [3].

Spirometry is a common and essential test for diagnosing and monitoring respiratory issues. It measures the flow and volume of gas during the inspiratory and expiratory processes, providing critical indexes for diagnosing these conditions. In India, the cost of a spirometry machine ranges from INR 15,000 to INR 70,000, while advanced hospital-grade machines can cost between INR 50,000 to INR 100,000 or more [4]. Despite its importance, the high cost of spirometry tests (around INR 1,000 to INR 2,000 per test) limits access for many people, particularly those in low-income and rural areas [5].

To address these challenges, our project aims to develop an affordable and accurate spirometer. Using an Arduino Uno as the microcontroller [6], a flex sensor to detect pressure and lung capacity with a balloon and bottle structure, and an M-135 gas sensor to measure the properties of exhaled gas (such as the amount of CO2 and the total volume of gas exhaled at various rates), we have created a low-cost spirometer [7], [8]. While similar projects exist, they typically measure only the total amount or flow of exhaled air or the pressure of the gas when blowing into a tube [9], [10]. Our device, however, offers a more comprehensive analysis of lung capacity and CO2 levels at a fraction of the cost, potentially revolutionizing respiratory health monitoring for a broader population.

II. MATERIAL METHODOLOGIES AND TECHNIQUES

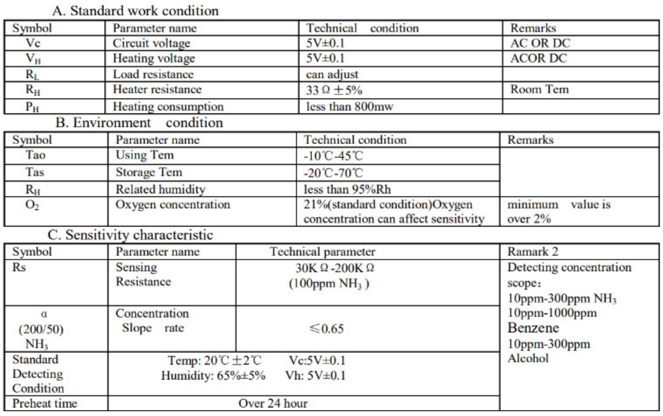
The development of our low-cost spirometer involved a comprehensive selection of materials and an innovative approach to methodologies and techniques. The core of our device is the Arduino Uno microcontroller, chosen for its versatility, ease of programming, and wide availability. The flex sensor plays a crucial role in detecting lung capacity and pressure, integrated into a simple yet effective balloon and bottle structure. This setup allows for accurate measurement of respiratory parameters by capturing the expansion and contraction of the balloon, translating it into digital data via the flex sensor. Additionally, the M-135 gas sensor was incorporated to measure the properties of exhaled gas, particularly focusing on the amount of CO2 and the total volume of gas exhaled at various rates. This sensor is highly sensitive and provides reliable data on gas concentrations, which is critical for diagnosing respiratory issues.

A. *MQ-135 Gas Sensor*

The MQ-135 sensor is an air quality sensor that detects various gases, including ammonia, carbon dioxide, benzene, and smoke, using a metal oxide semiconductor sensing element (SnO2) that measures changes in electrical resistance in response to gas exposure. Table 1 is the datasheet of MQ-135 Sensor by Hanwei Electronics Group Corporation.

CO2 is not a flammable gas, which makes its detection mechanism unique. Instead of interacting directly with the adsorbed oxygen on the sensor surface, CO2 detection involves an intermediate step. Initially, water vapor reacts with the adsorbed oxygen to produce hydroxide ions (OH^−) on the sensor surface. Subsequently, CO2 reacts with these hydroxide ions to form carbonate ions (CO3^2−). This sequence of reactions releases electrons back into the SnO2 conduction band, leading to an increase in the sensor's conductivity.

TABLE I
DATASHEET OF MQ-135 SENSOR BY HANWEI ELECTRONICS GROUP CORPORATION



A. Standard work condition

Symbol	Parameter name	Technical condition	Remarks
Vc	Circuit voltage	5V±0.1	AC OR DC
V_H	Heating voltage	5V±0.1	ACOR DC
R_L	Load resistance	can adjust	
R_H	Heater resistance	33Ω±5%	Room Tem
P_H	Heating consumption	less than 800mw	

B. Environment condition

Symbol	Parameter name	Technical condition	Remarks
Tao	Using Tem	-10℃-45℃	
Tas	Storage Tem	-20℃-70℃	
R_H	Related humidity	less than 95%Rh	
O_2	Oxygen concentration	21%(standard condition)Oxygen concentration can affect sensitivity	minimum value is over 2%

C. Sensitivity characteristic

Symbol	Parameter name	Technical parameter	Ramark 2
Rs	Sensing Resistance	30KΩ-200KΩ (100ppm NH_3)	Detecting concentration scope: 10ppm-300ppm NH_3 10ppm-1000ppm Benzene 10ppm-300ppm Alcohol
α (200/50) NH_3	Concentration Slope rate	≤0.65	
Standard Detecting Condition	Temp: 20℃±2℃ Vc:5V±0.1 Humidity: 65%±5% Vh: 5V±0.1		
Preheat time	Over 24 hour		

B. *Flex Sensor*

A flex sensor is a type of sensor that measures the amount of bending or flexing it undergoes. It typically consists of a thin, flexible material with a conductive strip embedded in it. As the sensor bends, the conductive strip changes its resistance, which can be measured to determine the angle or degree of flexing. The internal architecture of flex sensor can be seen in figure 1.

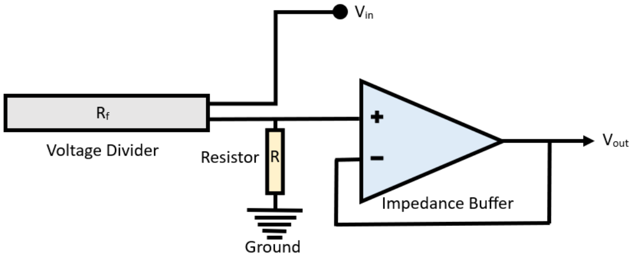
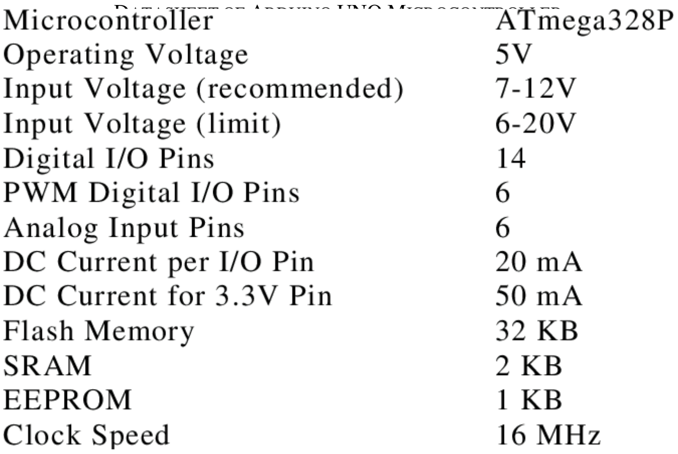


Fig. 1 Flex Sensor Internal Circuit

C. *Arduino UNO*

The Arduino Uno is a versatile microcontroller board used for building and prototyping electronics projects, featuring the ATmega328P chip and a variety of input/output pins. Table 2 is the datasheet for Arduino UNO microcontroller.

TABLE II
DATASHEET OF ARDUINO UNO MICROCONTROLLER



Microcontroller	ATmega328P
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limit)	6-20V
Digital I/O Pins	14
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
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

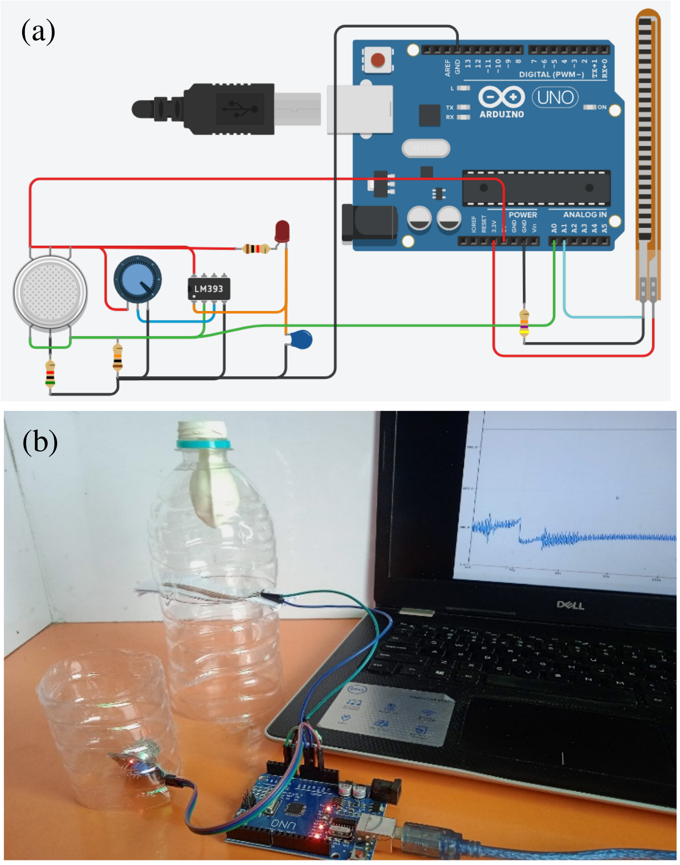


Fig. 2 (a) The Circuit Diagram, (b) Actual setup of proposed spirometer

D. The Code for proposed spirometer

```
const int gas = 0;
int MQ2pin = A0;
int flexsensor = A1;

void setup() {
    // put your setup code here, to run once:
  Serial.begin(9600);
  pinMode(flexsensor, INPUT);
}

void loop() {

   // initiating counters and arrays to store sensor values

  int count1 = 0;
  int count2 = 0;
  float flex[400] ={0};
  float gas1[400]={0};

  //taking initial values of sensors to start the further process
  int FLEX;
  FLEX = analogRead(flexsensor);
  float GAS,MQ2pin;
  GAS = analogRead(MQ2pin);
    //checking if sensor redy to work or not

  if((-5<= FLEX <=5)&& (13<=GAS<=15) ){
    Serial.print("ready to blow");

  for(int i=0;i<400;i++){   //storing values of flex sensor in arrays

    FLEX = analogRead(flexsensor);
    if(190<=FLEX<=250){
       flex[count1]=FLEX;
       count1++;
    }

  delay(10);
 }
 // analysing values of flex sensor
 if(count1>=200){
  Serial.print("flex report ok");
 }
 else{
  Serial.print("reduced lung holding capacity");
 }
   //storing values of gas sensor in arrays
 for(int i=0;i<400;i++){
    GAS = analogRead(MQ2pin);
    gas1[i]=GAS;
  delay(10);
  // analysing values of gas sensor
 }for(int i=0;i<400;i++){
   if(gas1[i]>19){
    Serial.print("gas report ok");
   }
   else if(13<gas1[i]<=19){
    Serial.print("high risk of diseases");
   }
   else if(10<=gas1[i]){
    Serial.print("gas report ok");
   }
   else if (gas1[i]==13){
    Serial.print("high risk of diseases");
   }
   else if(gas1[i]==12){
    Serial.print("moderate risk of diseases");
   }
 }
 }
}
```

III. DATA ACQUISITION AND UTILISATION

The project involves using an Arduino Uno, a MQ-135 gas sensor and a flex sensor to conduct a detailed assessment of lung capacity. Figure 2(a) and 2(b) shows circuit diagram and actual setup of the proposed spirometer. The process begins by utilizing data from the flex sensor using the Arduino IDE's Serial Monitor. The flex sensor, which is sensitive to bending or flexing, provides data at a rate of 50 values per second. This data is crucial for analysing lung function.

The experiment starts with the collection of flex sensor data over a period of 8 seconds. During this time, the sensor records a total of 400 values. These values are organized into an array for analysis. The core idea is to determine the performance of the lungs based on how well a person can maintain pressure while breathing out into a bottle and balloon setup. This setup simulates a scenario where the individual needs to hold their breath or maintain a specific pressure. The first step in analysing the data involves identifying the maximum value from the flex sensor data array. If this maximum value is observed to persist for 200 values or more, the individual passes the first lung test. This criterion is based on the assumption that the ability to sustain pressure indicates a certain level of lung capacity. If the maximum value does not meet this criterion, the test is considered a failure.

Following the initial test, the project moves on to a second stage, where the data collected in the subsequent 20 seconds (totalling 200 values) is stored in a new array. This array is then analysed to determine the lower and upper bounds of the data values. Specifically, the focus is on the lower value within this set of data. If the lower value is 10 or less, the individual passes the second lung test, indicating that their lung function is likely normal. However, if the lower value is above 13, the individual is considered at high risk, while a lower value of 12 suggests moderate risk. In both of these cases, the second test is deemed a failure. This test proves the individual capacity to blow up the inhaled air from lungs. The third and final test involves analysing the same array of data collected during the past 20 seconds. From this array, the highest value is extracted. This value is critical for determining the outcome of the third lung test. If the highest value is 19 or less, the individual fails the third test. Conversely, if the highest value exceeds 19, the individual passes the third test. The result of this test is indicative of the individual's lung capacity and overall health by measuring the CO2 level in exhaled air.

If any of the three tests fail, it suggests a potential risk of lung disease or serves as an early warning sign of possible health issues. A failure in one or more tests indicates that the lungs may not be functioning optimally. On the other hand, if all tests are passed, it signifies that the individual’s lungs are functioning well and their lung capacity is considered normal.

IV. RESULT AND CONCLUSION

The project uses three tests to evaluate lung health, with each test providing insights into potential diseases. Anomalies detected in any of these tests can suggest different health conditions related to the lungs or heart. For example, if the first test shows difficulty in maintaining pressure, it may indicate weakened lung capacity or respiratory issues. The second and third test, focuses on lower and higher sensor values respectively, could point to restrictive lung diseases or poor lung function.

The system aims to predict up to 26 potential diseases by analyzing the flex sensor data from these tests, providing a preliminary assessment of lung and heart health. The names of these diseases, along with their corresponding tests, are listed below.

A. DISEASES OBSERVED BY LOW CO2 LEVEL IN EXHALED GAS

Congestive Heart Failure (CHF)
Pulmonary Hypertension
Cor Pulmonale
Left-Sided Heart Failure
Pulmonary Edema
Severe Chronic Obstructive Pulmonary Disease (COPD)
Interstitial Lung Disease (ILD)
Pulmonary Fibrosis
Neuromuscular Diseases (e.g., Muscular Dystrophy,
Amyotrophic Lateral Sclerosis (ALS))

B. DISEASES OBSERVED BY LOW AMOUNT OF AIR EXHALED

Chronic Obstructive Pulmonary Disease (COPD)
Asthma (especially severe or poorly controlled)
Chronic Bronchitis
Emphysema
Bronchiectasis
Cystic Fibrosis
Obstructive Sleep Apnea (OSA)

C. DISEASES OBSERVED BY LOW PRESSURE/FORCE OF EXHALED AIR OR LUNG CAPACITY

Pulmonary Fibrosis
Interstitial Lung Disease (ILD)
Sarcoidosis
Asbestosis
Pneumoconiosis
Hypersensitivity Pneumonitis
Chest Wall Disorders (e.g., Kyphoscoliosis, Ankylosing Spondylitis)
Neuromuscular Diseases (e.g., Muscular Dystrophy, Amyotrophic Lateral Sclerosis (ALS), Myasthenia Gravis)
Obesity Hypoventilation Syndrome (OHS)
Mitral Valve Disease (severe cases can lead to reduced lung capacity due to pulmonary congestion)
Aortic Valve Disease (severe cases can lead to reduced lung capacity due to pulmonary congestion)
Congenital Heart Disease (certain types can lead to reduced lung capacity due to structural issues)

D. LIMITATIONS AND FUTURE IMPROVEMENTS

1. Display Enhancements: Replacing the PC with an integrated LCD screen would simplify data visualization and eliminate the need for a separate computer, making the system more user-friendly and compact.

2. Higher-Quality Sensors: Upgrading to more precise sensors would improve measurement accuracy and lead to more reliable health assessments.

3. Smaller Microcontrollers: Using compact microcontrollers, such as those from the ATtiny family, could make the system more portable and efficient compared to the larger Arduino Uno.

4. Expanded Data Analysis: Testing a larger sample size and enhancing data analysis could improve the system's accuracy and allow for the detection of additional diseases, offering a more comprehensive health assessment.

These improvements would enhance the system's effectiveness, making it a more accurate and practical tool for assessing lung health.

V. CONCLUSION

Most hospitals rely on spirometer machines that are often large and costly, presenting a challenge for widespread accessibility. To address this issue, a more affordable and portable solution has been proposed, utilizing a multidimensional approach to effectively tackle the problem. The innovative design of the portable spirometer features a three-level testing system, which significantly reduces both cost and size while maintaining high efficiency. This new approach allows for real-time data acquisition and analysis through simplified and less cumbersome methods. As a result, the portable spirometer offers a practical, cost-effective alternative to traditional, bulky spirometers, making respiratory testing more accessible and manageable to various people and regions.

REFERENCES

[1] S. Momtazmanesh et al., "Global burden of chronic respiratory diseases and risk factors, 1990–2019: an update from the Global Burden of Disease Study

2019," EClinicalMedicine, vol. 59, p. 101936, May 2023, doi: 10.1016/j.eclinm.2023.101936.

[2] S. D. Shukla et al., "Chronic respiratory diseases: An introduction and need for novel drug delivery approaches," in Targeting Chronic Inflammatory Lung Diseases Using Advanced Drug Delivery Systems, Elsevier, 2020, pp. 1–31. doi: 10.1016/B978-0-12-820658-4.00001-7.

[3] V. Cukic, V. Lovre, D. Dragisic, and A. Ustamujic, "Asthma and Chronic Obstructive Pulmonary Disease (Copd) and #8211; Differences and Similarities," *Materia Socio Medica*, vol. 24, no. 2, p. 100, 2012, doi: 10.5455/msm.2012.24.100-105.

[4] D. M. Carpenter, R. Jurdi, C. A. Roberts, M. Hernandez, R. Horne, and A. Chan, "A Review of Portable Electronic Spirometers: Implications for Asthma Self-Management," *Curr Allergy Asthma Rep*, vol. 18, no. 10, p. 53, Oct. 2018, doi: 10.1007/s11882-018-0809-3.

[5] N. Vanjare, S. Chhowala, S. Madas, R. Kodgule, J. Gogtay, and S. Salvi, "Use of spirometry among chest physicians and primary care physicians in India," *NPJ Prim Care Respir Med*, vol. 26, no. 1, p. 16036, Jul. 2016, doi: 10.1038/npjpcrm.2016.36.

[6] L. Louis, "Working Principle of Arduino and Using it as a Tool for Study and Research," *International Journal of Control, Automation, Communication and Systems*, vol. 1, no. 2, pp. 21–29, Apr. 2016, doi: 10.5121/ijcacs.2016.1203.

[7] F. N. Abbas, Mis. I. Mohsin Saadoon, Z. K. Abdalrdha, and E. N. Abud, "Capable of Gas Sensor MQ-135 to Monitor the Air Quality with Arduino uno," *International Journal of Engineering Research and Technology*, vol. 13, no. 10, p. 2955, Oct. 2020, doi: 10.37624/IJERT/13.10.2020.2955-2959.

[8] U. Salamah, Q. Hidayah, and D. Y. Kusuma, "CO2 detection system in mixed gas using MQ-135 sensor," *Newton-Maxwell Journal of Physics*, vol. 2, no. 2, Jan. 2022, doi: 10.33369/nmj.v2i2.18730.

[9] V. Agarwal and N. C. S. Ramachandran, "Design and development of a low-cost spirometer with an embedded web server," *Int J Biomed Eng Technol*, vol. 1, no. 4, p. 439, 2008, doi: 10.1504/IJBET.2008.020072.

[10] M. Laghrouche, R. Saddaoui, I. Mellal, M. Nachef, and S. Ameur, "Low-cost Embedded Spirometer Based on Commercial Micro Machined Platinum Thin Film," *Procedia Eng*, vol. 168, pp. 1681–1684, 2016, doi: 10.1016/j.proeng.2016.11.489.