DESIGN AND FABRICATION OF SEARCH AND RESCUE REMOTELY OPERATED GROUND VEHICLE (ROGV) FOR DISASTER RELIEF AND INSPECTION

A MAJOR PROJECT THESIS

Submitted by

ABHISHEK RAY (18ESIME200)

PRAKASH MISHRA (17ESIME018)

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IN

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Guided by

Mr. RAHUL MANDAL

Professor, Mechanical engineering

DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL AND CONSTRUCTION

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SHANKARA GROUP OF INTITUTIONS, JAIPUR

(Approved by AICTE & NCTE , Govt. of India)

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Signatureof the Supervisorwith date
Mr. RAHUL MANDAL
Professor
Department of Mechanical Engineering
Shankara Intitute of Technology
Kukas Jaipur, Rajashthan

Signatureof the HOD with date
Mr. SIKANDAR KHAN
Professor and Head
Department of Mechanical Engineering
Shankara Instiute of technology
Kukas Jipur , Rajashthan

CERTIFICATE OF EVALUATION

PROGRAM : Bachelor of Technology

BRANCH : Mechanical Engineering

SEMESTER VIII

Name of the Student ABHISHEK RAY
PRAKASH MISHRA

Title of the Project "DESIGN AND FABRICATION OF SEARCH AND RESCUE REMOTELY OPERATED GROUND VEHICLE (ROGV) FOR DISASTER RELIEF AND INSPECTION"

Name of the Guide Guide Name : Mr. RAHUL MANDAL

Designation: PROFESSOR

Department: MECHANICAL ENGINEERING

The report of the project work submitted by the above student in partial fulfillment for the award of Bachelor of Technology in Mechanical Engineering of Shankara Institute Of Technology for the Viva-voice examination held on / / has been evaluated and confirmed to the report of work done by the above student.

INTERNAL EXAMINER

Name:

Designation:

EXTERNAL EXAMINER

Name:

Designation:

Affiliation:

ABSTRACT

Human life faces natural disasters in various forms like earthquakes, tsunami, cyclones, etc. Though the frequency is very minimal, the subsequent loss is great and the recovery period large. There can also arise situations where inspection of an area may be required but it is life threatening to send human beings, like in mines or industrial buildings with leaked chemicals. Considering the impact on human life, a vehicle (robot) is planned to be developed which can be used for search and rescue, and inspection operations during such events. This vehicle is operated remotely using radio technology to control the vehicle's movement and direction. The ROGV is designed implementing a rocker-boogie mechanism to ease manoeuvring over uneven ground and unpredictable environments, capable to even climb stairs. It is fitted with a camera to monitor the path and explore the situation/environment around the vehicle which will be giving live video feed and can be recorded. There will also be infrared bulbs to aid the camera's vision in the dark or areas with low visibility. There is a thermal sensor added which can read the temperature from the environment to determine if there are any fires around, along with a gas sensor to detect the presence and concentration of LPG, propane, carbon-monoxide and smoke. Ultrasonic sensors will help the vehicle determine if there are any sudden drops (holes) that the vehicle could fall through in case the remote operator is unaware. The ROGV will be all terrain vehicle including manoeuvring over puddles of water which gives it amphibious properties. All telemetry data will be sent via radio to the controller which will store and display all sensor data to the remote operator. Keeping humans out of harm's way and collecting needed information can surely prove to be very useful.

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LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS	NOMENCLATURE
V	Volts
mV	milli Volts
V_{out}	sensor output voltage
°C	degrees Centigrade
$V_{25°C}$	Output voltage at 25°C
T	Time Taken
T_{trig}	HC-SR04 transmitted pulse time
T_{echo}	HC-SR04 received pulse time
V_{CC}	Loop voltage
V_H	Heater Voltage
R_L	Load Resistance
R_H	Heater Resistance
P_H	Heater consumption
R_S	Sensing resistance
S	Sensitivity
A	Slope
Ω	ohms
MHz	Mega Hertz (x 10^6)
GHz	Giga Hertz (x 10^9)
Cm	centimeter
M	meter
Km	kilometer
ppm	parts per million
ENA, ENB	Enable A and Enable B control lines
IN1, IN2, IN3, IN4	Input lines 1, 2, 3, 4

ABBREVIATION	NOMENCLATURE
PWM	Pulse Width Modulation
SPI	Serial Programmable Interface
LPG	Liquid Petroleum Gas
PA/LNA	Power Amplifier/Low Noise Amplifier
GPIO	General Purpose Input Output
USB	Universal Serial Bus
LoRa	Long Range
IP	Internet Protocol
DC	Direct Current
AC	Alternating Current

CHAPTER 1

INTRODUCTION

The purpose of this project is to inspect disaster hit areas, chemical leaked buildings, mines, and other industries for danger to human life. Inspection and relief are its main purpose. The prototype built can be used in many other situations where search and inspection can be an answer to the problem. An **unmanned ground vehicle** (**UGV**) is a vehicle that operates while in contact with the ground and without an onboard human presence. UGVs can be used for many applications where it may be inconvenient, dangerous, or impossible to have a human operator present. Generally, the vehicle will have a set of sensors to observe the environment, and will either autonomously make decisions about its behaviour or pass the information to a human operator at a different location who will control the vehicle through teleoperation.

The UGV is the land-based counterpart to unmanned aerial vehicles and unmanned underwater vehicles. Unmanned robotics are being actively developed for both civilian and military use to perform a variety of dull, dirty, and dangerous activities. Unmanned Ground Vehicle (UGV) is also called Remotely Operated Ground Vehicle (ROGV).

1.1 BACKGROUND

Millions of people are affected by natural disasters every year, and their impact can be calamitous. From the destruction of buildings to the spread of disease, natural disasters can devastate entire countries overnight. Tsunamis, earthquakes and typhoons do not just wreak havoc on land; they also disrupt people's lives in both densely populated cities and remote villages. A huge number among those affected by natural disasters constitute of the people who go missing during natural disasters. Another lot constitute of those who succumb to death who couldn’t be rescued on time. During any natural disaster the recovery time is much longer and so the chances of survival of trapped ones reduces.

Inspection of mines and other industrial buildings which pose danger to human health and lives is also becoming difficult with the increase in new types of health issues due to harmful substance in such areas. Putting a human life at risk for inspection is not something we can afford. Employing humans for inspection of certain sites can also be expensive compared to employing a ROGV.

1.2 OBJECTIVE

Our objective is to "DESIGN AND FABRICATION OF SEARCH AND RESCUE REMOTELY OPERATED GROUND VEHICLE (ROGV) FOR DISASTER RELIEF AND INSPECTION". This vehicle (robot) developed can be used for search and rescue, and inspection operations. This vehicle is operated remotely using radio technology to control the vehicle's movement and direction. The ROGV is designed implementing a rocker-boogie mechanism to ease manoeuvring over uneven ground and unpredictable environments, capable to even climb stairs. It is fitted with a camera to monitor the path and explore the situation/environment around the vehicle which will be giving live video feed and can be recorded. There will also be infrared bulbs to aid the camera's vision in the dark or areas with low visibility. There is a thermal sensor added which can read the temperature from the environment to determine if there are any fires around, along with a gas sensor to detect the presence and concentration of LPG, propane, carbon-monoxide and smoke. Ultrasonic sensors will help the vehicle determine if there are any sudden drops (holes) that the vehicle could fall through in case the remote operator is unaware. The ROGV will be all terrain vehicle including manoeuvring over puddles of water which gives it amphibious properties. All telemetry data will be sent via radio to the controller which will store and display all sensor data to the remote operator. Keeping humans out of harm's way and collecting needed information can surely prove to be very useful.

1.3 SCOPE

The ROGV can be employed in different situations depending upon the needs, search and rescue being its prime objective. The vehicle can also be employed in industries for inspection and surveillance. Inspection of buildings and installations with leaked harmful chemicals or areas which potentially pose danger to human lives can be inspected before sending humans. This bot can provide potentially useful sensor data that will help us understand the situation in a particular area. The increase in modernization and automation of industries also demands the upgradation of surveillance and inspection system. This bot can be a solution to that need.

Technological developments in sensors and remote-control technologies are propelling the demand of autonomous UGV. Teleoperated semi-automatic UGV is also gaining popularity in order to maintain higher degree of access. Industry participants are developing UGVs with advanced operational capabilities such as automatic and semi-automatic mode of operations. The small sized unmanned ground vehicles market will witness growth rate of more than 14% through 2026. Increasing requirement of small and medium sized UGV's to effectively perform operations where it is practically not possible for human is supporting the market growth. The figures Fig 1.1, Fig 1.2 and Fig 1.3 shows the current and future of UGV market. It also shows the increase in demand of Search and Rescue UGV and its predicted market size by 2026.

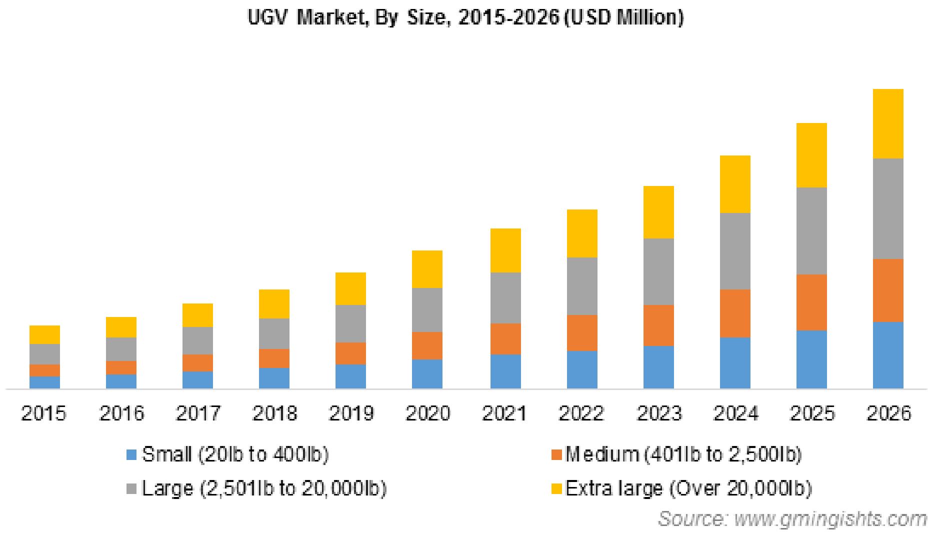

Fig 1.1 UGV Market, by Size, 2015- 2026.

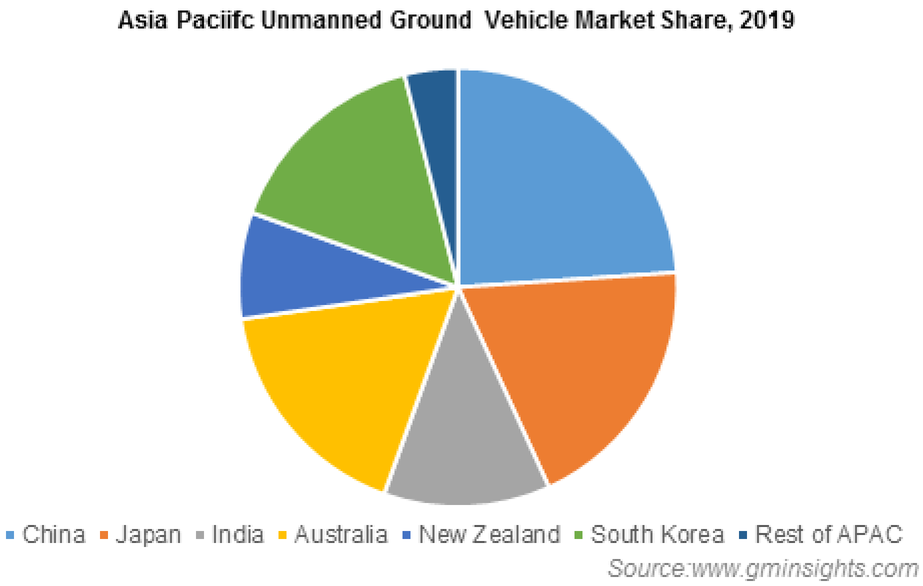

Fig 1.2 shows the Asia Pacific UGV market share in 2019.

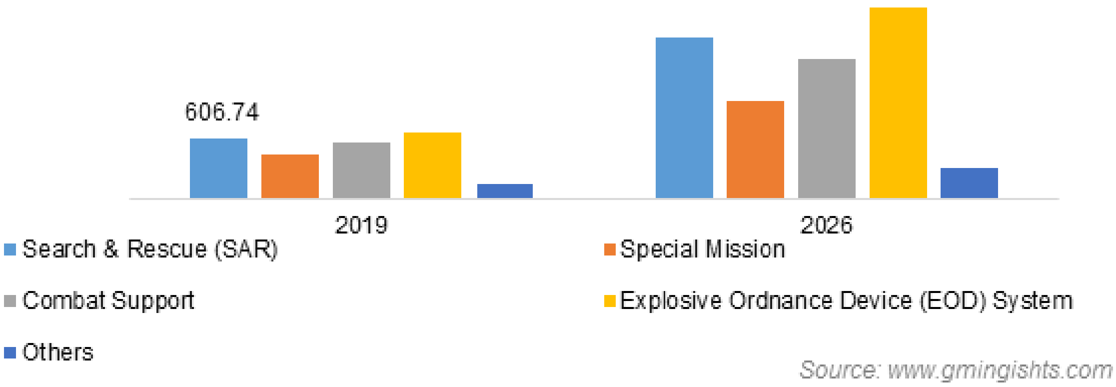

Fig 1.3 – UGV Market Size by Application, 2019 – 2026 (Million USD)

CHAPTER 2

LITERATURE REVIEW

2.1. Review of literature

Pradhan et al**.** (2013) in their study of the design and development of an automated all-terrain wheeled robot, observes a rapid progress in the field of robotics, and states that it is a good time to concentrate on the development of a robot that can work in all type of landscapes, ascend and descend stairs and sloping surfaces automatically. This paper presents details of a prototype robot which can navigate in very rough terrain, ascend and descend staircase as well as sloping surface and cross ditches. The robot is made up of six differentially steered wheels and some passive mechanism, making it suitable to cross long ditches and landscape undulation. Static stability of the developed robot has been carried out analytically and navigation capability of the robot is observed through simulation in different environment, separately. Description of embedded system of the robot has also been presented and experimental validation has been made along with some details on obstacle avoidance. Finally, the limitations of the robot have been explored with their possible reasons.

B. BABU et al. (2018) states that the Project work, “Rocker Bogie mechanism Geosurvey Rover” deals with the important aspect of improving the rover from its previous designs. The Geosurvey rover has to operate on rough and harsh environments for which it was designed but several factors restrict its operational capabilities, so the focus of our research is to overcome restrictions or to decrease it to within an acceptable range for its smooth performance. Our research on the restrictions of the rover conducted by our team focused mainly on the drive system and its drive modules which were not efficient, the linkage, the overturning or tilt range of the rover and the battery inefficiency from the other restrictions and problems that were obtained from the literature review and research so, we conducted research on how to improve that. The rover has been completely made from PVC to increase its capability to withstand shocks, vibrations and mechanical failures caused by the harsh environment where it is operated on. Using CAD software, the design of the rover has been fine-tuned and by experimenting with prototypes and models of the rover in the experimental setup of the live test, improvements and features were included into the Geosurvey rover. The result of the project was the implementation of independent directional control utilizing. minimum drive modules which increase the efficiency of the battery and increases the operating time of the rover, near zero tilt of the main body of the rover by self-balancing of the body counterweight method which decreases the tilt o rover turning percentage of the rover and its stability and finally by direct linkage of the various links comprising the rover which increases the loading capacity. Thus, the various improvements ensure structural, tilt stability, mechanical integrity and overall weight reduction and mechanical feasibility.

Szabo, et al**.** (2017) in their paper, says that the U.S. Army Laboratory Command, as part of its Robotics Initiative, Robotics Initiative, is developing a testbed for cooperative, real-time control of Geosurvey Rover. The system requires the development and integration of many elements which allow the vehicles to perform both autonomous and remotely functions. The National Institute of Standards and Technology is supporting this program by developing the vehicle control system using an architecture based on the Realtime Control System (RCS). RCS is a hierarchical, sensory-based control system, initially developed for the control of industrial robots and automated manufacturing systems. In this application, RCS controls all vehicle mobility functions, coordinates the operations of the other subsystems on the vehicle, and communicates between the vehicle and the remote to operator control station. This paper reviews the overall control system architecture and the design of the mobility and communication functions.

A. Fellan, et al. (2018) in the paper, "Enabling Communication Technologies for Automated Unmanned Vehicles in Industry 4.0", states that, within the context of Industry 4.0, mobile robot systems such as automated guided vehicles (AGVs) and unmanned aerial vehicles (UAVs) are one of the major areas challenging current communication and localization technologies. Due to stringent requirements on latency and reliability, several of the existing solutions are not capable of meeting the performance required by industrial automation applications. Additionally, the disparity in types and applications of unmanned vehicle (UV) calls for more flexible communication technologies in order to address their specific requirements. In this paper, we propose several use cases for UVs within the context of Industry 4.0 and consider their respective requirements. We also identify wireless technologies that support the deployment of UVs as envisioned in Industry 4.0 scenarios.

CHAPTER 3

METHODOLOGY ADOPTED

3.1 MECHANICS

3.1.1 Rocker-bogie mechanism

3.1.1.1 Basic description

The rocker-bogie system is the suspension arrangement developed in 1988 for use in NASA's Mars rover Sojourner, and which has since become NASA's favoured design for rovers. It has been used in the 2003 Mars Exploration Rover mission robots Spirit and Opportunity, on the 2012 Mars Science Laboratory (MSL) mission's rover Curiosity, and the Mars 2020 rover Perseverance.

The "rocker" part of the suspension comes from the rocking aspect of the larger, body-mounted linkage on each side of the rover. These rockers are connected to each other and the vehicle chassis through a differential. Relative to the chassis, the rockers will rotate in opposite directions to maintain approximately equal wheel contact. The chassis maintains the average pitch angle of both rockers. One end of a rocker is fitted with a drive wheel, and the other end is pivoted to the bogie.

The "bogie" part of the suspension refers to the smaller linkage that pivots to the rocker in the middle and which has a drive wheel at each end. Bogies were commonly used as load wheels in the tracks of army tanks as idlers distributing the load over the terrain, and were also quite commonly used in trailers of semi-trailer trucks. Both tanks and semi-trailers now prefer trailing arm suspensions.

The term “rocker” describes the rocking aspect of the larger links present each side of the suspension system and balance the bogie as these rockers are connected to each other and the vehicle chassis through a modified differential. In the system, “bogie” refers to the conjoining links that have a drive wheel attached at each end. Bogies were commonly used to bare loading as tracks of army tanks as idlers distributing the load over the terrain. Bogies were also quite commonly used on the trailers of semitrailer trucks as that very time the trucks will have to carry much heavier load. As accordance with the motion to maintain centre of gravity of entire vehicle, when one rocker moves upward, the other goes down. The chassis plays vital role to maintain the average pitch angle of both rockers by allowing both rockers to move as per the situation.

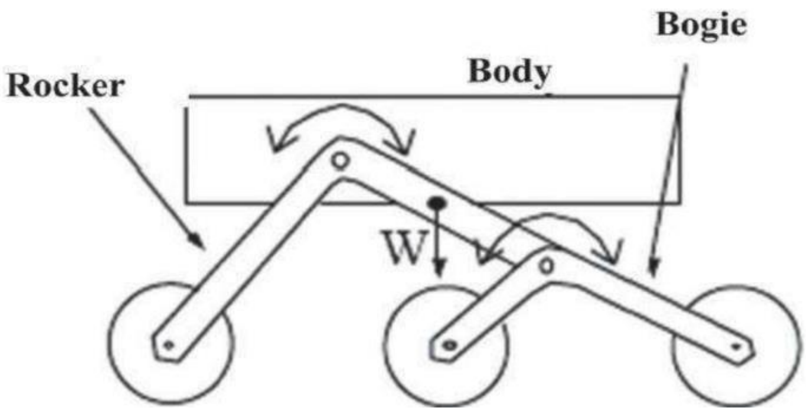

Fig 3.1 – Line diagram of Rocker Bogie Mechanism

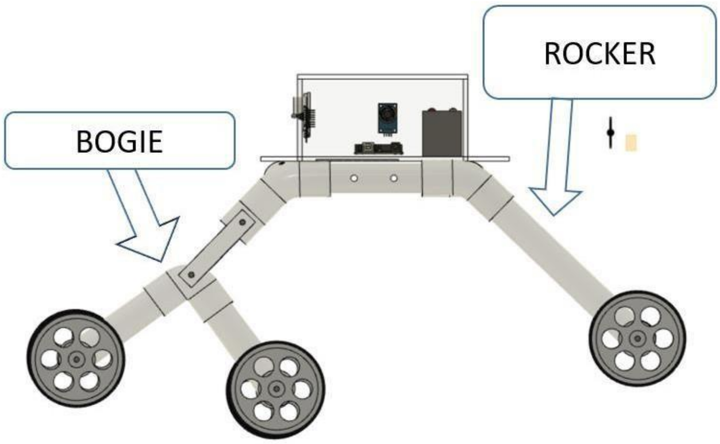

Fig 3.2– 3D Model of Intended Design

Fig 3.3 – Prototype image showing Rocker Bogie Mechanism

3.1.1.2 Advantages

1. The design incorporates independent motors for each wheel. There are no springs or axles, making
2. The design simpler and more reliable.
3. Rocker Bogie Suspension can withstand a tilt of at least 500 in any direction without overturning,
4. Which is the biggest advantage of heavy loaded vehicle.
5. It can move in harsh environment
6. It can work in place which are beyond human reach
7. Rocker Bogie consisting of no spring and stub axle in each wheel which allows the chassis to climb
8. Over any obstacles such as rocks, ditches, sands etc. That are upto double the wheels diameter in size

While keeping all the wheels on ground for maximum time.

3.1.2 Amphibious nature

Water proofing of electronics

The ROGV is partly amphibious in nature. By amphibious nature of implies that it will be capable of operating in small puddles is water. Waters with high current may not be suitable for the bot.

In this ROGV the majority of the electronics components is housed in a single waterproof compartment made of acrylic sheets. Many sensors are used in this bot. The sensors protrude out of the box through holes made on the acrylic sheets. The protruding sensors are projected by the top lid which extends forward. The holes made are waterproofed and secured from water entering the compartment. The box is mounted high to prevent the contact of electronics components with water. Epoxy putty has been used to make the electronics compartment waterproof. All the gaps have been covered.

Waterproofing of motors

Since the motors he's been situated very low or becomes very important to waterproof the motors properly.

The motors have been waterproofed using wax, hot melting adhesives (HMA, Glue Gun) and insulation tape.

The gear box of the motors was first opened and waterproofed using HMA, wax was used to cover the shaft end of the motor. The wired end was first cleaned thoroughly. Multiple layers of HMA were deposited on the wired end. After having the motors secured from all sides it was covered with insulation tape to prevent the wax and HMA from getting damaged. Now the motor has been secured and can be used in water without getting damaged.

Empty tetra pack juice bottles have been used as float material. These tetra pack has caps and doesn’t allow water to enter inside. The cuboid shape allows us to fix them to the rover easily. The tetra pack has been covered with another layer of heat shrinking plastic.

CHAPTER 4

DESIGN AND CALCULATION

4.1 DECIGN CALCULATION FOR ROCKER BOGIE MECHANISM

Design calculations for rocker bogie mechanism is based on Pythagoras Theorem. The Fig 4.1 shows the points A, B, C, M & N.

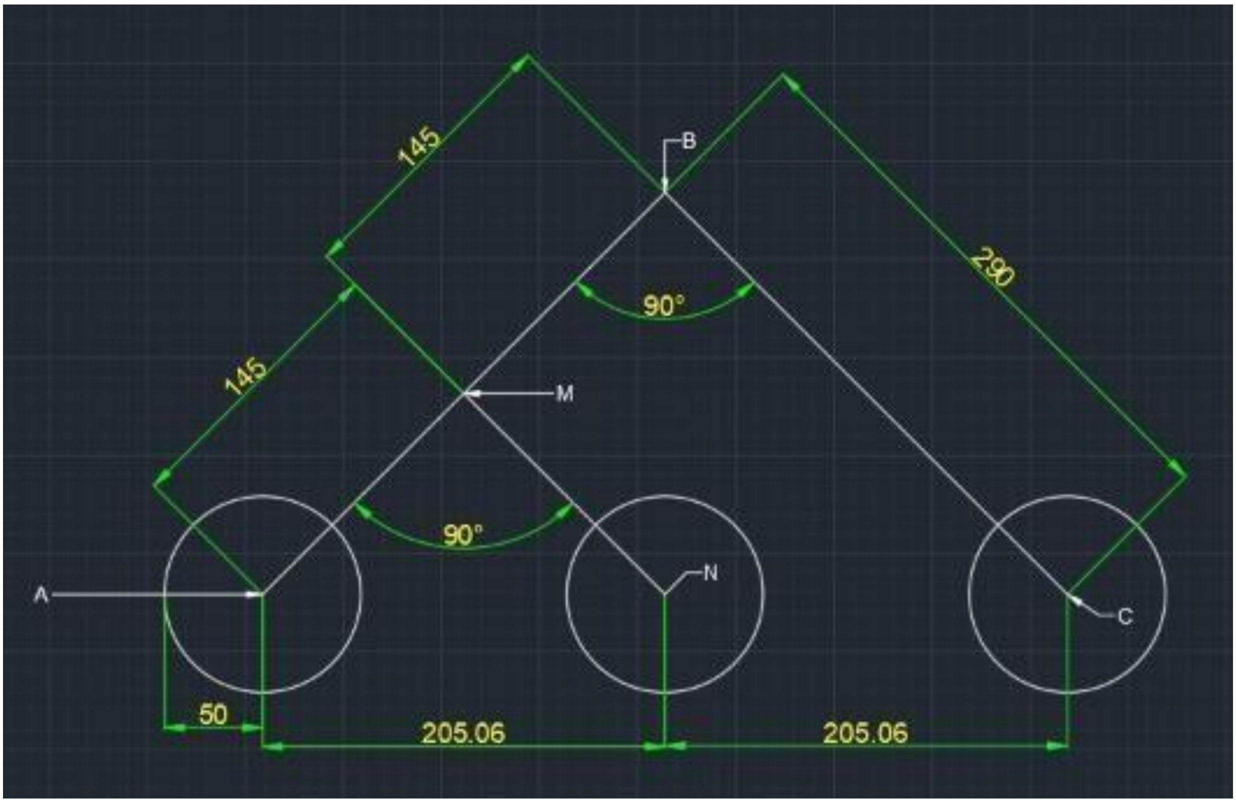

Fig 4.1 – Line diagram for design calculations for Rocker Bogie Mechanism

Wheel diameter = 100 mm

- If horizontal length of stairs is 280 mm
- Then wheel base = horizontal length of stairs – (Rf + Rr)
- Rf = radius of front wheel
- If horizontal length of stairs is 280 mm
- Then wheel base = horizontal length of stairs – (Rf + Rr)
- Rr = radius of rear wheel
- So, wheel base = 280 – (50+50)
- Wheel base = 180 mm

- Let $\theta = 45^0$
- In Triangle BNC, Angle BNC = 90^0
- Angle NBC = Angle NCB = 45
- Therefore, NC = NB
- $NC^2 + NB^2 = BC^2$ (from Pythagoras theorem)
- $BC^2 = 2(NC^2)$ ……. (1)
- $= 2(205^2)$
- BC = 205.5 mm
- Rounding off to 206 mm

Substituting in eqn (1) we get,

- $390^2 = 2(NC^2)$
- NC = 205.5 mm
- Also,
- NC = AN = 205.5 mm
- In Triangle AMN, angle AMN = 90^O
- $AM^2 + MN^2 = AN^2$
- $2(AM^2) = AN^2$
- AM = 145 mm

  - Now due to symmetry
- AM = MN =115 mm
- BM = AB – AM
- = 290-145 mm
- BM = 145 mm

Height of RBM

- $Height^2 = BC^2 – NC^2$
- $Height^2 = 290^2 – 205.5^2$
- Height = 205.5 mm
- Net Height = Height + radius of wheel
- = 206 + 50= 256 mm
  - BM = 145 mm

4.2 CAD MODEL

The CAD model was prepared using the software Autodesk Fusion 360. The 2D CAD Drawing and different views of the model i.e the top view, front view, side view, back view has been shown in Figures 4.2, 4.3, 4.4, 4.5, 4.6 and 4.7. The prototype and the model prepared is very similar.

1. **Top View**

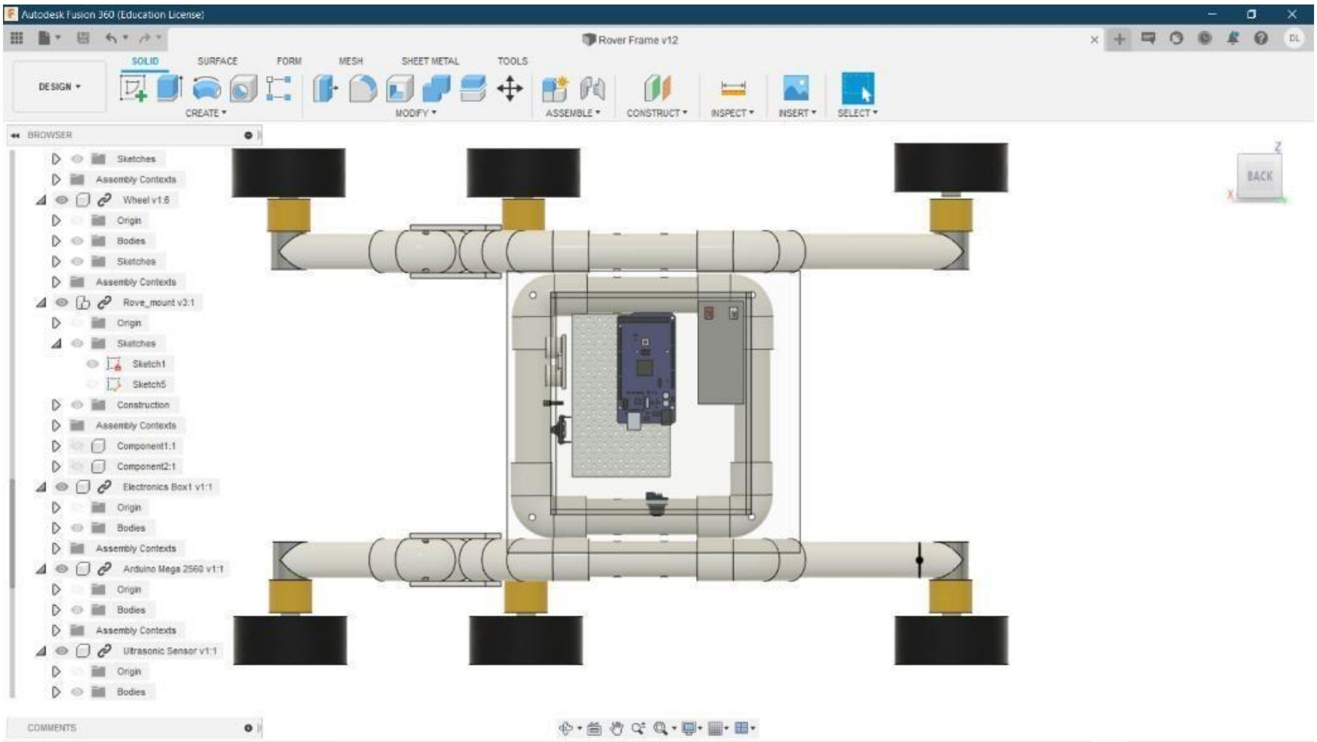

Fig 4.2. Top View of the CAD Model

2. Front View

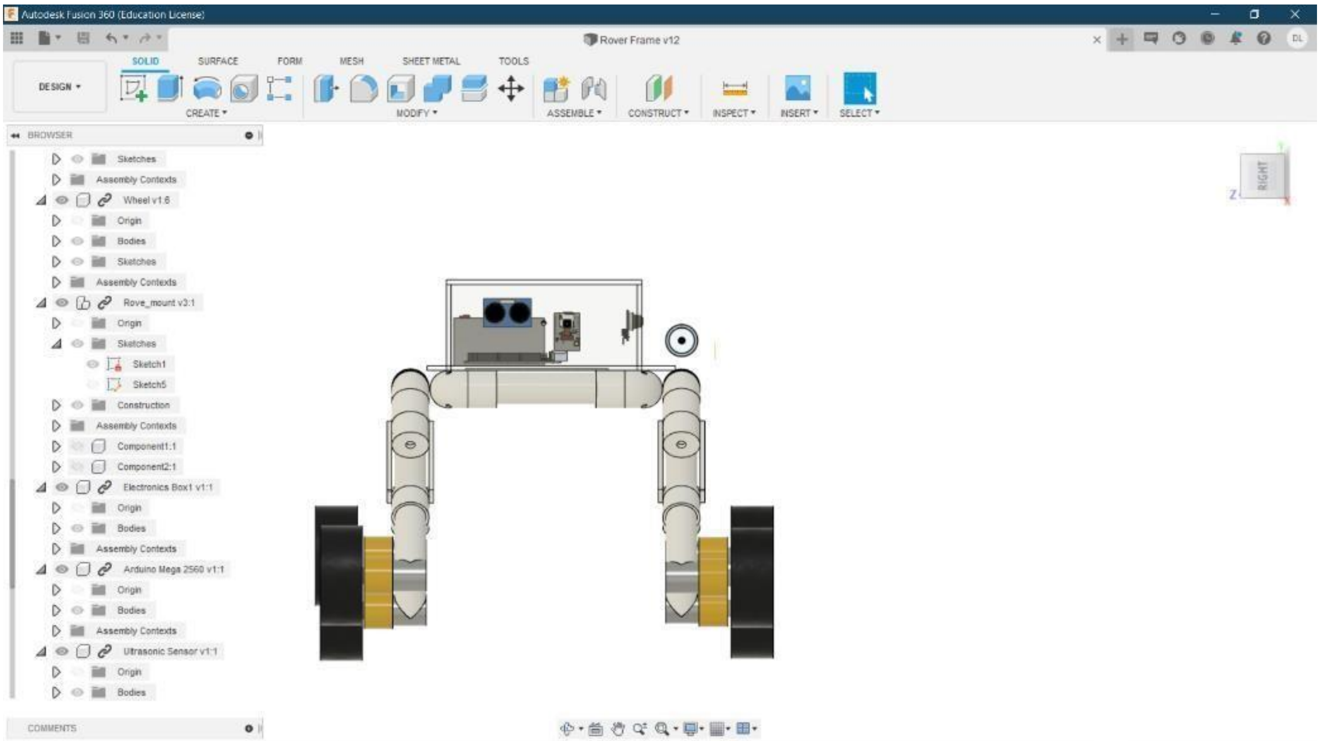

Fig 4.3 – Front View of CAD model

3. Back View

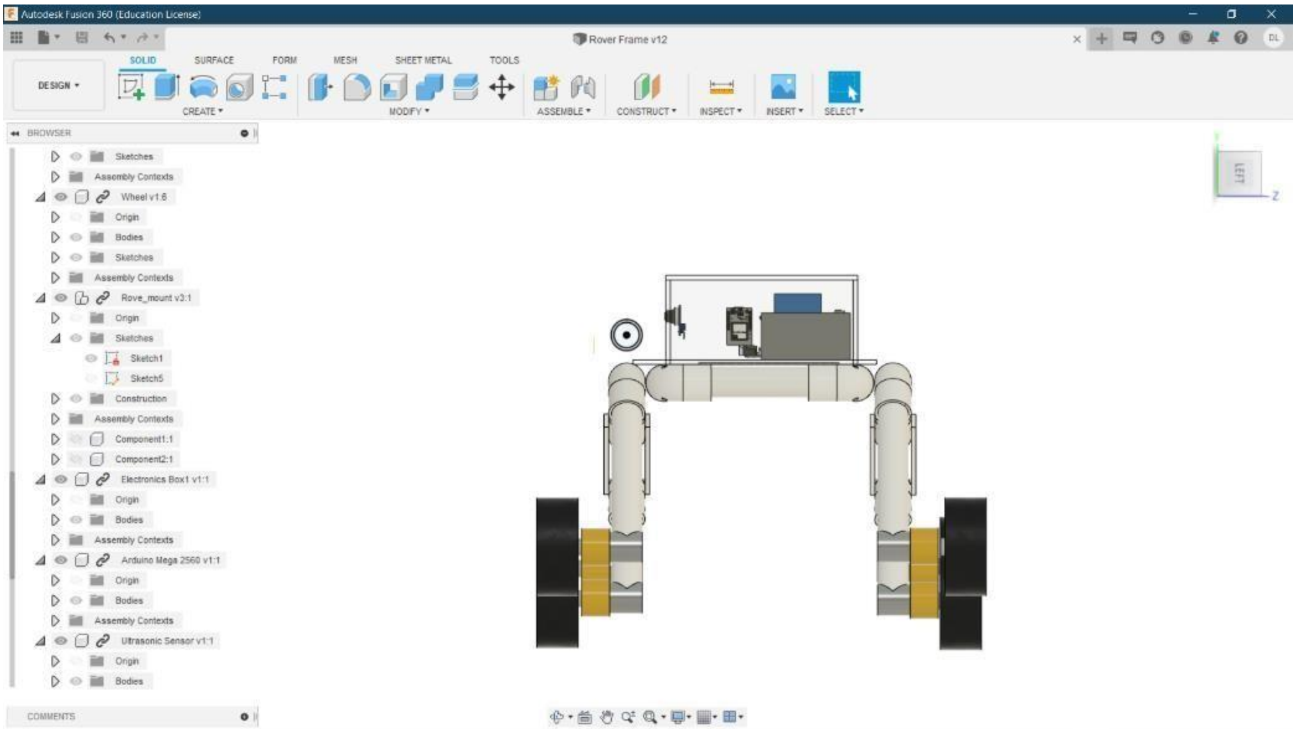

Fig 4.4 Back View of CAD Model

4. Side View

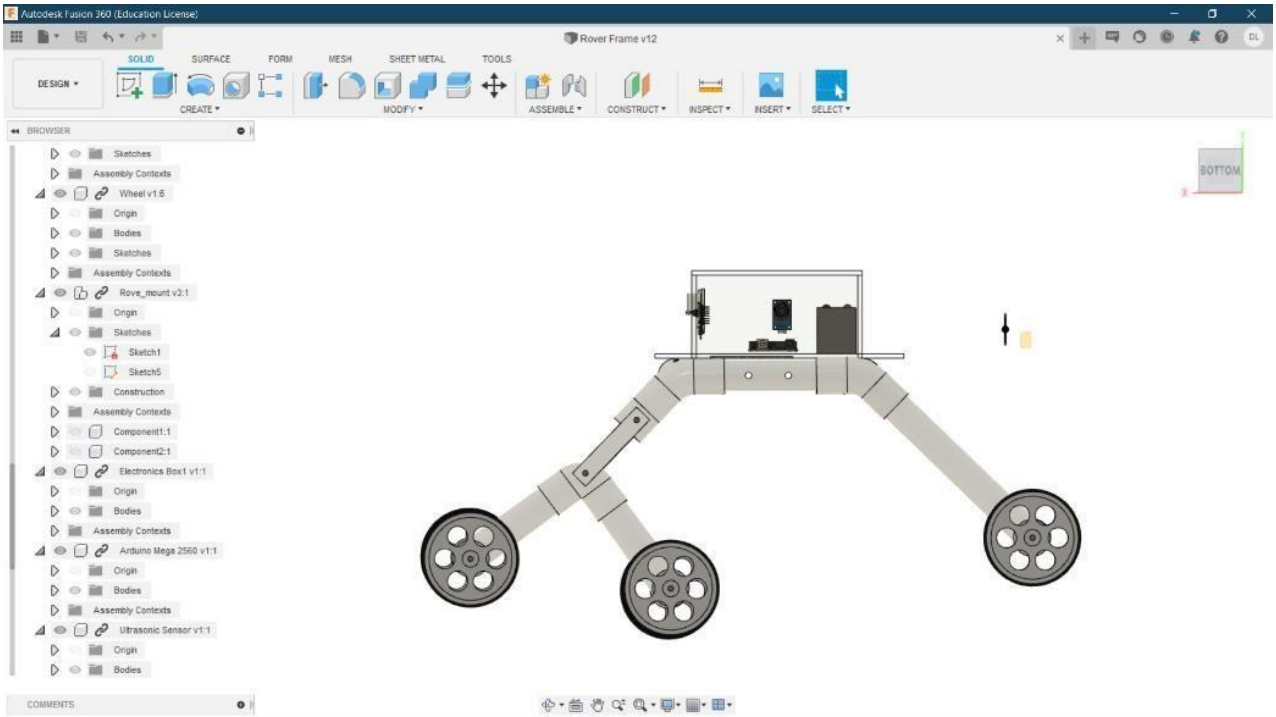

Fig 4.5 – Side View of CAD Model.

5. 3D CAD Model

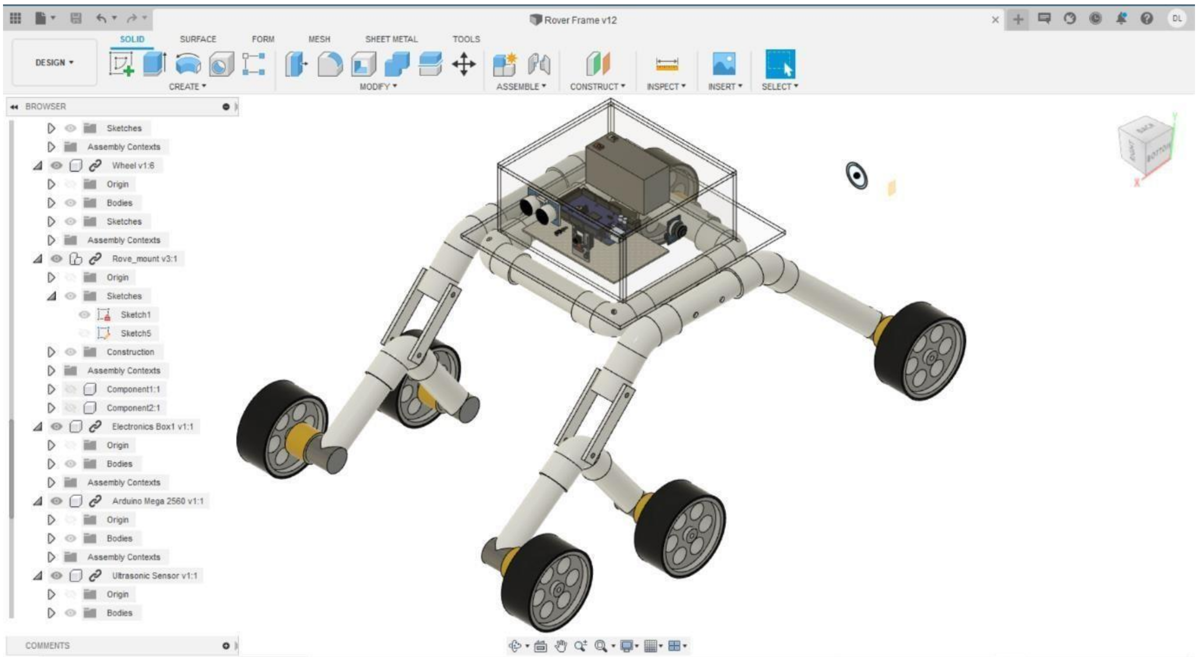

Fig 4.6 – 3D CAD Model

4.3 DESIGN AND CALCULATIONS FOR CONTROL AND SENSOR SYSTEMS

4.3.1 Code structure

The raspberry pi pico microcontroller can be programmed using micro-python or C++ language. As micro-python is much simpler the microcontroller has been programmed in micro-python. The code has been divided into two sections for both the remote as well as the rover. Since the pi pico is a dual-core processor we have implemented a multi-threaded programming approach to distribute computing power and save time.

ROVER:

The rover code is mainly comprised of the communication instructions, motor control and reading sensor values. As the sensor require calculations to convert the readings into readable values, the code for reading sensor data, computing and updating environment variables is run on the second core, while the first core deals with receiving of the motor control data, sending the control data to the motor controller and then sending the sensor data to the controller after computing its values.

Rover_main.py *

```
#Run second core for sensor data and calculations
def sensor_data_thread():
    #Call global variables inside thread to be able to modify it
    global rover_sys_temp, environment_temp, distance, lpg_level
    #Thread progam
    while True:
        #system and external environment temperature
        sys_voltage = sys_temp.read_u16() * conversion_factor
        rover_sys_temp = int(27 - (sys_voltage/1000 - 0.706) / 0.001721)
        ext_voltage = int(ext_temp.read_u16() * 1750/65535)
        environment_temperature = int((ext_voltage) / 10)
        #ultrsonic sensor data
        distance = int(get_distance())
        #gas sensor data
        LPG_levels = getLPGData()
        CO_levels = getCOData()
        SMOKE_levels = getSmokeData()
        utime.sleep(0.5)
#Starting thread to run on core 2
_thread.start_new_thread(sensor_data_thread, ())

#Ultrasonic sensor distance calculator
def get_distance(timer):
    trigger.high()
    utime.sleep_us(10)
    trigger.low()
    while echo.value() == 0:
        start = utime.ticks_us()
    while echo.value() == 1:
        stop = utime.ticks_us()
    duration  = stop - start
    distance = (duration * 0.0343)/2
    #print("Distance", distance, "cm")
    return distance
timer.init(freq = 2, mode = Timer.PERIODIC, callback = get_distance)
```

Fig 4.7 – Code showing Multi-threaded programming for Rover

REMOTE:

A similar multithreaded programming approach is used for the remote as well. The primary core (first core) deals with all the communication between the rover and the remote, i.e., to send motor control data and receive the sensor values. The first core also reads the joystick analog values and scales it down to reduce the noise, and this data is further sent to the rover.

The second core is used for printing the sensor data variables on the screen. And also alerting the remote operator if any sensor values reach a certain threshold.

Remote_main#.py

```
_SLAVE_SEND_DELAY = const(10)

if sys.platform == "rp2":
    cfg = {"spi": 0, "miso": 4, "mosi": 7, "sck": 6, "csn": 15, "ce": 14}
else:
    raise ValueError("Unsupported platform {}".format(sys.platform))
pipes = (b"\xe1\xf0\xf0\xf0\xf0", b"\xd2\xf0\xf0\xf0\xf0")
#nrf24l01 set-up
def set_up():
    csn = Pin(cfg["csn"], mode=Pin.OUT, value=1)
    ce = Pin(cfg["ce"], mode=Pin.OUT, value=0)
    nrf = NRF24L01(SPI(cfg["spi"]), csn, ce, payload_size=32)
    # enable auto-ack on all pipes
    nrf.reg_write(0x01, 0b11111000)
    nrf.open_tx_pipe(pipes[0])
    nrf.open_rx_pipe(1, pipes[1])
    nrf.start_listening()
    led_start.value(0)
    led_on.value(0)
    return nrf
#Running second core to calculate and print telemetry data
def sensor_data_thread():
    global rover_sys_temp, obstacle_distance, lpg_level, ext_temp
    while True:
        #Calculating raw sensor data to readable output
        reading = sys_temp_read.read_u16() * conversion_factor
        temperature = 27 - (reading - 0.706)/0.001721
        alert = False
        if obstacle_distance >= 500:
            alert = True
        #PRINTING SENSOR DATA
        print("                  REMOTE DATA...")
        print("SYSTEM TEMPERATURE:          ", temperature, "*C")
        print("SELECTED SPEED:              ", speed)
        #print()
        print("                  ROVER DATA...")
```

Fig 4.8 – Code showing Multi-threaded programming for Remote

4.4 ROVER SYSTEM DESIGN:

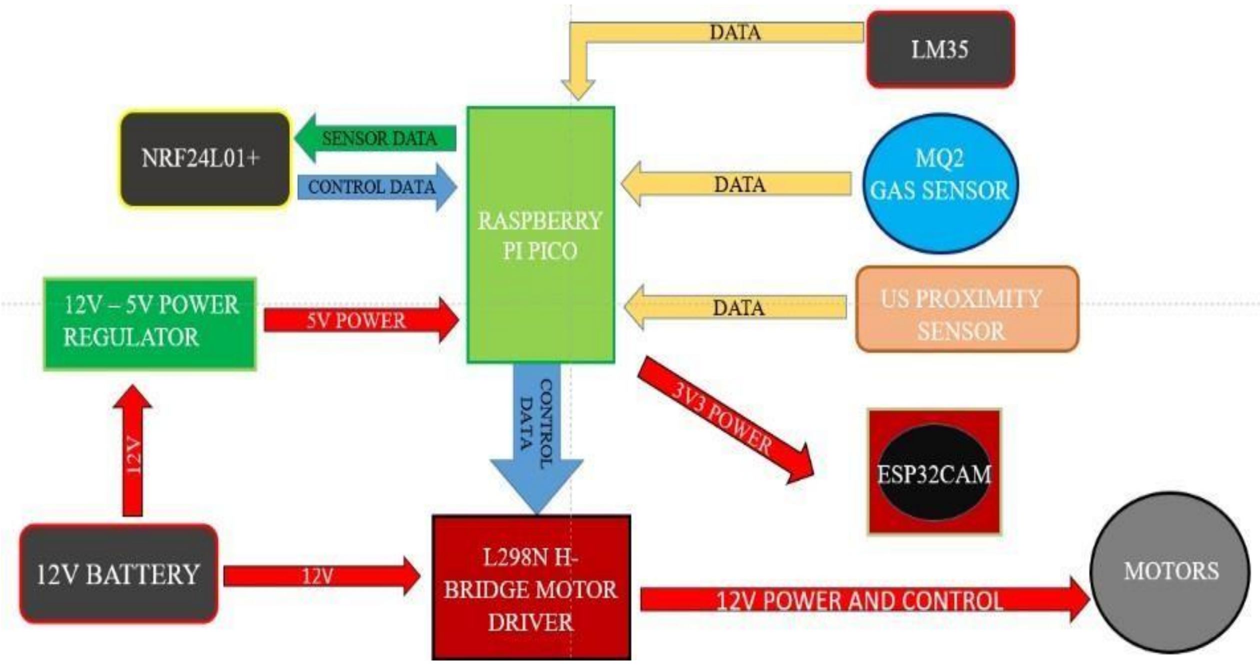

Fig 4.9 – Rover System Design Flow Chart

4.4.1 Sensor calculations:

A. TEMPERATURE:

The LM-35 temperature sensor is transistor type sensor, who's voltage changes with respect to rise in temperature. The higher the temperature the higher the voltage output. The following table shows the technical data for the LM35 Temperature sensor. Refer table/figure 4.10.

Table 4.1 Showing technical data for LM35

PARAMETER	TEST CONDITIONS		LM35			LM35C, LM35D			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
Accuracy, LM35, LM35C[1]	$T_A = 25°C$			±0.4			±0.4		°C
		Tested Limit[2]			±1			±1	
		Design Limit[3]							
	$T_A = –10°C$			±0.5			±0.5		
		Tested Limit[2]							
		Design Limit[3]						±1.5	
	$T_A = T_{MAX}$			±0.8			±0.8		
		Tested Limit[2]			±1.5				
		Design Limit[3]						±1.5	
	$T_A = T_{MIN}$			±0.8			±0.8		
		Tested Limit[2]							
		Design Limit[3]			±1.5			±2	
Accuracy, LM35D[1]	$T_A = 25°C$						±0.6		°C
		Tested Limit[2]						±1.5	
		Design Limit[3]							
	$T_A = T_{MAX}$						±0.9		
		Tested Limit[2]							
		Design Limit[3]						±2	
	$T_A = T_{MIN}$						±0.9		
		Tested Limit[2]							
		Design Limit[3]						±2	
Nonlinearity[4]	$T_{MIN} \le T_A \le T_{MAX}$, $–40°C \le T_J \le 125°C$			±0.3			±0.2		°C
		Tested Limit[2]							
		Design Limit[3]			±0.5			±0.5	
Sensor gain (average slope)	$T_{MIN} \le T_A \le T_{MAX}$, $–40°C \le T_J \le 125°C$			10			10		mV/°C
		Tested Limit[2]			9.8				
		Design Limit[3]						9.8	
				10			10		
		Tested Limit[2]			10.2				
		Design Limit[3]						10.2	
Load regulation[5] $0 \le I_L \le 1$ mA	$T_A = 25°C$			±0.4			±0.4		mV/mA
		Tested Limit[2]			±2			±2	
		Design Limit[3]							
	$T_{MIN} \le T_A \le T_{MAX}$, $–40°C \le T_J \le 125°C$			±0.5			±0.5		
		Tested Limit[2]							
		Design Limit[3]			±5			±5	

Fig 4.10 Showing technical data for LM35

It can be powered between 4V – 20V.

The max output signal of the LM-35 temperature sensor is 1750mV,

Max output voltage,

V_{out} = 1750mV

As the anolog input pins of the pi pico are 12-bit, we will have a maximum read value of,

$2^{12} = 4096$,

However, the pi-pico is capable of internally converting the 12-bit read into a 16-bit value,

Hence, we have,

Max Read Value = 65535, *

[* $2^{16} = 65536$, read width is 65536 but since 0 is included the max value is 65535]

Now a conversion factor is to be calculated which will give us the current sensor reading in millivolts.

Conversion factor = V_{out} / (Max Read Value)

Conversion factor = 1750 / 65535

The LM-35 has a linear slope of +10mV per degree rise in temperature (10mV/ °C)

At 25°C, the sensor output 250mV,

$V_{25°C}$ = 250mV

Thus, to get the current temperature value,

Temperature = (25 + (($V_{25°C}$ – (Analog Read Value * Conversion factor)) / 10)) °C

B. PROXIMITY:

The HC-SR04 is an ultrasonic transducer that sends out pulses of ultrasonic sound and receives the reflected pulses when there is an obstacle in front of it.

The working of this sensor is relatively simple, we just have to measure the time taken for the sound to be received after being transmitted.

Let ‘T’ be the time taken between the transmitted and received sound, ‘C’ be the speed of sound in air at 25°C, the time taken when the pulse is sent out is ‘T_{trig}’ and the time at which it is received is ‘T_{echo}’,

$$T = T_{echo} – T_{trig}$$

Thus, the distance to be calculated is given by,

$$Distance = (T * C) / 2$$

The distance is halved as the path the sound travels to the object and back is twice the distance from the transmitter.

C. GAS SENSOR:

The MQ-2 gas sensor is metal-oxide semiconductor sensor. Its sensing element is a filament of SnO_2 which has lower conductivity in thin air. When a flammable gas is present, the resistance of the sensing material, i.e., SnO_2 decreases, thus increasing the output voltage.

The following **table 4.2** shows the technical data of the sensor and the reading thus obtained are derived from the graph shown below in **figure 4.11 & 4.12.**

Table 4.2 – Technical data for MQ-2 Gas Sensor

Model No.			MQ-2
Sensor Type			Semiconductor
Standard Encapsulation			Bakelite (Black Bakelite)
Detection Gas			Combustible Gas and Smoke
Concentration			300 – 10000 ppm (Combustible Gas)
Circuit	Loop Voltage	V_{CC}	≤ 24V DC
	Heater Voltage	V_H	5.0V ± 0.2V AC or DC
	Load Resistance	R_L	Adjustable
Character	Heater Resistance	R_H	31Ω + 3Ω (Room temperature)
	Heater Consumption	P_H	≤ 900mW
	Sensing Resistance	R_S	2k Ω - 20k Ω (in 2000ppm C_3H_8)
	Sensitivity	S	R_S (in air)/ R_S (1000ppm isobutane) ≥ 5
	Slope	α	≤ 0.6 ($R_{5000ppm}$ / $R_{3000ppm}$ CH_4)
Condition	Temp. Humidity		20˚C ± 2˚C ; 65% ± 5% R_H
	Standard test circuit		V_{CC}: 5.0V ± 0.1V; V_H: 5.0V ± 0.1V
	Preheat time		Over 48 hrs

Sensitivity Characteristics

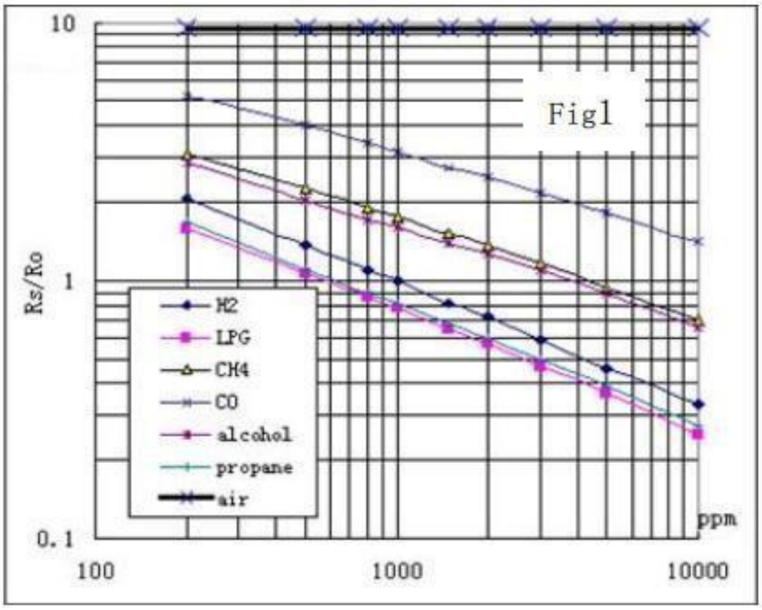

Fig 4.11 – Graph Gas Concentration VS Filament Resistance

Influence of Temperature/Humidity

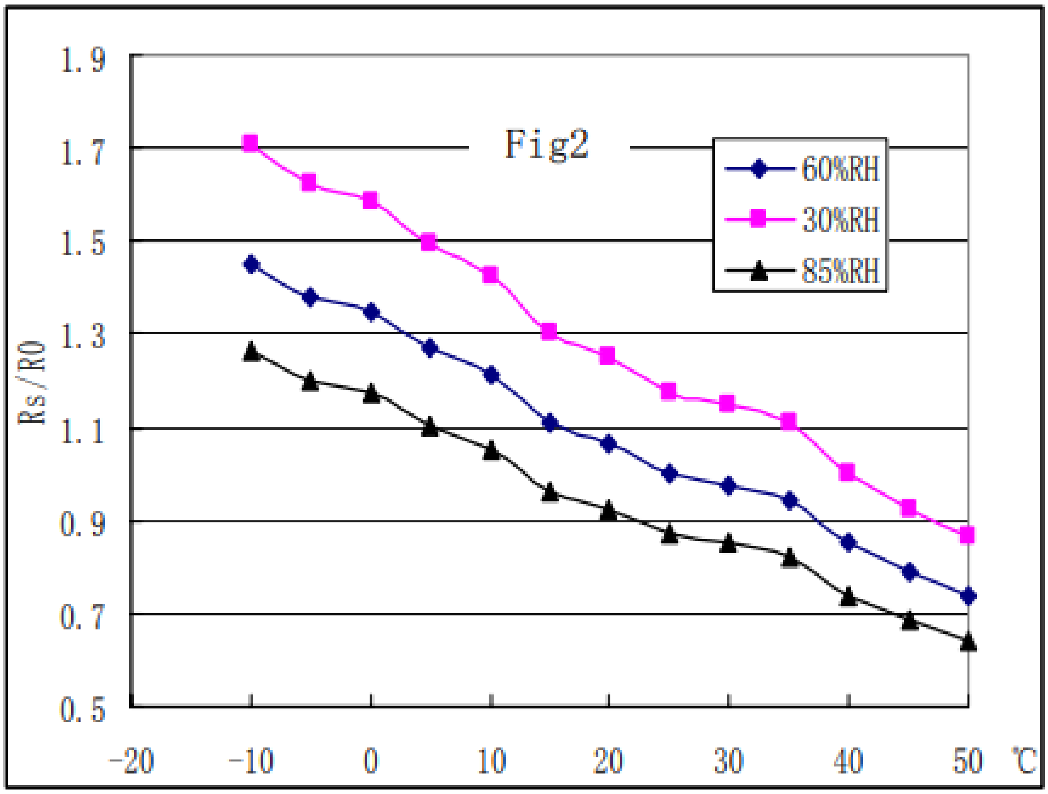

Fig 4.12 - Graph Humidity/Temperature VS Filament Sensitivity

The above is basic test circuit of the sensor. The sensor needs to be given 2 voltages, heater voltage V_H and test voltage V_{cc}. V_H used to supply certified working temperature to the sensor, while V_{cc} used to detect voltage V_{RL} on load resistance R_L whom is in series with sensor.

The sensor has light polarity, V_{cc} need DC power. V_{cc} and V_H could use same power circuit with precondition to assure performance of sensor. In order to make the sensor with better performance, suitable R_L value is needed:

Power of Sensitivity body (P_s): $P_s = V_{cc}^2 \times R_s / (R_s + R_L)^2$

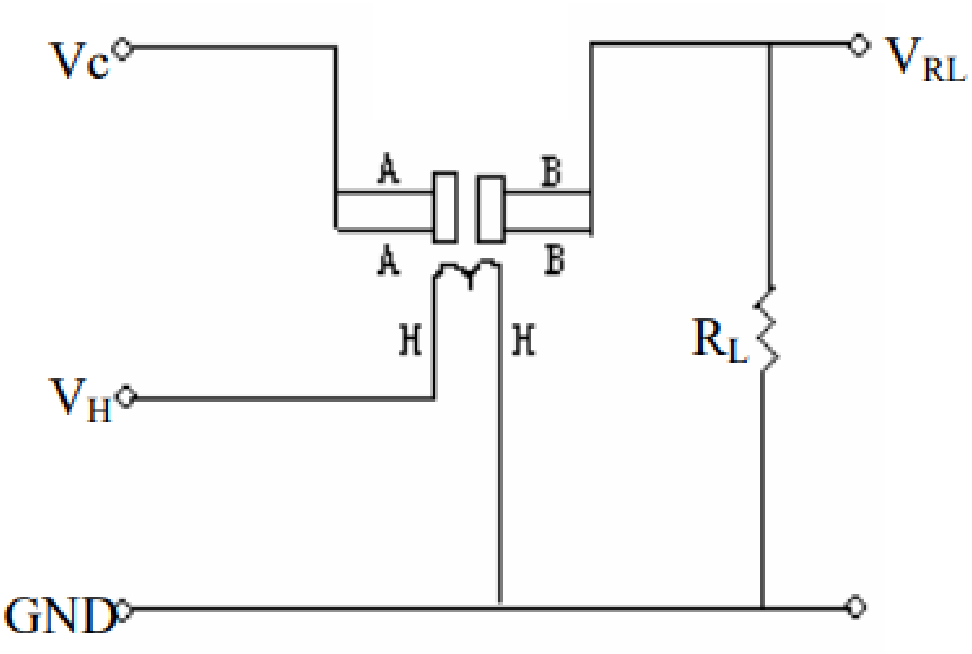

Fig 4.13 – MQ2 Sensor Circuit Diagram

CHAPTER 5

EXPERIMENTAL SET-UP AND PROCEDURE

5.1 EXPERIMENTAL SETUP MECHANICS

The designed prototype was made in a laboratory and all the work was done completed using basic tools used in CDIO Laboratory in the university.

5.1.1 Materials used

SL NO	ITEM	SPECIFICATION	QUANTITY
1	PVC pipes	1 Inch (diameter)	6 meters
2	PVC Joints	120^o	4
3	PVC Joints	90^o	2
4	Acrylic Sheet 2 m^2	5 mm Thickness	2m^2
5	L Joint	25 mm	10
6	Nuts and Bolts	-	40
7	Screws	-	10
8	Washer	-	35
9	Wheels	100 mm Diameter	6
10	Ring Clamps	-	6

Table 5.1 – Materials used

5.1.2 Tools and machinery used

1. Drilling machine
2. Drill-bits of different sizes
3. Grinding machine
4. File
5. Mallet
6. Hand cutter
7. Hammer
8. Table vice
9. Hacksaw

5.2 EXPERIMENTAL SETUP ELECTRONICS CONTROL AND COMMUNICATION SYSTEMS:

5.2.1 Communication: RADIO

The main mode of communication between the remote operator and the ROGV will be through radio technology. Radio waves have a longer wavelength and offer more reliable transmission of data over long distances, without much loss of the transmitted data. Various electronic modules operating with this technology are available in the market. They operate in a variety of standard communication bands like 433MHz, 900MHz and 2.4GHz used by the respective popular modules used, 433MHz standard rf modules, LoRa Modules and NRF24L01 radio modules.

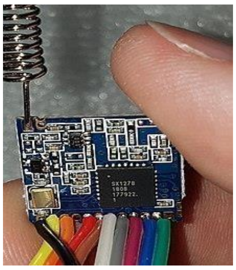

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Fig 5.1 – 433MHz Radio Module   Fig 5.2 – NRF24L01+   Fig 5.3 - LoRa Module

The module chosen for this design is the NRF24L01+ (PA+LNA) (Power Amplifier and Low Noise Amplifier). This module is one of the very few modules that offer full-duplex communication capabilities, i.e., a single module can transmit as well as receive data over two different communication pipes. **Fig 5.2**. Other radio devices mentioned earlier have separate modules for transmitting and receiving data, which makes them half duplex. **Fig 5.1 & Fig 5.3.** To sever the purpose of the ROGV, for it to be able to receive control data and send back data from the environment around it using sensors, the NRF24L01+ module was chosen.

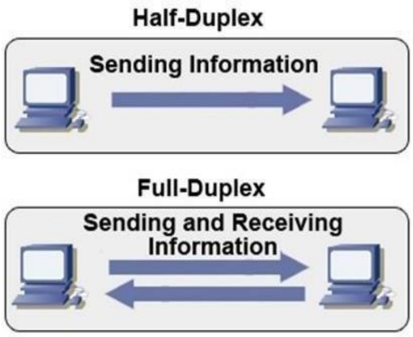

Fig 5.4 – Half duplex vs full duplex communication

This module comes in a few different form factors varying in communication ranges from 30m upto 1km in open air. The chosen module is named 'PA+LNA', meaning it has a power amplifier as well as a low noise amplifier, to boost the transmit signal and range through the antenna and amplify the incoming received signal respectively.

The communication between the remote operator the rover is divided into two pipes, one pipe for sending control signals to the rover which is the receiving pipe for the rover, and the other pipe is for sending sensor data from the rover to the receiving remote. Each pipe here specifies a path for the data to be transmitted in one direction, i.e., either sending or receiving for either module.

5.2.2 Sensors:

5.2.2.1 Camera

The camera mounted on the rover will stream live video data to the remote operator. A WiFi module fitted with an OV2460 camera, is used to get the video data and transmit it to a web server with a specific I.P. address. Access to this web address through a browser will give the remote operator options to change the camera's video quality and also view live video footage.

The OV2460 is a 2 megapixels camera that is embedded onto the ESP32CAM board. A decent video quality stream can be achieved using this module. It can be supplied with two voltage levels, 5V and 3.3V, 3V3 volt being the primary operating voltage though a preferred voltage of 5V is supplied as this makes it more stable during operation.

Fig 5.5 – ESP32 CAM module

5.2.2.2 Proximity sensor

The HC-SR04 proximity sensor is an ultrasonic transducer that sends out pulses of ultrasonic sound waves and detects the reflected sound at the receiver. The time taken between the transmitted pulse and the received sound is measured and the distance is calculated by multiplying the speed of sound with the time taken and then making it half as the distance is doubled when considering both the transmitter and receiver.

Fig 5.6 - HC-SR04 Proximity Sensor

The camera will be able to give the remote viewer a decent view of the environment around the rover, however the remote operator may not be able to see the ground at that point of time during inspection. While looking around for example, in some damaged building, there may a portion of the floor that has collapsed. In this case the remote operator may not be able to see the ground if he is looking at something else, and the proximity sensor can give a warning about the lack of ground and stop the vehicle for safety. The sensor can also give the operator an alert about any obstacle too close to the rover.

5.2.2.3 Temperature sensor

A thermal sensor with a range of -150°C to 150°C is fitted onto the rover to sense environment temperature. This information will be sent back to the rover through radio. The analog output of this sensor is connected to the analog input of the microcontroller. Based on the microcontroller’s operating size off analog data, 8-bit, 10-bit, 16-bit etc, calculations will be made to convert the reading to a voltage and using the data sheet, convert this into degrees Celcius.

Fig 5.7 – LM 35 Temperature Sensor

5.2.2.4 Air quality sensor

Since the rover designed is going to be operating in hostile environments, it is important to know the presence of dangerous chemicals in the air to determine whether it is safe for a human to be there or not. The air-quality sensor used is the MQ-2 gas sensor which is capable of detecting flammable gases like Carbon-monoxide, LPG, Propane, Butane, Alcohol and smoke concentrations.

To get concentration values however, the datasheet of this sensor needs to be used and calculations are to be made accordingly.

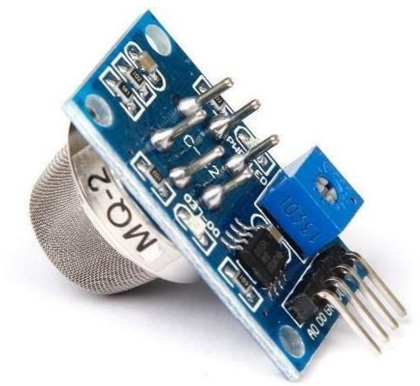

Fig 5.8 – MQ-2 Gas Sensor

5.2.3 Controllers

5.2.3.1 Microcontroller

The microcontroller chosen for this project is the Raspberry Pi pico, based of the RP2040 microcontroller chip developed and designed by Raspberry Pi in the UK. It runs on a dual-core Arm Cortex-M0+ processor with a flexible clock running up to 133 MHz.

It has the following features:

- 264KB on-chip SRAM, 2MB on-board QSPI Flash
- 26 multifunction GPIO pins, including 3 analogue inputs
- 2 × UART, 2 × SPI controllers, 2 × I2C controllers
- 16 × PWM channels
- 1 × USB 1.1 controller and PHY, with host and device support
- 8 × Programmable I/O (PIO) state machines for custom peripheral support
- Supported input power 1.8–5.5V DC
- Operating temperature -20°C to +85°C
- Low-power sleep and dormant modes
- Accurate on-chip clock
- An inbuilt temperature sensor.

Fig 5.9 – Raspberry Pi Pico

The processor is relatively faster and offers high computing power over other microcontrollers, also offering dual core processing power in a small form factor.

5.2.3.2 Motor controllers

For the motor control, one L298N H-bridge motor driver is used which can control upto two motors simultaneously. The H-bridge feature allows for direction change of the motor rotation in either clockwise or counter-clockwise direction. It has 6 inputs pins, namely ENA, IN1, IN2, IN3, IN4 and ENB, three of which are for the first motor and the remaining three are for the second.

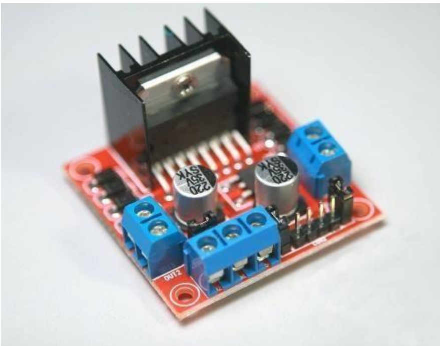

Fig 5.10 – L298N Motor Driver

The IN1 and IN2 lines control send current and ground to the motor connections to run them and their direction can be reversed by the H-bridge. The same goes for the IN3 and IN4 lines. The enable lines ENA and ENB are the main switches that turn the motor on or off. Only if the enable lines are running then the motors will also run based on the IN1 to IN4 outputs. Pulse Width Modulation (PWM) technique can be applied to the ENA and ENB lines to control the speed of the motor.

5.2.3.4 Joystick

The joystick controller modules will be with the operator embedded into the remote of the rover. The joystick will read direction values given by the remote operator when he/she moves the joystick and this is translated into motor commands by the code written in the microcontroller which is then sent wirelessly to the rover.

Fig 5.11 – Joystick Module

Two joysticks are used. One for controlling the rover’s motion and the other for controlling servos that change the camera’s viewing direction.

5.2.3.5 Power distributer

The HW-131 Power supply module provides a stable constant supply of current for the microcontrollers, sensors and radio modules. It takes in 12V DC from the battery and outputs two different changeable voltages, either 5V or 3.3V.

Fig 5.12 – HW-131 Power Distributer

CHAPTER 6

RESULTS AND DISCUSSION

Considering the conventional manufacturing costs for such technology, its affordability and practicality, the rover was developed. The unmanned ground vehicle so developed served its purpose while proving to be cost effective, simple to make, had a decent range and had a good performance in rough terrain. The results for the verification of the rover developed can be divided into two sections.

The first section will deal with the frame design and the validation of the rocker-bogie mechanism, while the second section will deal with the results obtained from the sensors which send back the environment data and the communication between the rover and the remote.

a. Design Validation: (Rocker-bogie)

The design of the rocker bogie frame used proved to be valid when tried off road as well for climbing stairs. However, it is to be noted that for climbing steep stairs as shown in the figure, minor external assistance was required to help aid the rover overcome the obstacles. This can still be worked around by modifying the mechanism and improving design**.**

The following shows how the rover movers over steep obstacles in progression form figure 6.1 to 6.4.

Fig 6.1 – One

Fig 6.2 - Two

Fig 6.3 - Three Fig 6.4 – Four

b. Telemetry Data and Communication:

The communication between the remote and the rover proved to be successful, and the sensors worked as desired. The microcontrollers successfully calculated all the sensors values and converted them to a more readable format, after which it successfully transmitted back the sensor data to the remote operator. The microcontroller was connected via USB to a laptop on which the telemetry data was displayed on the micro-python IDE shell. The following results were obtained:

```
Shell
               REMOTE DATA...
SYSTEM TEMPERATURE:        32.19398 *C
SELECTED SPEED:            1
               ROVER DATA...
ENVIRONMENT TEMPERATURE:   28.15645 *C
OBSTACLE DISTANCE:         42.545 cm ,     DROP ALERT:  False
LPG LEVELS:                246 ppm
CO LEVELS:                 45 ppm
SMOKE LEVELS:              82 ppm
```

Fig 6.5 – Received Sensor Data from the Rover

The following data so displayed was handled by a program running as a separate thread, i.e., running on another core of the microcontroller's processor. As the display of this was done so successfully, thus the multithreaded programming approach used has been verified as well. The multithreading also greatly improved processing performance and reduce communication packet losses as one single core on each of the microcontrollers (of the rover and the remote) were used for communication while the other for computation. Thus, desired results were obtained.

c. Live video stream:

The video stream was obtained from a system using an OV2640 camera integrated with an ESP32 microcontroller chip. The video stream was successful and the video stream was obtained from a local sever started by the ESP32 module. The camera would stream data onto this server and to be able to view the footage, the remote operator had to simply access the camera sever by entering its respective IP address. The following image shows the camera stream obtained on a web browser.

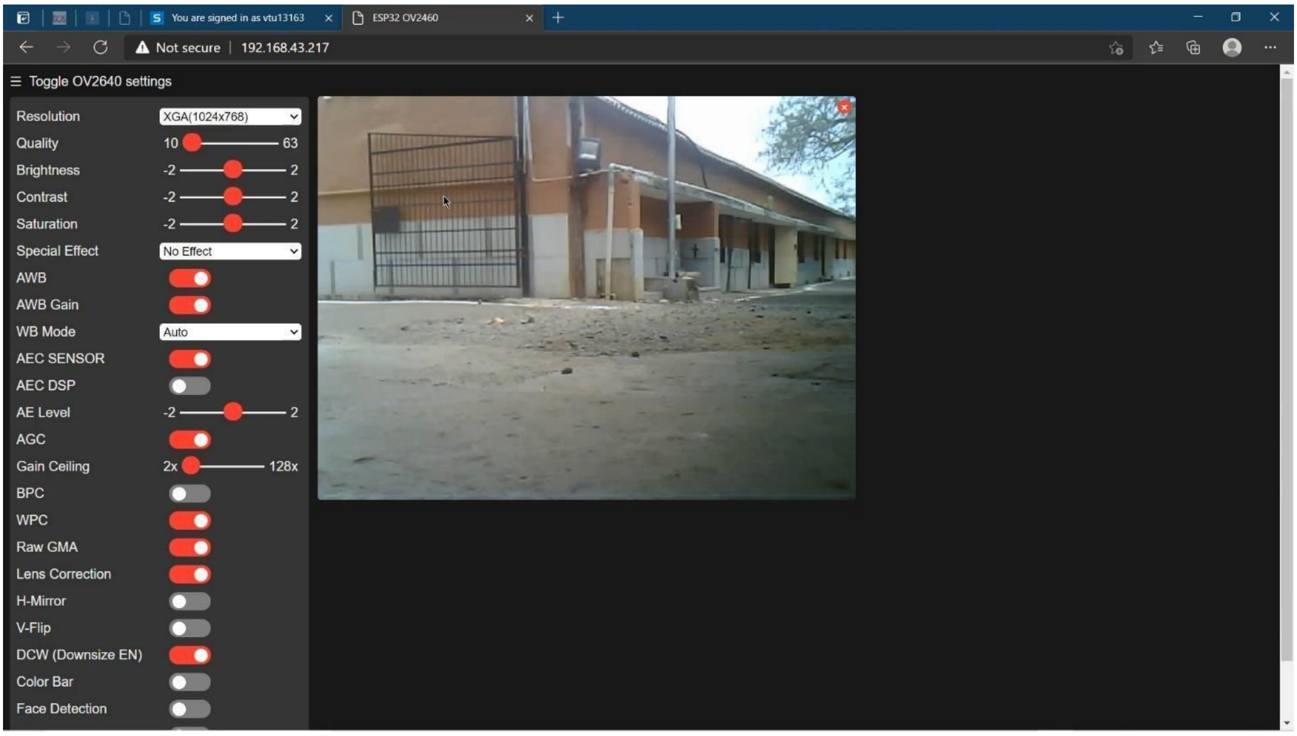

Fig 6.6 - Camera stream obtained on a web browser

d. Range and Endurance:

On conducting a few test-runs with the rover, it was observed that an average operation time of about 20 minutes was achieved. The 12V battery preformed fairly well, providing a decent, constant well-balanced supply of current to the system with all its sensors, microcontrollers and motors.

The radio modules used were the NRF24L01+ (PA/LNA), which offered quite a reliable communication system for the project, by using communication acknowledgements, and timeout functions. Though the modules were observed to be very sensitive to noise and interferences with other communication technologies operating at a similar band, i.e., 2.4GHz band. However, much of these problems were solved using a capacitor and also by changing the channels used for communication. An average range of about 650m was observed in open air before packet losses were evident, and through walls or other obstacles, the ROGV's connection performed fairly well with quite a decent range. A range of up-to 400m in this scenario can be expected.

CHAPTER 7

CONCLUSION

With the use of readily available parts/materials that we use every day, a relatively technology-heavy robot vehicle can be developed. The use of the vehicle extends over to a wide variety of applications and all of this by using cheap readily available material which greatly reduces cost and the amount of waste generated while still serving the purpose it has been designed for.

The ROGV (Remotely Operated Ground Vehicle) also referred to as UGV (Unmanned Ground Vehicle) that has been developed, tackles the defined problem effectively. The sensors integrated into the system provide valuable information about the surrounding environment it is operating in and also provides a live video stream to be able to see where the rover is going. This same stream is used for inspection purposes as well.

The rocker-bogie mechanism proved to be effective in rough terrain, and gave the rover the ability to manoeuvre over such environments easily. Its wheels also played an important role in allowing it to climb over big obstacles and also made it relatively more stable.

The design was very economical as compared to other conventional rovers available that use very similar technologies. Its cheap design makes it very affordable and also if in case during operation the rover may be subject to damage or destruction, the loss is significantly lower, thus making it more desirable and practical.

Thus, overall, the ROGV developed proved to be useful, effectively tackles the defined problem and can help save many lives and/or keep many humans out of harm’s way and help make better choices when working in dangerous situations.

CHAPTER 8

FUTURE SCOPE

Conventional unmanned ground vehicles also known as remotely operated ground vehicles that are available today are very expensive to develop, especially with the technology that has been implemented in the rover. Although the ground vehicle developed serves the purpose it has been designed for, there is potential for further improvement while still keeping costs at the minimum.

a. Battery Management System

One of the most desired improvement expected of this technology would be endurance. How long the battery will be able to supply current to the electronics and control systems would determine how reliable the vehicle will be able to operate before it needs recharging, thus increasing its useful operation time. This could be done by either using a better battery, using a specialized battery management system or using a battery pack or all three of them together.

b. Range

Another factor that would greatly influence the performance of the rover would a reliable communication capability. The modules so used were quite reliable when using acknowledgements and auto-resend when packets are lost, though it was quite sensitive to noise. This issue was resolved by scanning for channels in which the noise was less. Since the operating band of the NRF24L01+ modules is in the 2.4GHz range, it's range will be relatively low and subject to noise. This problem can be overcome by using a lower frequency operating band and technologies like LoRa which can communicate upto 500km depending on the module used, though this will come at a higher cost. This will depend on its application and the required model can be chosen appropriately.

c. AI Technology

AI technology can also be adopted and integrated with rover electronics to keep improving on its detection capabilities. The video footage obtained from the rover's camera can be used to detect a human face or human features which can be used to predict a possible human survivor under debris.

Path tracking, for auto return of the rover can also be implemented using this technology.

d. Other Applications

The ROGV can not only be used for societal purposes or disaster relief, its applications can extend to other fields as well. As it is designed to be an all-weather, all-terrain vehicle it can help monitor an area before infantry troops are sent out to that field for their missions. It can be modified and adapted to detect mines that may be buried under ground and if there are any mines that accidentally blow-up the vehicle, the loss wouldn't be too great as the vehicle would be made out of cheap material.

e. Manoeuvrability and Control:

The ROGV developed has been made waterproof, and designed to withstand going over puddles of water, however it can be further improved to be able to have full amphibious properties as well, allowing it to be better be able to move over a stream of water.

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