International Journal of Research in Engineering, Science and Management
Volume-2, Issue-12, December-2019
www.ijresm.com | ISSN (Online): 2581-5792

Design and Experimental Analysis of Magnetic Climbing Robot

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***Abstract*: Many industrial applications, specifically piping industrials faces performance evaluation issues of working condition. This Project work basically focused on integration of robotics and magnetic applications with permanent magnetic tracks to facilitate cleaning inspection issues of pressure vessels. This work includes an experimental evaluation of robot assembly system with wall climbing robot and permanent magnetic adhesion mechanism for inspecting pipes and duct system. Conceptual design of proposed system considering all working parameters is done by suitable CAD modeler (CATIA). Hardware includes many sensors and Arduino controller to facilitate smooth automation. Arduino programming is studied in this work for experimental evaluation of robotics system.**

***Keywords*: Robot, pressure vessels, CATIA, Arduino, Sensors.**

1. Introduction

Pressure vessel inspection was identified by the industry as a key challenge in maximizing economic return. The robot, incorporating advanced inspection technologies, will help increase production up-time, reduce costs and improve efficiency. Work is going on to develop a new robot crawler equipped with 3D laser scanning and non-destructive testing technology. Recently, crawlers are used only when there is clear line-of-sight for the operator. Ideas are focused on predicting, preventing, detecting and repairing corrosion under insulation. Presently, magnetic climbing robots are implemented to facilitate the investigation, maintenance and building tasks due to new locomotion types and adhesion principles. One of the main aspects is safety, which considers the ability of robots to inspect dangerous constructions of human beings to perform the requested tasks, climbing robots as all other technical systems have to accomplish several fulfillments which depend on the area of application. Required inspection parameters can be implemented for practically all climbing robots in the range of investigation and support. This technique for magnetic inspection robots includes electromagnets and permanent magnets, which are placed on the surface or held at a specific distance. This project work can be useful for metallic (ferromagnetic) components and related applications as it can produce high adhesion forces on specific surface area.

A. Problem Statement

It was observed that to inspect the vessel was difficult for humans, so it was a required a system which can inspect the internal part of the vessel which was impossible due to hazardous gases and risky situations. So, magnetic climbing robot was designed for that purpose.

B. Objective

1. Development of robot climbing using locomotive mechanism.
2. Automatic controlling of Robot using Arduino controller.
3. Magnetic based Climbing Operation of robot.
4. Temperature sensing using LM 35 sensor.
5. Provide Real time image using Camera.
6. Detection of smoke level and gases like LPG, Butane, propane using gas sensor.

C. Methodology

First we will do the analysis and research on robot then designing of new robot with more reliability and lesser weight. Then prototype creation and testing of wall climbing robot is to be done. And after which the manufacturing of final prototype with optimization will done. Power for actuation of robot is transmitted from electric motor to the gearbox which is connected through robotic arm. When robotic arm is actuated, robot is moved to the intended direction with the help of adhesion mechanism by virtue of permanent magnetism.

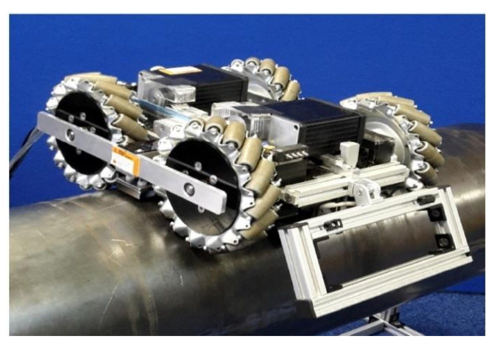


Fig. 1. Pipe inspection robot

2. Literature review

Laboratoiredes Sciences du Numerique de Nantes LS2N, Ecole Centrale de Nantes (2018): In this paper the mechanical and control design of a magnetic tracked mobile robot is presented. The robot is designed to move on vertical steel ship hulls and to be able to carry 100 kg payload, including its own weight. The mechanical components are presented and the sizing of the magnetic tracks is detailed. All computation is embedded in order to reduce time delays between processes and to keep the robot functional even in case of signal loss with the ground station. The main sensor of the robot is a 2D laser scanner that gives information on the hull surface and is used for several tasks. This work focuses on the welding task and exposes the control algorithm that allows the robot to follow a straight line for the welding process. [1]

Ravindra Singh Bisht (2018): This paper presented experimental excremental studies on permanent magnet based wheel mechanism for safe navigation of climbing robot on ferrous wall surface structures. Three types of wheel mechanism are manufactured and compared for their working performance experimentally for climbing robot locomotion trials. The Wheel 1 mechanism with MS hub is very compact, simple in design with easy assemble/dissemble features, and having less manufacturing cost. Wheel 1 design is further improved by developing Wheel 2 and Wheel 3 versions by changing hub materials from mild steel to aluminum. These Wheels mechanisms are light in weight and more powerful to achieve maximum adhesion force that is 210N and 251N with and without rubber grip, respectively, at only 200g Wheel weight has compared to previously reported permanent magnetic adhesion mechanism. Thus, more payload carrying capacity climbing robot can be developed using these developed mechanisms for field trials of climbing robot. A comprehensive experimental study on the influence of rubber grip thickness, air gap, wheel tilt angle and test surface thickness variation on adhesion force of these developed. The influence of both static and kinetic coefficient of friction (COF) for vertical surface of locomotion of climbing robot has also been investigated. These developed wheel mechanisms have been further demonstrated using a four-wheel differential drive prototype climbing robot for safe navigation testing force on a 2D frame plane wall structure and a next on 3D frame wall structure. It is found from the laboratory trials that based on these wheel mechanisms, the climbing robot can safely navigate remotely on even surface for these chosen structure. [2]

Uppu Ramachandraiah (2017): The large numbers of research are carried out in the field of wall climbing robots. These wall climbing robots are utilized for variety of applications including hazardous operations. The wall climbing robots must be capable of manoeuvring in different wall surfaces without sacrificing its mobility. For such capabilities, wall climbing robots should be enabling with proper adhesion mechanism such as suction based absorption technology. In this paper, the modeling and experimental analysis of suction pressure generated inside the suction chamber with different chamber contours is analyzed. In this study, a novel bottom restrictor is included at the bottom of the design suction chamber. The suction motor, suction chamber with different contours and bottom restrictor is modeled using 3D package. The impact on the adhesion efficiency of the climbing robot with the design bottom restrictor is experimentally evaluated and tested on non-plastered brick walls. [3]

Bing Li, Kenshin Ushiroda, Ling Yang, Qiang Song (2017): The impact echo (IE) acoustics inspection method is a non-destructive evolution technique, which has been widely applied to detect the defects, the structural deterioration level, and thickness of plate like concrete structures. This paper presented the novel climbing robot, namely Rise rover, to perform automated signal collection from concrete structures with IE signal analyzing base on machine learning techniques. Rise rover is our new generation robot and it has a novel and enhances absorption system to support heavy load, and crawler like suction cups to maintain high mobility performance while crossing small grooves. The design enables a seamless transition between ground and wall. This paper applies the fast Fourier transform and wavelet transform for feature detection from collection IE signals. A distance metric learning base support vector machine approach is newly proposed to automatically classify the IE signals. With the visual inertial odometry of the robot, the detected flaws of inspection area on the concrete plates are visualized in 2D\3D. Field test on a concrete bridge deck demonstrate the efficiency of the proposed robot system in automatic health condition assessment for concrete structures. [4]

Yanwei Liu (2016): In this paper the design and experiment of a Bioinspired wall-climbing robot with spiny arrays is studied. Inspired by the Sericaorientalis Motschulsky's tarsal system, a spiny structure is designed, and the robot's foot which has two grippers using the structure is designed. An inchworm-like gait is employed and its trajectory is planned. The robot's foot as well as the whole prototype is fabricated and tested. It is verified that the foot has remarkable adhesive ability and the robot can scale vertical and inverted rough surfaces including the ceiling. [5]

MD Omar Faruq Howlader (2015): Wall climbing robot can provide easier accessibility to tall structure for non- destructive testing (NDT) and improve working environments of human operators. However, existing adhesion mechanism for climbing robots for vortex, electromagnet etc. At development stage an offer no feasible adhesion mechanism. As a result, few practical products have been developed for reinforce concrete surface. Though wall climbing robots have been researched for many years. This paper proposes a novel magnetic adhesion mechanism for wall climbing robot for reinforce concrete surface. Mechanical design parameters such as distance between magnets, the yoke thickness, and magnet arrangements have been investigated by finite element analysis (FEA). The adhesion module can be attached under the chassis of a prototype robot. The magnetic flux can penetrate maximum concrete cover of 30mm and attain adhesion force of 121.26N. The prototype provides high force to weight ratio compare to other reported permanent magnet base robotic system both experiment and simulation results prove that the magnetic adhesion mechanism can generate efficient adhesion force for the climbing robot to operate on vertical reinforce concrete structures. [6]

Riad Hossain Faisal, Nafiz Ahmed Chisty (2018): This paper work deals with the design and implementation of a wireless controlled motor vehicle with the ability to move in both vertical and horizontal plane. Aerodynamic techniques have been used to hold the vehicle in any inclined vertical plane. The paper work covers both electrical and mechanical portions. The mechanical portion has been designed using Solid works and 3D studio MAX while the electrical parts have been designed and simulated using Proteus VSM tool. [7]

Mohamed G. Alkalla (2015): In this paper author discussed about proposing and designing a new climbing robot to explore the interiors of industrial vessels and enable a human outside the vessels to implement required regular inspection tasks efficiently. There are two main adhesion systems in the literature: magnetic and air suction systems. The magnetic system climbs surfaces made of ferromagnetic materials only, while air suction system cannot handle irregular surfaces due to possible seals damage. Opposite to previous climbing robots, the proposed robot here can climb and navigate vessels made from different materials besides handling possible irregular surfaces during inspection. Its main task is visual inspection of welds and any critical spots inside these vessels. The novelty of this robot comes from utilizing a hybrid actuation system. This hybrid actuation system consists of upturned propellers fixed on mobile robot and motorized wheels of the mobile robot. The pressure generated from the upturned propellers increase the friction force between the wheels of the mobile robot and the wall. The wheels' motors generate the required torque either to fix the robot in any position or to move it to any place. Since the motion of the robot comes mainly from the motorized wheel, the stability of the system during navigation is guaranteed. Size and topology optimizations are carried out to achieve optimum design of the proposed robot. Simulation results of the designed robot using ADAMS software prove its feasibility. [8]

International Journal of Scientific & Engineering Research, Volume 5, Issue 7, and July-2014: The project aims in designing a pipe climbing Robot which is operated using computer wirelessly from a remote location wirelessly using ZigBee modules. The advent of new high-speed technology and the growing computer Capacity provide realistic opportunity for new robot controls and realization of new methods of control theory. This technical improvement together with the need for high performance robots created faster, more accurate and more intelligent robots using new robots control devices, new drivers and advanced control algorithms. [9]

Ke Wang (2013) in this paper authors discussed about 'How to develop practical robots with high artificial intelligence to replace the traditional manual method of on-site inspection of glass- curtain-walls needs to be solved urgently. Therefore, a double-cavity climbing robot that can automatically conduct safety inspection of glass-curtain-wall is researched and presented in this paper. The robot includes adsorption module based on the principle of negative pressure adsorption, servo-drive system to control traveling distance, vibration testing device and safety device. The mechanical structure and its optimization are described in detail, which is followed by a presentation of the robot control system. Finally the wall-climbing and vibration testing experiments are conducted on glass-curtain-wall, and effectiveness of the design is approved. [10]

Mahmoud Tavakoli (2013): This paper introduces omni climber, a new climbing robot with high manoeuvrability for inspection of ferromagnetic flat and convex human made structure. In addition to manoeuvrability, adaptability to various structures with different curvatures and materials are address. The conceptual and detail design of omni climbers are presented and two prototype of the robot are introduced. Several laboratory and field test are reported. And the results are discussed. [11]

Kristin Fondah, Markus Eich, Johannes Wollenber, Frank Kirchner, (2012): Currently, the inspection of sea-going vessels was performed manually. Ship surveyors did a visual inspection in some cases they also use cameras and non-destructive testing methods. Prior to a ship surveying process, a lot of scaffolding has to be provided in order to make every spot accessible for the surveyor. In this work a robotic system was presented, which was able to access many areas of a cargo hold of a ship and perform visual inspection without any scaffolding. The paper also described how the position of the acquired data is estimated with an optical 3D tracking unit and how critical points on the hull can be marked via a remote controlled marker device. Furthermore, first results of onboard tests with the system are provided. To make a use of the marking unit in a real world environment, it was needed to be equipped with a more suitable varnish for metallic surfaces. This varnish must not clog the outlet of the spray container and has to be suitable for multiple if not all surfaces in a ship. The transmission problems of the video images were to be prevented, as other repairs cannot be put to a hold during the inspections. Therefore, a new video transmission was later integrated into the robot with a 5.8 GHz submission rate and 2.5 times stronger signal. The transmission remains to be tested onboard a ship but the noise ratio inside the lab decreased drastically with this setup. [12]

Weiguang Dong, Hongguang Wang, Aihua Liu (2011): In this paper the novel wall climbing robot mechanism designed for anti- hijacking task is presented. This mechanism consists of a negative pressure adhesion module, a vacuum suction module and planetary gear train. The design of biped-wheel hybrid locomotion mechanism, with the advantages of wheel robots and legged robots, allows the robot to move fast and crossover obstacle easily. This design qualifies the robot for the motion of moving straight, turning in plane and crossing between inclined surfaces. Then the kinematics equations are derived and the locomotion modes are analyzed. Many experiments have been implemented and the results prove that the robot such characteristics as rapid speeds, excellent transition ability between inclined surfaces and curved surface adapt ability. Therefore, this novel wall climbing mechanism could be used for the application of inspection, surveillance and reconnaissance. [13]

A. Albagul, A. Asseni, O. Khalifa (2011): A wall climbing robot is a robot with the capability of climbing vertical surfaces. This paper describes the design and fabrication of a quadruped climbing robot. We are required to design and create a wall climbing robot which uses suction as means of sticking to the wall. The robot will be controlled using basic stamps and the movement of its legs will generated by two servomotors. Each servomotor will control legs which are located on the left and right side of the robot. The leg rotations mimic stepping motions through the use of a slider and a crank. The suction force will be supplied by two vacuum pumps that will turn on intermittently. The main body of the robot will carry all the components except for the compressor thus making it mobile. Currently robot is only design for linear movement. However, plans to incorporate maneuverability and other functions can be implemented after the first stage of the development achieves success. [14]

Surachai Panaich (2010): The problem of a wall climbing robot is holding on the wall. This is challenge for researchers. There are many factors, which effect in holding, all forces, robot movement and mechanical design. This study proposes movement step design for wall climbing robot. In design the robot use pneumatic system as main unit to move on the wall. The robot can move in four directions, forward, backward, left and right. They analyzed force acting with the wall that the wall should have only slope from 0 degree (parallel with the ground) to 90degree (vertical line). At equilibrium condition, we express all forces in equilibrium by sum all forces that equal zero. For further work they proposed to choose parameter to improve the climbing efficiency that the robot can climb much slope. For the first way, to change the wall material to increase μs and for the second way, also to improve vacuum force by means of increasing pneumatic system efficiency. [15]

3. Design and CAD modelling

A. Power Calculations:

$$\text{Power} = \frac{2\times\pi\times N\times T}{60} = \frac{2\times\pi\times 10\times 10}{60} = 10.47\text{W}$$

$$GearRatio = \frac{N1}{N2} = \frac{23}{23} = 1$$

Power of gear 1 = Power of gear 2 (N1 = N2)

$$\therefore \frac{2\times\pi\times N1\times T1}{60} = \frac{2\times\pi\times N2\times T2}{60}$$

$$\frac{2\times\pi\times 10\times 10}{60} = \frac{2\times\pi\times 10\times T2}{60}$$

T2 = 10 N.m

Load carrying capacity = 10 kg (Including self weight)

Actual load carrying capacity = Total load carrying capacity - Self weight = 10 - 1 = 9 kg

Displacement of Robot in one direction of rotor:

As robotic arm rotates so displacement = Diameter of circle traced by arm = 2r = 2*80 = 160 mm

Power required for travelling 160 mm of one rotation

$$P = \frac{2\times\pi\times N\times T}{60} = \frac{2\times\pi\times 1\times 10}{60} = 1.04W$$

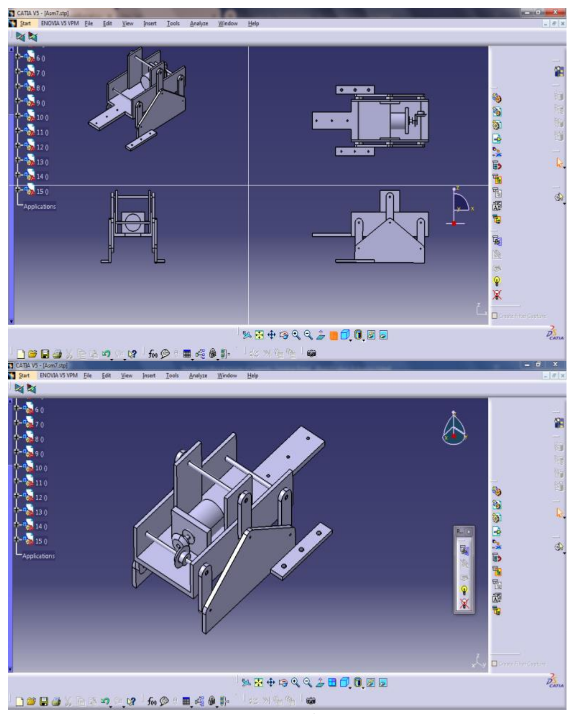


Fig. 2. CAD Model of proposed set up

B. Robot Design

Robot design determines the inherent capabilities of a robot. Robot design requires making trades among many factors, such as functional capability and complexity, weight and strength of mechanical parts, weight and power of actuators, cost and performance of sensors, and so on. It is a complicated process that has not a single optimal solution. The high-level guideline that we used throughout our work is to achieve the functions needed for free-climbing with the simplest possible design.

C. Kinematic design

The kinematic design of Capuchin required us to consider several important issues, in particular: number of limbs, number of degrees of freedom (DOFs) in each limb and body, distribution of these DOFs over the robot structure, and detailed specification of each link of the limbs and body. After resolving these issues, our work focused on the detailed design of each part. During the initial phase of the process, we loosely used the body structure of humans and animals that are good at climbing as a source of inspiration. We then ran more formal and quantitative simulations to evaluate key capabilities, like workspace reach ability.

D. Working Principle

Each of the 4 cranks is connected with the slider part and sucking cup. Only 2 legs will generate motion of the slider crank mechanism while 2 legs remain fixed at a certain position. The numbers of DOF are the number of components of motion that are required in order to generate the motion. The formula of DOF of any planar mechanism through number of moving links (n), number and types of joints (f1 and f2) can be expressed as:

$$F = 3*n - 2*f1 - f2$$

Where, f1 is the number of one DOF joint and f2 is the number of two DOF joint. The DOF for the slider-crank mechanism of the robot leg can be calculated.

No. of links = 3

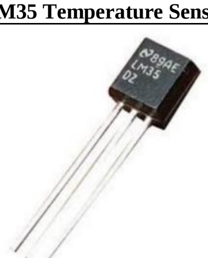
No. of one DOF = 4 (3 joints and 1 slider)

F = 3*3 – 2*4 – 0 = 1

4. Experimental set-up

A. Hardware

Types of Sensors used

Infrared Sensor	Features
	• 5V DC Operating voltage • I/O pins are 5V and 3.3V compliant • Range: Up to 20cm • Adjustable sensing range • Built-in Ambient Light Sensor • 20mA supply current • Mounting hole
LM35 Temperature Sensor	
	• Calibrated directly in degree Celsius (centigrade) • Linear at 10.0 mV/℃ scale factor. • 0.5℃ accuracy guarantee-able (at 25℃) • Rated for full -55℃ to a 150℃ range, Suitable for remote application. • Low cost due to wafer-level trimming • Operates from 4-30V.
Gas Sensor (MQ6)	
	• High sensitivity to LPG, iso-butane, propane. • Small sensitivity to alcohol, smoke. • Detection Range: 100 – 10,000 ppm iso-butane, propane. • Fast response time: <10s • Simple drive circuit. • Heater voltage: 5V.

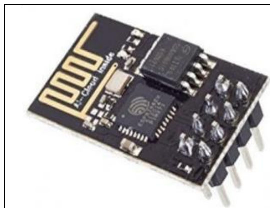
B. Electronic components

Arduino UNO

Features:

- Microcontroller: ATmega328P.
- Operating voltage: 5V
- Input voltage: 7-12V
- Digital I/O Pins: 14 (of which 6 provide PWM output)
- Analog input pin: 6.
- DC Current: 40-50 mA.
- Flash memory: 32KB.
- SRAM: 2KB
- EEPROM: 1KB
- Clock speed: 16 MHz

ESP8266- WIFI Module:

	• Low cost, compact and powerful Wi-Fi Module • Power supply: +3.3V only. • Current consumption: 100mA. • I/O Voltage: 3.6V (max). • I/O source current: 12mA • 512KB Flash memory • Can be used as station or access point or both combined • Support serial communication • Can be programmed using Arduino IDE or AT-command or Lua Script • The WI-FI range is up to 100 metres.

L293D Motor Driver board:

	• L293D motor driver IC. • Male burg sticks connectors for supply, ground and input connection • Screw terminal connectors for easy motor connection • On Board LM7805 Voltage Regulator.

Geared Motor:

	• 10RPM 12V DC motor with metal gearbox and gears. • 18000 RPM base motor • 6mm Dia shaft with M3 thread hole • Gearbox diameter 37mm. • Motor Diameter 28.5mm • Length 63mm without shaft • Shaft length 30mm • 180gm weight • 120kgcm Torque • No-load current = 800mA, Load current = up to 7.5A.

OV7670 Camera Module:

	• High sensitivity for Low-light operation • Low operating voltage for embedded portable apps • Lens shading correction. • Flicker (50/60Hz) Auto-detection • De-noise level auto adjusts • Image quality controls including color saturation, hue, gamma, sharpness (edge enhancement), anti-blooming

C. Software

We have used IDE (Integrated development environment) software to program Arduino and it provides comprehensive facilities to computer program for software development. An IDE normally consists of at least or source code editor, build automation tools, and a debugger.

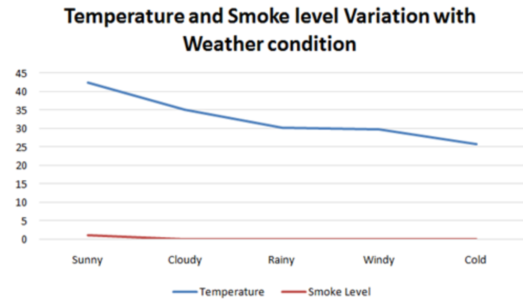
Arduino programs

```
#include<SoftwareSerial.h>
#define DEBUG true
SoftwareSerial esp8266(2,3);
const int lm35_pin = A1;  /* LM35 O/P pin */
int smokeA0 = A0;
int sensorThres = 400;
void setup()
{
Serial.begin(9600);    ///////For Serial monitor
esp8266.begin(115200); ///////ESP Baud rate
pinMode(11,OUTPUT);     /////used if connecting a LED to pin 11
digitalWrite(11,LOW);
pinMode(7,INPUT);
pinMode(13,OUTPUT);
pinMode(8,OUTPUT);
pinMode(9,OUTPUT);
pinMode(smokeA0, INPUT);
pinMode(lm35_pin, INPUT);
digitalWrite(13,HIGH);
sendData("AT+RST\r\n",2000,DEBUG); // reset module
sendData("AT+CWMODE=2\r\n",1000,DEBUG); // configure as access point
sendData("AT+CIFSR\r\n",1000,DEBUG); // get ip address
sendData("AT+CIPMUX=1\r\n",1000,DEBUG); // configure for multiple connections
sendData("AT+CIPSERVER=1,80\r\n",1000,DEBUG); // turn on server on port 80
}
float sensetemp() ///////function to sense temperature.
 {
int val = analogRead(A1);
float mv = ( val/1024.0)*5000;
float celcius = mv/10;
return(celcius);
}
int connectionId;
void loop()
{
 int analogSensor = analogRead(smokeA0);
int  percentValue = ((analogSensor-110)/(1023-110))*100;
digitalWrite(8,LOW);
digitalWrite(9,HIGH);
 if(digitalRead(7)==0)
{
digitalWrite(13,LOW);
digitalWrite(8,LOW);
digitalWrite(9,LOW);
delay(2000);
digitalWrite(8,HIGH);
digitalWrite(9,LOW);
delay(5000);
  }
 else{
digitalWrite(13,HIGH);
}
 if(esp8266.available())
 {
if(esp8266.find("+IPD,"))
 {
delay(300);
connectionId = esp8266.read()-48;
if(esp8266.find("pin="))
  {
Serial.println("recieving data from web browser");
  int pinNumber = (esp8266.read()-48)*10;
pinNumber += (esp8266.read()-48);
digitalWrite(pinNumber, !digitalRead(pinNumber));
   }
Else
 {
  String webpage = "<h1>Duct Inspection Robot</h1>";
espsend(webpage);
 }
  if(sensetemp() != 0)
   {
String add1="<h4>Temperature=</h4>";
String two =  String(sensetemp(), 3);
 add1+= two;
add1+="&#x2103";   //////////Hex code for degree celcius
 String add2="<h6>Smoke Level<h6>";
String three = String(percentValue, 3);
add2+= three;
 if(digitalRead(7)==0)
{
digitalWrite(13,LOW);
//int object =1;
 String add3="<h8>Object Detected<h8>";
//String four=(object,3);
//add3+=four;
```

```
espsend(add3);
  }
espsend(add2);
espsend(add1);
 if (analogSensor>sensorThres){
String add4="<h8>Smoke Level is High<h8>";
}
 }
else
 {
String c="sensor is not conneted";
espsend(c);
  }
 String closeCommand = "AT+CIPCLOSE=";
///////////////close the socket connection////esp command
closeCommand+=connectionId; // append connection id
closeCommand+="\r\n";
sendData(closeCommand,3000,DEBUG);
    }
 }
}
void espsend(String d)
 {
String cipSend = " AT+CIPSEND=";
cipSend += connectionId;
cipSend += ",";
cipSend +=d.length();
cipSend +="\r\n";
sendData(cipSend,1000,DEBUG
sendData(d,1000,DEBUG);
 }
//gets the data from esp and displays in serial monitor/////////
String sendData(String command, const int timeout, boolean debug)
{
String response = "";
esp8266.print(command);
long int time = millis();
while( (time+timeout) >millis())
{
 while(esp8266.available())
 char c = esp8266.read(); // read the next character.
 response+=c;
  }
 }
  if(debug
  {
Serial.print(response); //displays the esp response messages in arduino Serial monito
  }
 return response;
  }
```

5. Result

S. No.	Weather Condition	Temp. (ºC)	Smoke Level
1	Sunny	42.446	Medium
2	Cloudy	35.156	Low
3	Rainy	30.267	Low
4	Windy	29.842	Low
5	Cold	25.785	Low



6. Conclusion and Future scope

A. Conclusion

- We developed a climbing robot using locomotive mechanism of four bar chain which gives a forward and backward movement.
- The motion of the robot was controlled by Arduino controller which has ATmega328P microcontroller that allows the logical operations to be performed.
- The climbing operations of the Robot has been permanent magnetic based which provide adhesive force to stick on vertical surface.
- Various sensors such as LM 35, IR sensor, MQ6 gas sensor, are used to provide the information regarding various characteristics.
- Hardware and software are integrated in such a way to provide imaging-based automatic inspection and analysis for such applications as automatic inspection, and robot guidance.

B. Future Scope

- The wall climbing robot is one kind of the special mobile robots. Because the workspace of this kind of robots is often on the vertical plane, not only does the wall climbing robot need to have the same locomotion mechanism as mobile robots.
- It also needs the special adhesion mechanism to support it to absorb on the vertical walls. Therefore, it is more challenging to develop a wall climbing robot that a mobile robot.
- To increase operation efficiency and protect human's health and safety in hazardous tasks makes the wall climbing robot very attractive.
- The climbing robot is widely applied in different industrial departments, such as the inspection and

maintenance of storage tanks in nuclear power plants and petrochemical enterprises, ship hull welding and cleaning, rescue robots for firefighting, the cleaning of high-rise buildings, etc.

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