Terran Viper: Semi Autonomous Terrain Reconnaissance and Surveillance Security Robot

A project report for end term evaluation

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ACKNOWLEDGMENT

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1. Introduction

Terran Viper: Semi-Autonomous Terrain Reconnaissance and Surveillance Security Robot

- **Objective**: Develop a hypermobile snake robot capable of traversing rough terrains for reconnaissance and surveillance purposes, with video telemetry and 3D mapping capabilities.
- **Key Features**:
  - Multimodal locomotion (serpentine, rectilinear and sidewinding).
  - Versatile communication (wired RS485 and wireless LoRa).
  - Real-time video streaming and 3D environmental mapping.

Background and Need

Reconnaissance in hostile or inaccessible terrains is a critical need in both defense and civilian sectors. Terran Viper is designed to fulfill this gap by offering:

- **Hypermobile Traversal**: Its multimodal locomotion allows operation on uneven, sandy, or narrow spaces.
- **Compact Design**: Suitable for confined environments like caves or collapsed buildings.
- **Real-Time Surveillance**: Equipped with cameras for live video telemetry and mapping.

Motivation

India's geographic and infrastructural diversity presents challenges like:

- Border surveillance in extreme terrains.

- Urban search-and-rescue in collapsed structures.
- Inspection of industrial plants, pipelines, or mines.

  The Terran Viper robot aims to enhance operational safety and efficiency by enabling remote reconnaissance in these scenarios.

Applications

- **Military**: Terrain reconnaissance for the Indian Army, paramilitary forces, and border security.
- **Disaster Management**: Search and rescue during natural calamities.
- **Industrial Inspection**: Pipeline and structural integrity monitoring in industries.
- **Wildlife Monitoring**: Surveillance in forest or jungle environments without disturbing habitats.

Potential Users in India

- **Defense**:
  - Indian Army.
  - Border Security Force (BSF).
  - Central Reserve Police Force (CRPF).
- **Government Agencies**:
  - National Disaster Response Force (NDRF).
  - Geological Survey of India (GSI).
- **Private Sector**:
  - ONGC (Oil and Natural Gas Corporation).
  - Reliance Industries for industrial inspections.
- **Research and Development**:
  - DRDO (Defence Research and Development Organisation).
  - IITs or research institutes specializing in robotics.

Aim of the Project

To deliver a robust, semi-autonomous robotic system capable of adaptive locomotion, advanced surveillance, and real-time data integration. Terran Viper will act as a cost-effective, scalable, and field-ready solution for challenging terrains and confined spaces.

This sets the foundation for an innovative, multidisciplinary project addressing real-world problems with practical engineering solutions.

2. User/Field Study

2.1 Potential Use Cases in India

The snake robot has a wide range of applications across multiple sectors in India, particularly in environments where human access is difficult or dangerous.

- **Military Applications:** The Indian Army can use the robot for terrain reconnaissance in deserts, forests, and mountainous regions. Its ability to navigate confined and rugged environments makes it ideal for gathering intelligence and detecting threats in sensitive border areas.
- **Disaster Management:** The robot can assist the **National Disaster Response Force (NDRF)** in locating survivors trapped under debris during earthquakes, landslides, or collapsed buildings. Its ability to enter tight spaces and transmit real-time video can significantly improve rescue operations.
- **Industrial Surveillance:** Industries such as **oil refineries, power plants, and underground pipelines** require regular inspections. The snake robot can be deployed to access hazardous or confined areas where human entry is difficult, ensuring safety and efficiency.

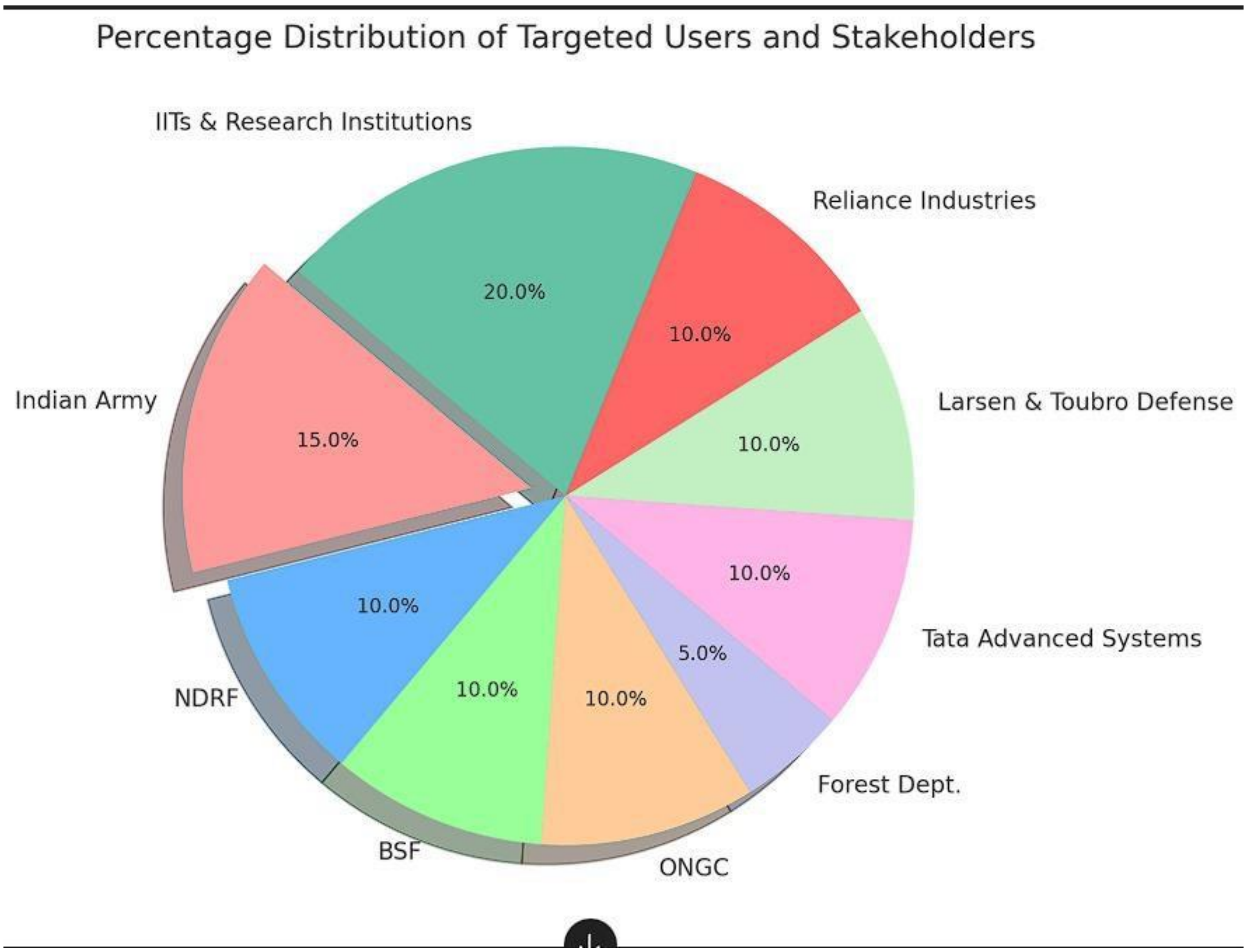
- **Wildlife Monitoring:** The **Forest Department** can utilize the robot for **non-invasive wildlife observation** in dense forests and sanctuaries. Its silent operation allows for the study of animal behavior without disturbing the natural habitat.

2.2 Targeted Users and Stakeholders

- **Government Departments**:
    - Indian Army (Reconnaissance and Surveillance Wing)
    - National Disaster Response Force (NDRF)
    - Border Security Force (BSF)
    - Oil and Natural Gas Corporation (ONGC)
    - Forest Department (Wildlife and Conservation Teams)
- **Private Companies**:
    - Tata Advanced Systems (Defense Manufacturing)
    - Larsen & Toubro Defense
    - Reliance Industries (Industrial Surveillance)
- **Academic and Research Institutions**:
    - Indian Institutes of Technology (IITs) for robotics research.

2.3 Stakeholder Requirements

- Robust operation on varied terrains.
- Remote video streaming with low latency.
- Long operational life and efficient power consumption.
- Safe operation in hazardous environment



3. DATA ANALYSIS

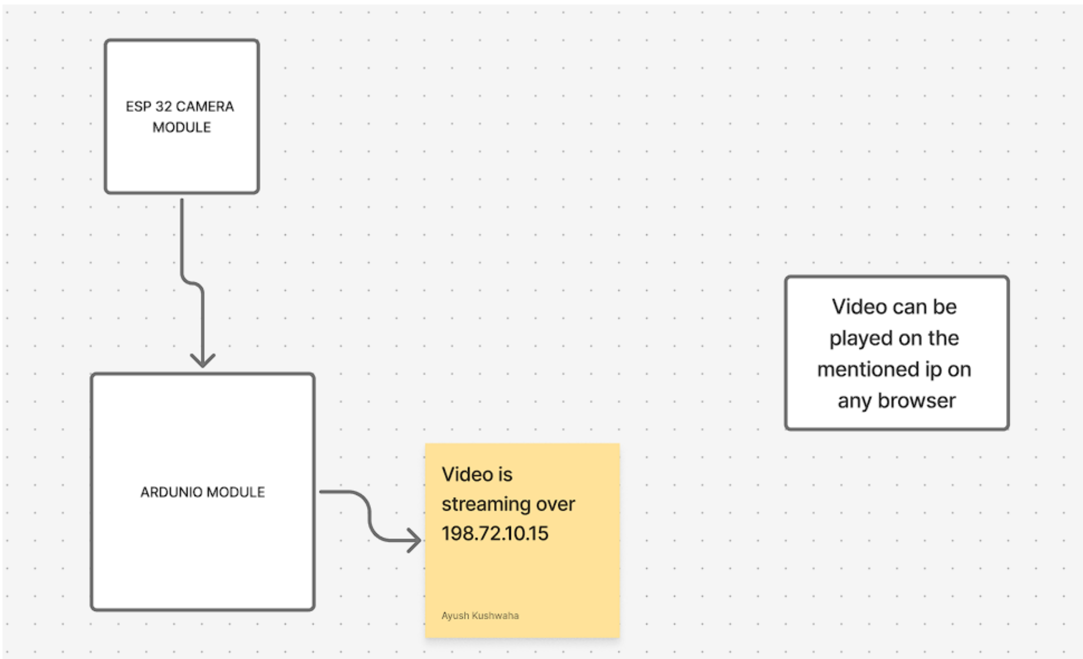
3.1 Terrain Analysis and Operational Requirements

- **Common Terrains**: Sand, gravel, uneven rocks, forest floor, and debris.

- **Challenges**: Slippage on loose soil, low friction on hard surfaces, obstacles like roots and boulders.

3.2 Video Telemetry System Performance Evaluation

- **ESP 32:** It will be connected to the Arduino, and it will stream over Ip eg.198.72.10.18



3.3 Power Consumption and Battery Life Estimation

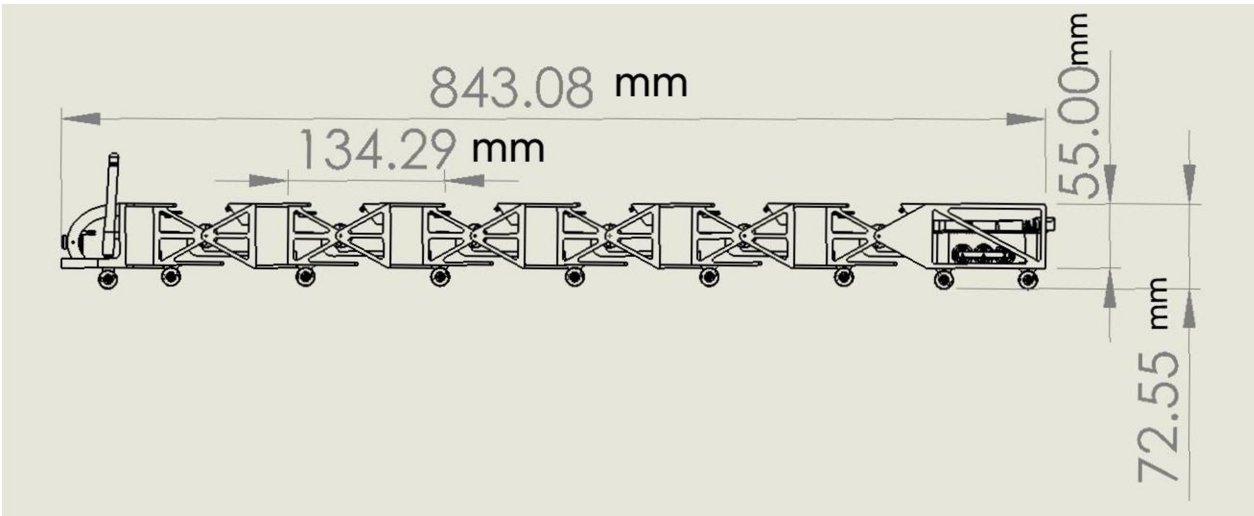
Overview: Power would be consumed by servo motors,Ardunio Uno,camera module and nrF module.

Model: Orange A Grade ISR 18650(This Orange A Grade ISR 18650 2000mAh (10c) Lithium-ion Battery gives value for money. It is a single cell, compact, and powerful battery

Operating parameters:2200mAh, 3.7V in 2S4P configuration, at full capacity providing 11-12 Ah capacity for 1- hour runtime with 20% safety margin. At normal capacity 2 - hours of safe runtime can be relied on.

4. TECHNICAL/PRODUCT SPECIFICATIONS

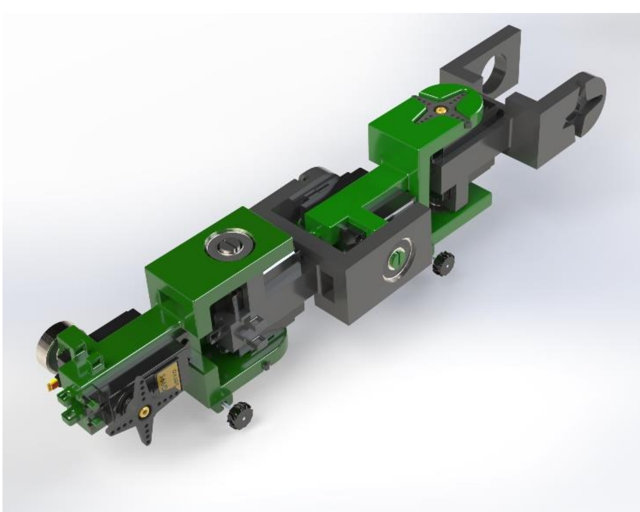
4.1 Mechanical Design

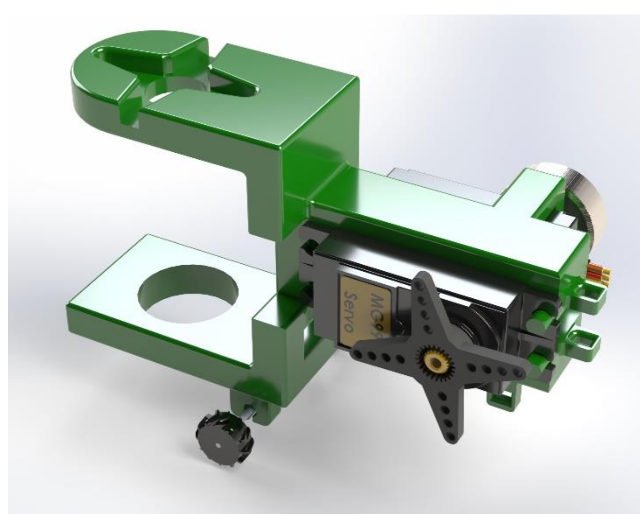


Overall Design: The Robots consists of 7 units including a unit for Camera in the front and a unit at rear for Arduino Mega and Batteries.

Yaw and Pitch Motion:

Two high torque MG995 Servo Motors mounted orthogonally, responsible for Yaw and Pitch motion of the links.

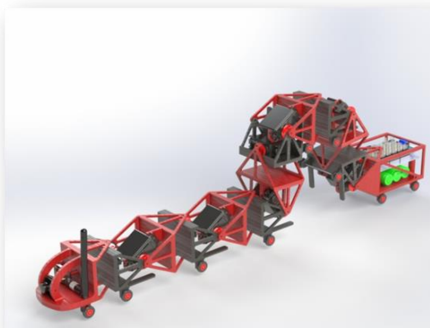




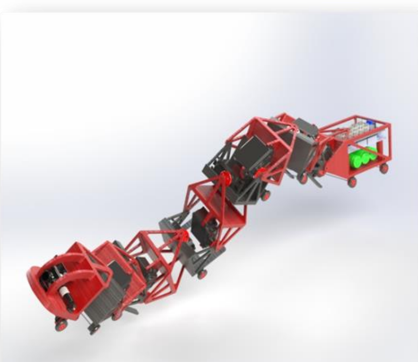
- **Motions**:
    - **Serpentine Motion:**

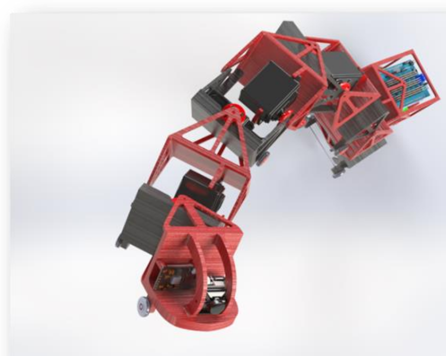


- **Rectilinear**

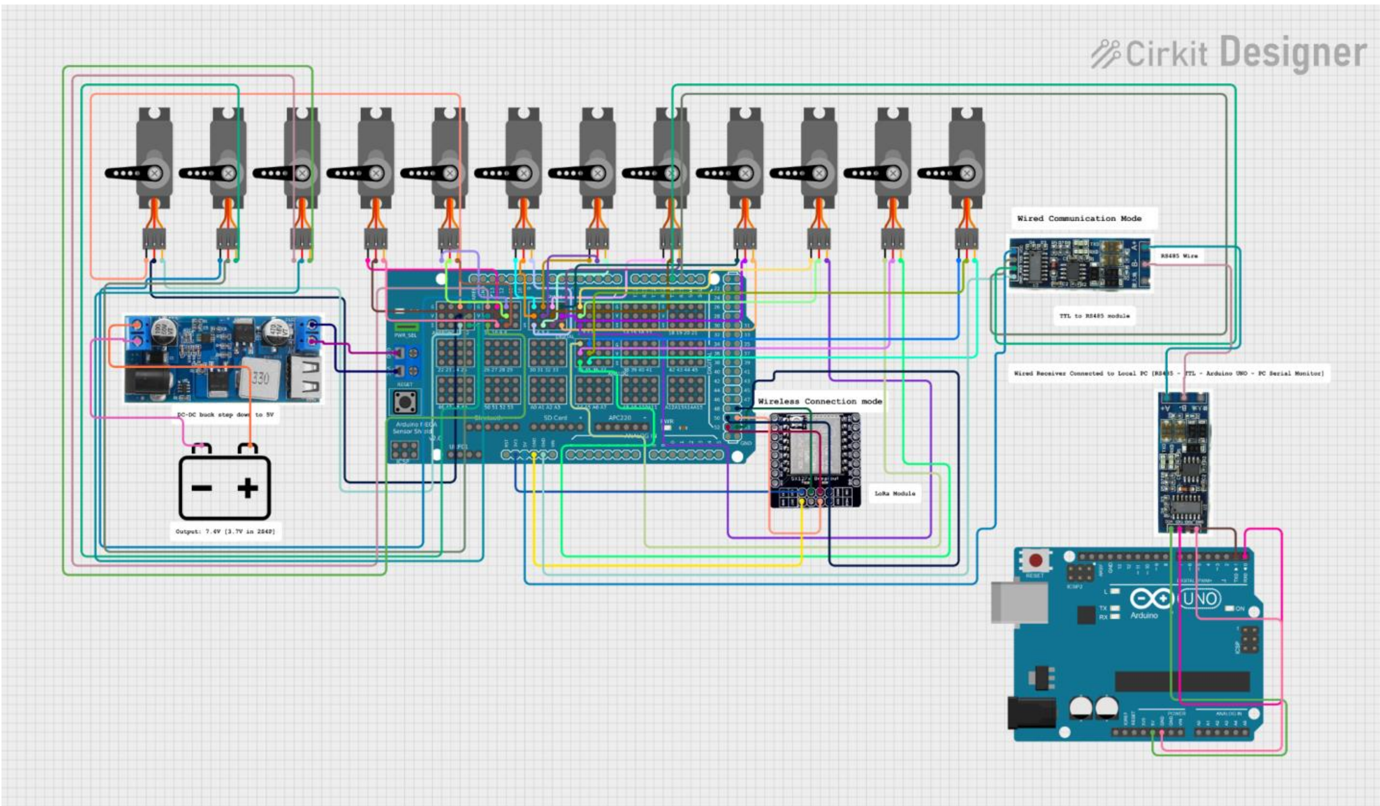




- **Sidewinding**





4.2 Electronics and Communication Systems



Circuit Diagram

- **Controller**: Arduino Mega R3 (ATmega2560).
- **Sensors**: Cameras (ArduCAM and ESP32-CAM).
- **Servo motor:** MG995 13 kg-cm servo motor

- **Communication Modes**:
  - Wired: RS485 over 1.2km.
  - Wireless: LoRa for up to 300m. Very reliable upto 50m. Dependant on surrounding

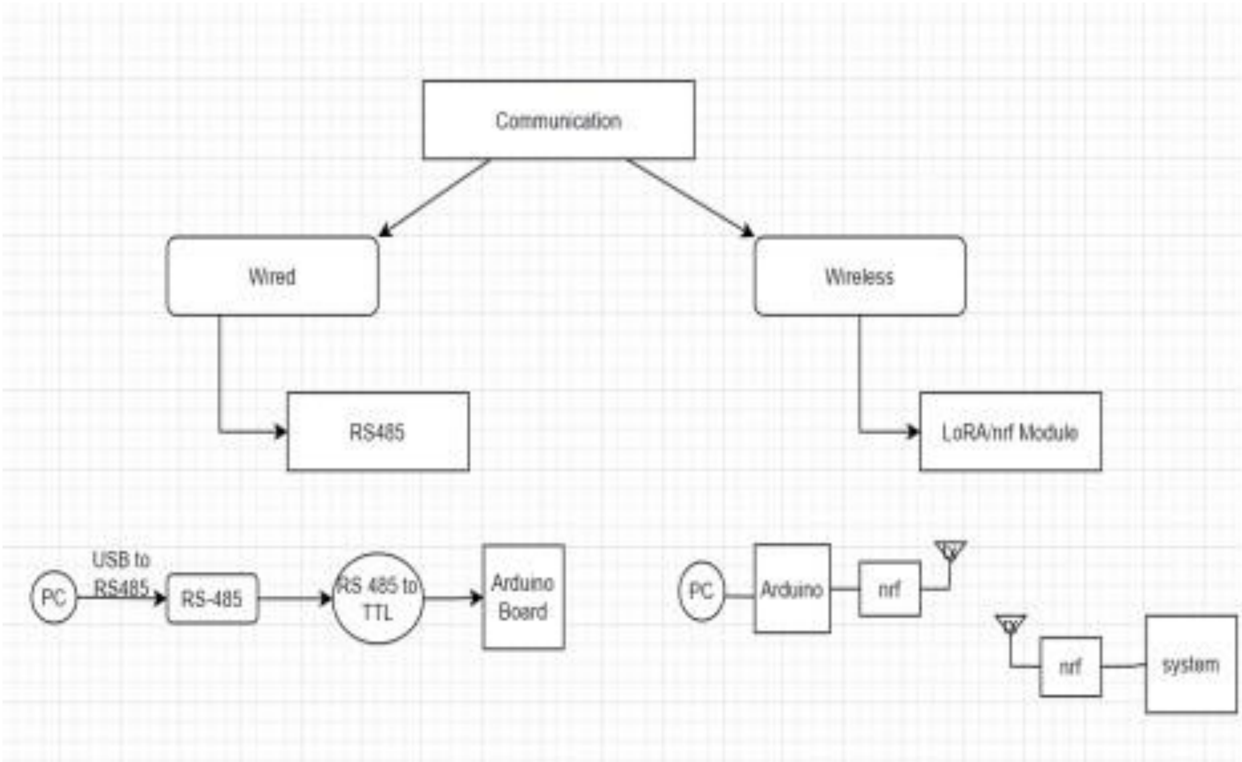


Fig. 3: This flowchart describes wireless and wired communication flow.

4.3 Video Transmission and Processing

- **Depth Estimation**:3d map with the help of MIDAS model with the help of Esp 32 module
- **3D Mapping**: Voxel mapping/3d point cloud image integrated with depth estimation.
- **Warning: A** beep sound is produced if object gets too close to the camera module

5. CONCEPT GENERATION

5.1 Motion Planning Algorithms and Motion Mechanisms

Development of adaptive algorithms for efficient movement on varying terrains.

- **Serpentine Motion**: **Smooth Locomotion:**

  - **Smooth Locomotion**: Servo motors generate sine or cosine waves for smooth forward and reverse motion.

  - **Directional Control:** Wave offsets adjust for left and right turns with smooth transitions.

  - **Realistic Movement:** The robot mimics real snake locomotion with precise undulations.

  - Equation:

$$\theta_i(t) = A\sin(kx_i - \omega t)$$

- **Sidewinding Motion**:

  - **Wave Pattern:** A horizontal cosine wave is applied to odd-numbered servos, while a vertical cosine wave, offset by 90 degrees, is sent to even-numbered servos.

  - **Resulting Motion:** The combination of horizontal and vertical waves produces a sidewinding motion suitable for traversing shifting terrains like sand.

  - **Specialized Locomotion:** Sidewinding enables effective movement on unstable surfaces by leveraging synchronized horizontal and vertical waveforms.

    - Equations:
      - Horizontal plane:

$$\theta_{i,h}(t) = A_h \sin(k_h x_i - \omega_h t)$$

      - Vertical plane:

$$\theta_{i,v}(t) = A_v \sin(k_v x_i - \omega_v t + \phi)$$

- **Rectilinear Motion**:
  - **Inchworm Motion:** The snake moves in rectilinear motion by creating a vertical hump, but turning is not yet feasible in this configuration.
  - **Turning Mechanism:** A continuous rotation servo with a large wheel is being tested to enable turning by lowering the wheel and rotating it left or right.
  - **Motion Control:** The system is designed to transition between forward motion and turning by adjusting the wheel's position.
    - Forward segment:

$$\theta_i(t) = \begin{cases} A\sin(\omega t) & \text{if } i \in \text{pushing segment} \\ 0 & \text{otherwise} \end{cases}$$

5.2 Microcontroller

- Arduino Mega R3 development board(Atmega 2560) is used to interface servos and communication modules.
- **54 digital I/O pins** (of which 15 can be used as PWM outputs) and **16 analog input pins**. This is significantly higher than many other Arduino boards like the Uno, making it ideal for controlling multiple servos without the need for additional I/O expansion hardware.
- **Flash memory**: 256 KB (8 KB used by bootloader) allows for more complex programs and additional libraries, which may be needed for servo control algorithms and communication protocols (e.g., LoRa, UART).
- **SRAM**: 8 KB is sufficient for handling the dynamic variables and buffers for servo signal calculations.
- **EEPROM**: 4 KB for storing calibration data or other persistent settings.
- The Mega 2560 has **4 hardware UART ports**, allowing simultaneous communication with various peripherals (e.g., LoRa module, PC, or debugging tools). This eliminates the need

for software emulation of serial communication, reducing processing overhead.

- Compared to other microcontrollers with similar features, the Mega is relatively affordable, especially considering its performance-to-price ratio.

5.3 Communication Modes

- Dual-mode(**wired and wireless**) operation for continuous operation in confined spaces.

1) **Wireless communication**: achieved using LoRa Module which provides reliable range upto 300m in open spaces and nearly 80m in confined spaces.

2) **Wired communication:** achieved using RS485 serial communication using twisted pair cables.

Wireless (LoRa) vs. Wired (RS485):

Wireless (LoRa)	**Wired (RS485)**
Provides unrestricted mobility, allowing the snake robot to navigate confined spaces without cable constraints. It enables remote operation over long distances, making it ideal for hazardous or hard-to-reach environments.	Ensures stable, low-latency communication in signal-restrictive areas. Additionally, the wired connection allows the robot to be physically pulled through rough terrain if it gets stuck, aiding in retrieval and maneuverability.

5.4 Depth Estimation and 3D Mapping Concepts

This process involves two major steps: **Depth Estimation Mapping** and **Voxel Mapping**, which are combined to create a structured 3D representation of the environment.

Goal: Estimate the depth of objects in the scene from a single video feed (monocular) or stereo video feed.

But stereo mapping is **expensive** as the camera itself costs much

1.Depth Estimation Mapping

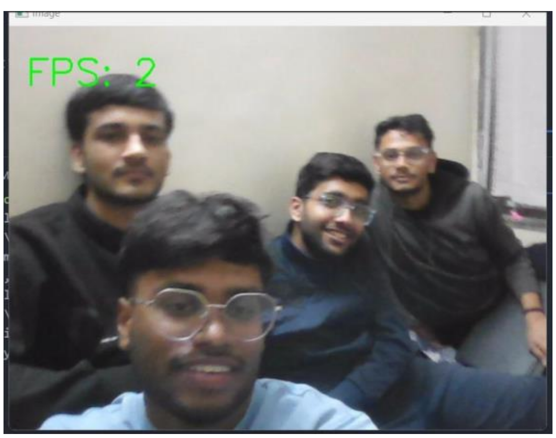
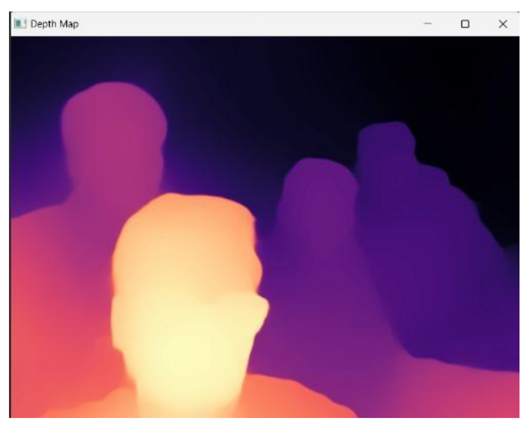
Steps:

1. **Input Video Feed**:
    - Will be using ESP 32 to capture the video feed.
2. **Compute Depth**:

    Used pre-trained deep learning models (e.g., MiDaS, Monodepth2).

3. **Generate Depth Map**:

    2D depth map where pixel intensity represents the distance of objects from the camera.

Video feed	Depth Map
	

In depth map, the **intensity (color brightness)** represents depth information:

- **Brighter areas (yellow/white regions)** indicate objects **closer** to the camera.
- **Darker areas (blue/purple/black regions)** indicate objects **farther** from the camera

2. Tools and Libraries

- For Depth Estimation:
  - OpenCV (stereo vision disparity computation).
  - PyTorch/TensorFlow (deep learning models).
- For Voxel Mapping:
  - Open3D (voxel creation/visualization).
  - PCL (point cloud processing).
  - OctoMap (probabilistic occupancy grids).

5.5 Power Supply

1. Servo Power Requirements

- Each MG995 servo:
  - Idle: ~10 mA
  - Operating: ~0.5–1.5 A (load-dependent)
  - Stall: Up to 2.5 A
- Assume each servo draws 1.5 A during operation for safety.
- Total for 6 servos = 6 × 1.5 A = 9 A.

2. Additional Components Power Requirements

- nRF Module: ~15–20 mA → 0.02 A.
- Arduino Uno (or similar): ~50 mA each → 0.1 A for 2 boards. ● Camera Module: ~200–250 mA → 0.25 A.

3. Total Current Consumption

- Total = 9 A (servos) + 0.02 A (nRF) + 0.1 A (Arduino) + 0.25 A (Camera).
- Total = 9.37 A.

4. Battery Capacity Calculation

- Runtime assumption: 1 hour.
- Capacity formula:
  - Capacity (Ah) = Total Current (A) × Runtime (h).
  - Capacity = 9.37 A × 1 h = 9.37 Ah.

5. Adding Safety Margin

- Include a 20% safety margin to ensure stable operation:
  - 9.37 Ah × 1.2 = ~11.25 Ah.

6. Utilised Battery Specifications

- Hence, it is best to use Orange A Grade ISR 18650 3.7V 2200mAh 5C Li-ion Battery * 8 batteries in 2S4P configuration.

5.6 Safety and Reliability Features

- **Power Supply:** 8 Li-ion 18650 batteries (2200mAh, 3.7V) in 2S4P configuration, providing 11-12 Ah capacity for 1-hour runtime with 20% safety margin.

- **Servo Power Management:** Total current draw of 9A for 6 MG995 servos, ensuring efficient energy usage without overload.
- **Battery Protection:** Li-ion batteries have overcharge, over-discharge, and short-circuit protection with a BMS for monitoring.
- **Component Compatibility:** Components (servos, Arduino, cameras) operate within specified voltage/current limits to prevent overload.
- **Thermal Management:** Servos handle up to 2.5A stall current, designed to avoid overheating during operation.
- **Communication:** RS485 for wired communication (up to 1.2 km) and LoRa for wireless communication (80-300m range).

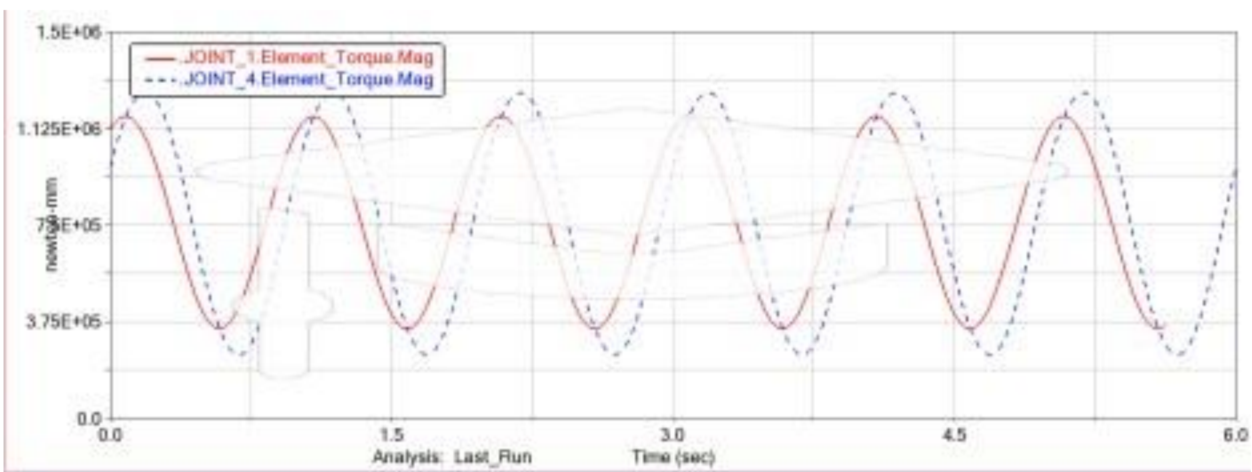


fig5:MOTION ANALYSIS OF SNAKE ROBOT(4 links member)

6.Cost of Fabrication

Name	Price	Quality	Total Cost
Arduino Mega R3 (Atmega2560-16U2) Model: -Atmega2560	₹ 1199	1	₹1199
TowerPro Servo MotorModel:-Pro-Range MG995	₹272.5	12	₹3720
SX1278 LoRa module(For wireless Communication)	₹398	2	₹796
LoRa Antenna(For wired Communication)	₹54	2	₹108
600TVL 170 Degree Mini FPV AV Camera with Audio	₹838	1	₹838
Boscam FPV 32CH 5.8G 600mW Wireless Transmitter	₹2028	1	₹2028

5.8G UVC OTG Android AV Phone Receiver	**₹2370**	**1**	**₹2370**
DMEGC INR21700-45E 3.7V 4500mAh Li-Ion Battery (Power Supply)	**₹272**	**5**	**₹1360**
MAX485 TTL To RS485	**₹24**	**2**	**₹48**
Arduino Uno	**₹229**	**2**	**₹458**
eSun PLA+ 1.75mm 3D Printing Filament 1kg-White	**₹1239**	**1**	**₹1239**
DC-DC Step-up Module with Adjustable Booster Power Supply Module	**₹139**	**1**	**₹139**
Male to Male	**₹67**	**1**	**₹67**

Jumper Wires 40 Pin 30cm			
LWC-CA-SMA-JACK-BH-ST-UFL-1.13mm RF Cable Assemblies-15cm	₹69	2	₹138
Male to Female Jumper Wires 40 Pin 40cm	₹107	1	₹107
EasyMechM4 X 16mm CHHD Bolt and Nut Set-20 pc	₹29	2	₹58
RF433MhzModule	₹271	2	₹542
Total			₹15,412

7.CONCLUSION

7.1 Current Status

- Low-Fidelity prototype demonstrating serpentine motion successfully simulated.
- CAD design and motion simulations completed.
- Depth image generation is completed and voxel/3d cloud mapping is under process.
- Communication systems are integrated.

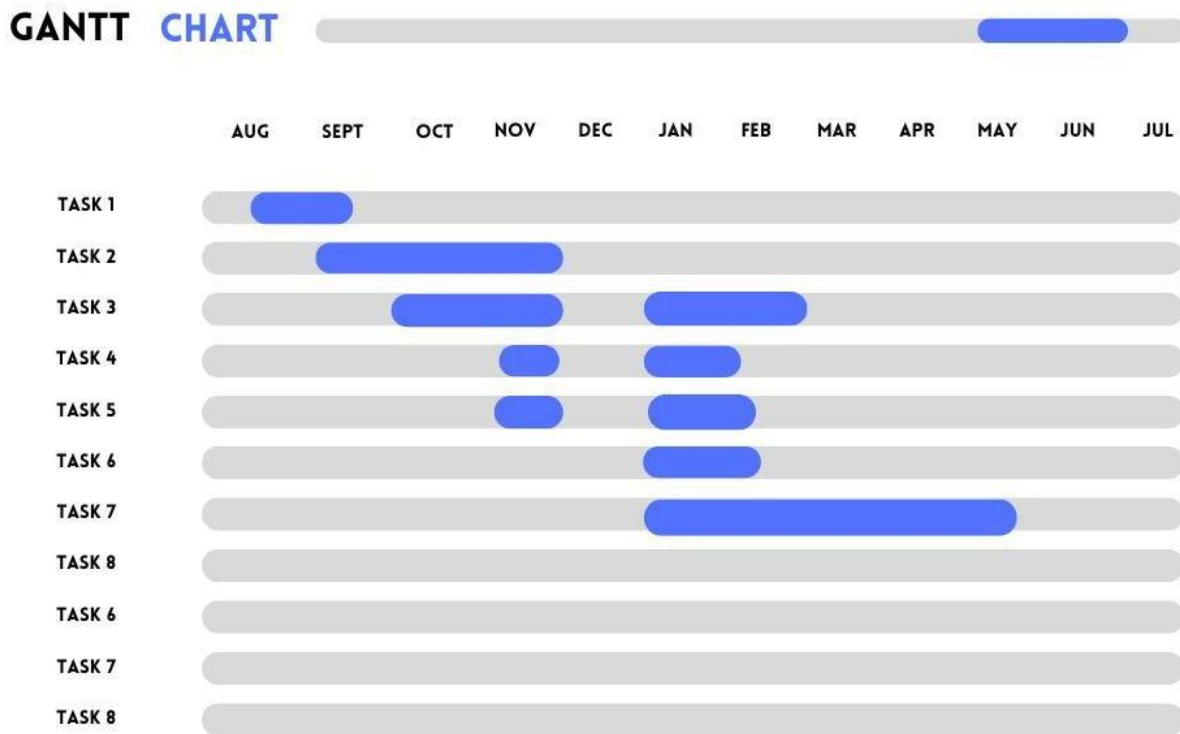
7.2 Future Work

- Use of more advanced camera for better camera feed that would result in better depth And voxel mapping.
- Extended testing on real-world terrains.

7.3 Expected Outcomes

- Deployment-ready prototype for rugged terrain reconnaissance.
- Advanced mapping and telecommunication capabilities.

7.4 Gantt Chart/Time Estimates



Task1: Project Ideation.

Task2: Project Conceptualisation according to latest research and advancements.

Task3: Study of snake motion mechanisms, video transmission and communication.

Task4: Finalising our product specification

Task5: CAD Model preparation.

Task6: Fabrication of Low fidelity prototype.

Task7: Fabrication of end product.

8.REFERENCES

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