b. POWER CONSUMPTION ANALYSIS

The total estimated peak power draw for the system is **~350.58 Watts**.

Detailed Power Breakdown:

- **Actuation (Servo Motors):** 2.5A × 5V × 18 = **225.0 W**
- **Computing & Control:**
  - Raspberry Pi 4: **~5.0 W**
  - Teensy 4.1: **0.3 W**
- **Sensing & Perception:**
  - IR Camera: **2.0 W**
  - 24GHz Radar: **0.6 W**
  - USB Camera: **3.6 W**
  - LIDAR Sensor: **2.0 W**
  - Ultrasonic Sensor: **0.075 W**
  - GPS Module: **0.1 W**
  - Gas Sensor: **0.3 W**
  - Temperature/Humidity Sensor: **0.0005 W**
- **Audio & Communication:**
  - Microphone: **0.15 W**
  - Speaker: **~1.0 W** (Estimated, not explicitly stated)
- **Illumination:**
  - LED Strips: **10.0 W**
- **Thermal Management:**
  - Cooling Fan/Heatsink: **~2.0 W** (Estimated for a small fan)

Battery Life Estimation

Using **4S 16.8V, 5200mAh (5.2Ah)** LiPo battery:

1. **Total Current Draw:** I = P / V = 350.58W / 16.8V ≈ 20.86A
2. **Theoretical Runtime:** Capacity / Draw = 5.2Ah / 20.86A ≈ 0.249 hours
3. **Runtime in Minutes:** 0.249 hrs × 60 ≈ 14.95 minutes

Conclusion: Under full load (all servos moving and all systems active), the estimated operational time is **approximately 15 minutes** per 5200mAh battery. The use of two batteries in parallel would double this runtime to **~30 minutes**.

Block diagram:

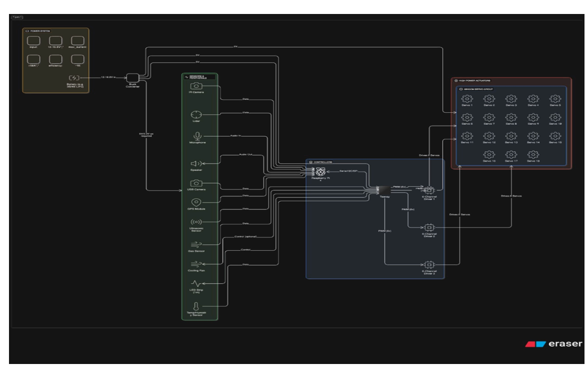

Fig.17: Circuit representation

c. Sensor Fusion and Communication

- SARAH integrates environmental sensors (gas concentration, temperature, humidity, sound) into its decision pipeline, with threshold-based alerts for immediate hazard notifications like toxic gas spikes or abnormal temperature rises.

- Sensor readings also feed a lightweight ML classifier to distinguish normal background variations from true hazards, while microphone audio cues (crying, tapping) are either relayed live or processed for anomaly detection.

- For communication, SARAH uses Wi-Fi as the primary link for high-bandwidth infrared video and telemetry, while LoRa serves as a fallback channel to ensure critical status and victim alerts can still be transmitted in obstructed or underground environments.

  This multimodal data fusion and hybrid communication enhance SARAH's ability to detect victims and assess environmental risks, improving mission safety and situational awareness during rescue operations.

C) PROGRAMMING SPECIFICATION

Software Architecture

a. Robot Description and Control

- The robot's mechanical design is captured in URDF/Xacro with a detailed description of links, joints, and sensors.

- The ros2_control framework abstracts hardware interfaces and manages position control of 18 servos via servo driver boards.

- Controllers:
  - joint_state_broadcaster for publishing joint states.
  - position_controllers for commanding precise joint trajectories.

- Real-time control ensures coordinated leg movement for stable locomotion across uneven terrains.

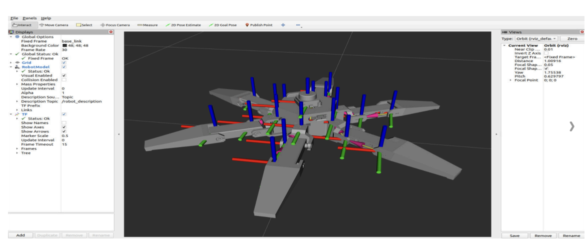

Fig.18a

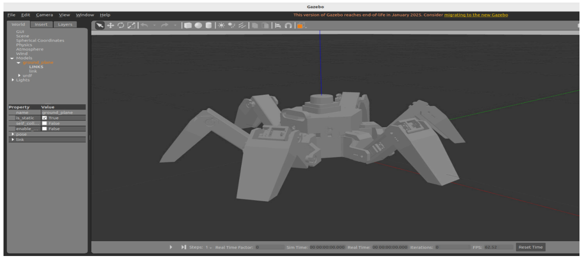

Fig.18b

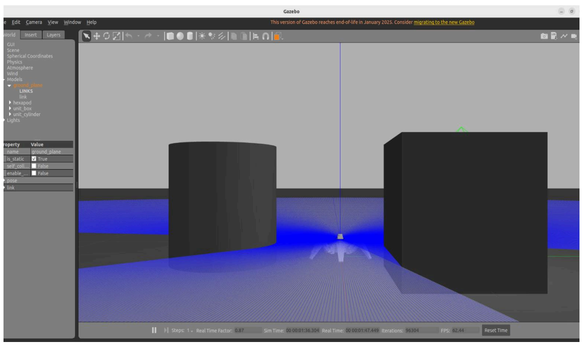

Fig.18c

b. Perception and SLAM

- A 2D LiDAR sensor streams laser scans processed by Google's **Cartographer** SLAM framework.
- Cartographer performs real-time scan matching, loop closure, and pose graph optimization to build an accurate 2D occupancy map in GPS-denied environments.
- SLAM data is fused with IMU and leg odometry to provide robust pose estimation despite the complex dynamics of walking..
- Environmental sensors (gas, temperature, humidity) provide critical data for hazard detection.

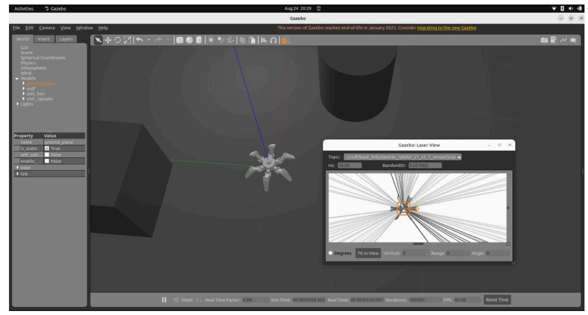

Fig.19

c. Autonomous Navigation

- The navigation stack consumes SLAM maps to plan and execute collision-free paths using adaptive gait controllers.
- Autonomous path planning optimizes for rugged terrain, continually updating plans as new sensor data arrives.
- Motion commands are converted into servo joint trajectories to execute smooth, reliable locomotion.

d. ML Integration

- SARAH integrates a lightweight ML subsystem using a pretrained

YOLO-based model fine-tuned on thermal and low-visibility images from the IR camera for reliable human victim detection in challenging environments.

- Radar micro-movement data is fused with vision outputs using supervised classifiers (Random Forest) to reduce false positives and enhance detection accuracy, while environmental sensors add contextual hazard information.

- The ML pipeline runs real-time on an onboard Raspberry Pi 4, optimized with TensorRT, ensuring robust multimodal victim localization and hazard awareness to improve search and rescue effectiveness.

e. GUI and Telemetry

- A user interface displays live video feeds, LiDAR maps, environmental sensor data, and system diagnostics.

- Operators monitor robot status and environment conditions on an above-ground screen.

- The GUI is telemetry-focused, providing insight without interfering with autonomous control to maintain system responsiveness.

- Visualizations use RViz2 combined with custom GUI elements for integrated situational awareness.

- Manual control can be enabled through the GUI when operator intervention is required.

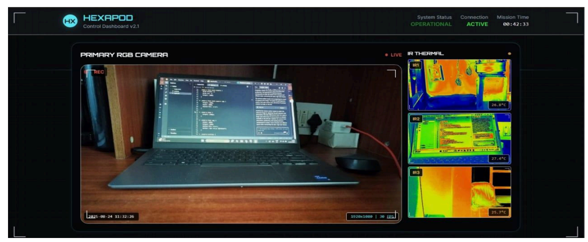

Fig.20a GUI

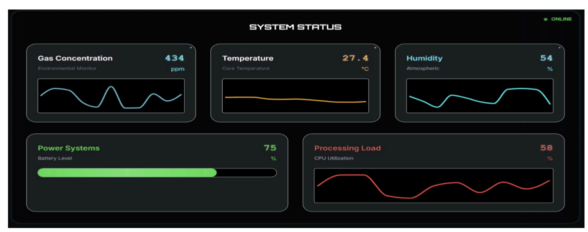

Fig.20b System Status Panel

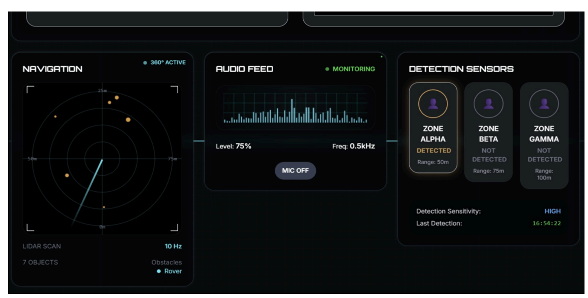

Fig.20c Navigation and Detection Interface

Integration and Deployment

- Software runs primarily on a Raspberry Pi 4 capable of real-time SLAM and control under ROS2.
- A Teensy microcontroller aggregates sensor readings and manages servo PWM signals with low latency.
- Communication is managed via ROS2 DDS middleware ensuring reliable scalable data flow.
- Gazebo simulation with ROS2 plugins supports testing and development of control and perception stacks.

System Workflow

- Initialization of hardware interfaces and sensor nodes.
- Continuous LiDAR scanning and SLAM-based map building.
- Navigation planner calculates paths based on updated occupancy grid.
- Sensor data relayed to GUI for operator monitoring.
- Autonomous locomotion with continuous sensor fusion for environmental awareness.

S.A.R.A.H is a rugged hexapod designed for autonomous operation in debris-filled underground disaster zones such as earthquakes or landslides. Its legged locomotion ensures stable traversal over rubble, pits, and inclines, where wheeled or tracked robots fail. Equipped with 2D LiDAR and real-time SLAM, it builds detailed occupancy maps for navigation and localization. Beyond autonomy, S.A.R.A.H integrates microphones and speakers for two-way communication with trapped victims, while its sensor-driven decision-making allows it to pause at junctions, alert operators, and coordinate rescues without risking human lives.