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Robotics in Hazardous Environments: Enhancing Safety and Efficiency

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Abstract - *This project showcases the creation and assembly of a hexapod robotic spider that can be operated wirelessly with an Arduino Uno and an HC-05 Bluetooth module. The six-legged robotic system is appropriate for surveillance and environmental monitoring applications since it is made to be stable and flexible in any kind of terrains. An ESP32-based webcam is built within the robot's upper portion, allowing for remote monitoring and real-time video transmission. The system also has humidity and gas sensors for collecting environmental data and offer data concerning atmospheric conditions and air quality. Real-time hazard detection is made possible by the integration of various sensors, which makes the robot an appropriate choice for smart environmental monitoring, disaster response, and industrial inspections. This hexapod robotic spider is an innovative and flexible platform for study and real-world applications in automation, surveillance, and hazardous area investigation because to its wireless control, robotic mobility, and real-time environmental monitoring at hazardous platform.*

Keywords: Hexapod robotic spider, collecting real time data , monitoring, effective movement etc..

1. INTRODUCTION

This project demonstrates the hexapod robotic spider, a self-balancing and remotely controlled robotic system equipped with an ESP32 webcam module for real-time monitoring. Because the hexapod is designed for exploration in challenging circumstances and incorporates gas and humidity sensors to collect and send environmental data, it is ideal for applications such as industrial inspections, disaster response, and restricted space research.

Because of its six-legged mobility, the hexapod outperforms traditional wheeled or tracked robots in terms of stability and efficiency on uneven surfaces. Because the ESP32 camera module can transmit live video, operators can remotely monitor circumstances in real time. Moreover, the inbuilt gas and humidity sensors provide useful atmospheric data that help for the early detection of dangerous situation and weather conditions.

This robotic system uses real-time data analytics to make better decisions, reduce human exposure to risky circumstances, and improve safety. Its small size, wireless connectivity, and sensor integration make it a useful tool for many different kinds of industrial and research applications.

Because it is designed to be used in hazardous and inaccessible environments, the hexapod robotic spider is a valuable tool for a number of companies and research fields. In order to monitor air quality and detect hazardous gas leaks, it can investigate subterranean tunnels, gas and chemical plants, and reduce the risks to human inspectors in industrial safety and inspection. In disaster response, the robot may explore locations that traditional wheeled robots might have difficulties, including mines, buildings that have collapsed, or areas exposed to radiation. In remote or challenging locations, such as forests, caves, or volcanic regions, it can also be utilized for environmental monitoring to look into temperature, humidity, and air pollution.

The hexapod is also ideal for space exploration, military surveillance, and search and rescue operations where real-time data collection and monitoring are crucial due to its compact size and adaptability. Furthermore, the modular architecture makes upgrades simple and adaptable to different missions and future improvements. It is capable of moving over rubbish, uneven terrain, or tight spaces because to its independent leg movement, which guarantees improved obstacle negotiating. The robot's ability to make decisions on its own can be further improved by integrating artificial intelligence and machine learning algorithms. This will enable it to recognize dangers, detect motion, and choose the best course in unfamiliar situations.

In addition to being helpful for safety applications, the real-time data collecting feature can be used in agriculture to track soil humidity, air quality, and pest detection. When fitted with waterproofing improvements, its adaptability across many terrains makes it appropriate for underwater excursions, expanding its uses to include marine research. The ESP32 module's low power consumption guarantees extended operation in distant areas, and with integrations of solar or other energy sources, it may be able to operate for extended periods of time without direct human assistance.

The Hexapod Robotic Spider offers a strong answer to a variety of problems in the scientific, industrial, and exploratory domains

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2. PROBLEM STATEMENTS

2.1) Low oxygen levels: Low oxygen levels, gasses, and excessive humidity can be dangerous for human workers in tight spaces, underground mines, and industries. In these kinds of environments, traditional monitoring systems might not offer mobile, real-time observation, which could present safety risks.

We propose a hexapod robotic spider. Which is capable of monitoring oxygen levels and identify dangerous gasses while navigating difficult-to-reach areas.

Fig-2.1: Tight Space (Low Oxygen area)

2.2) Toxic Garbage Area: In addition to the dangerous gasses, high humidity, and unstable terrain, toxic waste disposal sites provide serious threats to both human health and the environment. Conventional monitoring techniques expose workers to hazardous environments, raising the risk of accidents, pollution, and respiratory disorders. Accurately assessing environmental conditions and air quality is also difficult due to the absence of real-time observation and data collecting.

Fig-2.2: Toxic Garbage area

2.3) Coal Mining Area: Due to poor vision, coal mining regions provide serious risks. Classical inspection techniques frequently expose human workers to hazardous conditions like carbon monoxide poisoning, methane leaks, structural collapses, and excessive humidity.

Fig-2.3: Coal Minig Area

For miner's safety and effective mine operations, real-time monitoring and early environmental threat detection are essential. The robotic spider provides which reduces the hazards connected with coal mining operations by improving mine surveillance, enabling early danger detection, and improving worker safety

2.4) Critical unplan surface: Critical unplan surfaces rough, uneven, or unstable terrains where mobility and stability are essential are frequently difficult for traditional wheeled and tracked robotic systems to navigate. The efficacy of remote inspections is limited by these surfaces, which are present in industrial sites, disaster areas, and hazardous environments and present difficulties for real-time monitoring and data collecting.

Fig-2.4: Unplan Surface area

We create a robotic device that can successfully navigate complicated surfaces, offering improved environmental data collecting and surveillance in places where traditional robots fall behind.

3. PROPOSED SOLUTION

3.1) The Stable Web Cam View: It addresses the challenge of capturing clear and uninterrupted real-time video footage despite the movement of its six legs. Due to the dynamic nature of hexapod locomotion, vibrations and instability can affect the ESP32 camera’s feed, leading to blurry or distorted visuals. To mitigate this optimized motion control algorithms for the hexapod's legs ensure smoother transitions and balanced movement, reducing unnecessary jerks.

Fig-3.1: The Stable Web Cam View

3.2) Walking at any surface: The hexapod robotic spider's six-legged locomotion technology ensures stability and adaptation as it traverses uneven and unstructured terrain. To keep their balance when traversing unplane surface areas, each leg which is controlled by an Arduino Uno follows a precise stride pattern. The robot is appropriate for dangerous or inaccessible areas because of the incorporation of an ESP32 webcam, which enables real-time video streaming for remote monitoring, and gas and humidity sensors, which allow environmental data collecting.

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3.3) Monitoring at location: Human presence in hazardous circumstances is extremely dangerous because of the presence of toxic gasses, high humidity, and unstable terrain. In these kinds of situations, the Hexapod Robotic Spider offers a secure and effective way to monitor in real time.This robotic system improves safety in industrial, disaster response, and research applications by reducing human exposure to risks via the use of wireless connection for remote control and data transfer.

Fig-3.2: Monitor at any location

3.4) Fully IOT Biased: The Fully IoT-Based Hexapod Robotic Spider incorporates gas and humidity sensors for environmental evaluation and an ESP32-powered webcam for live video streaming, making it ideal for real-time monitoring and data collection in hazardous areas. The system uses Internet of Things connectivity to send video feeds and sensor data to the cloud, allowing for remote monitoring and analysis.

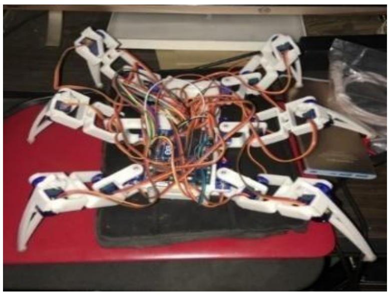

Fig-3.3: IOT Baised

4. TECHNICAL DESIGN AND METHODOLOGY

4.1) Hardware components:

A) SG90 Servo motor: Multiple servo motors are used by a hexapod robotic spider to precisely regulate its leg motions. In order to replicate the natural stride of actual spiders, each leg usually contains three servo motors: one for lifting, one for forward/backward motion, and one for rotation. Together, these servos enable walking patterns like wave, which provide stability and versatility on uneven surfaces. signals are sent to the servos, which modifies their angles to enable coordinated movement.

Fig-4.1.1: Mini SG90 servo motor

B) Arduino Uno: The Arduino Uno functions as the central control unit of a hexapod robotic spider, coordinating the robot's motions. To change the leg angles, it receives information from sensors, runs control algorithms, and instructs the servo motors. The hexapod can walk, turn, and maintain balance because the Arduino Uno manages the timing and coordination needed for complex motions and makeovers. Because of its programmability and adaptability, it is crucial for adjusting the robot's behaviors and reacting to different surroundings.

Fig-4.1.2: Arduino Uno

C) Bluetooth module hc-05: The HC-05 Bluetooth module allows wireless connection between a hexapod robotic spider and a computer or smartphone, which is a common remote-control device. Through Bluetooth, humans may give commands and direct the robot's motions, enabling real-time programming and changes. The HC-05 module receives and processes these commands, transmitting instructions to the Arduino Uno so that it may control the robot's behaviours accurately move its legs through the servo motors.

Fig-4.1.3: Bluetooth HC05 Module

D) ESP-32 Webcam: For real-time monitoring and surveillance, the ESP32-based webcam which frequently uses the ESP32-CAM module is a small and reasonably priced option. Up to 1600x1200 pixel resolutions are supported by its OV2640 or OV7670 camera sensor. The module's Bluetooth and Wi-Fi connectivity enable remote access and wireless video streaming. It supports JPEG and MJPEG image formats and features a microSD card slot for local storage. GPIO pins for extra sensors and low power consumption

Fig-4.1.4: ESP-32 with Multiple effect of ESP32 Webcam

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E) Gas Sensor: By monitoring variations in conductivity, resistance, or chemical reactions, a gas sensor can identify particular gases present in the surrounding air. Gas type (e.g., CO_2, CO, CH_4, LPG, NH_3), sensitivity (ppm or ppb range), response time (usually a few seconds), Additional variables include output type (analog, digital, or UART), precision, and working temperature (often between -10°C and 50°C).

Fig-4.1.5: Gas MQ-5 sensor

F) Humidity and Tempreture Sensor: Heat levels are detected and measured by a temperature sensor in a system, which then transforms the data into electrical impulses for control and monitoring. When necessary, it activates heating or cooling systems to help maintain ideal conditions. Thermistors, thermocouples, and digital sensors such as the DHT11 are common varieties.

Fig-4.1.6: Humidity Sensor

4.2) Model Design:

1. Lower Part:

A) 3D parts of model (Lower Part):

1. Upper Body Attachment.

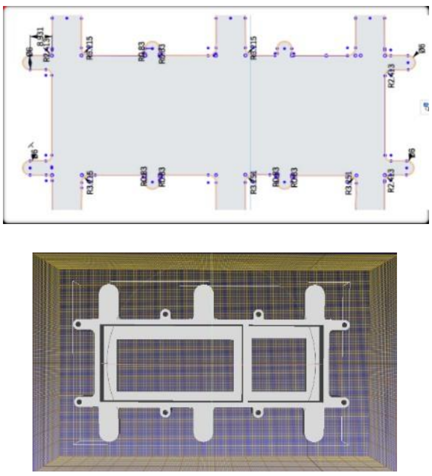
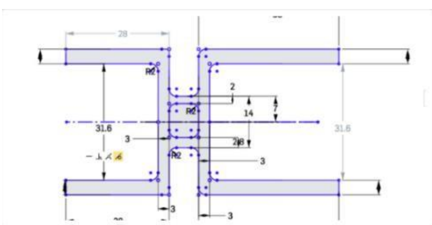


Fig-4.2.1: Upper Body Part

2. Upward leg part



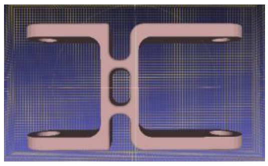


Fig-4.2.2: Upward leg Part

3. Downward leg support part

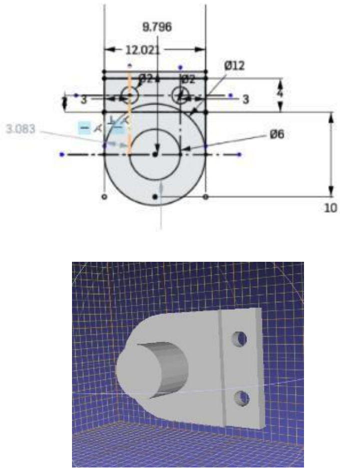


Fig-4.2.3: Downward led Part

4. Middle leg Joining part

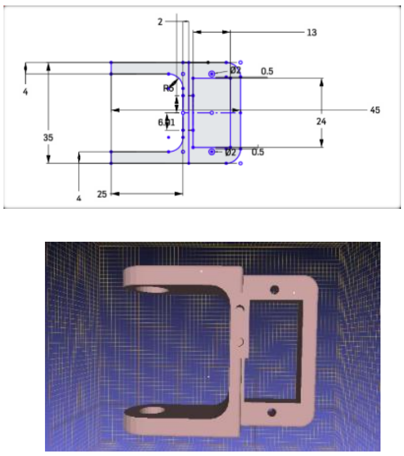


Fig-4.2.4: Middle leg joining

5. Bottom of leg

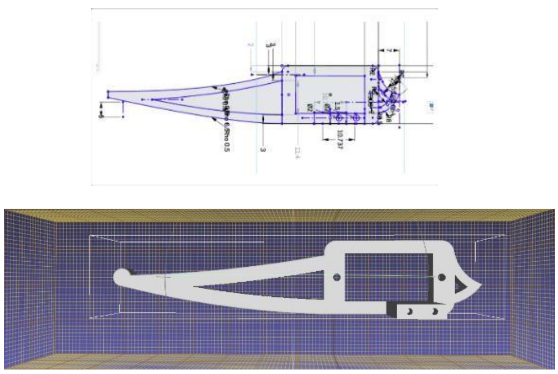


Fig-4.2.5: Bottom leg part

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B) Overall Design of Model: After the successfully assemble of whole relate parts of hexapod robotic spider it can be conclude as final stage means design of final model which design as six legs which connected with upper body attachment. Each leg has three joining parts with three servos

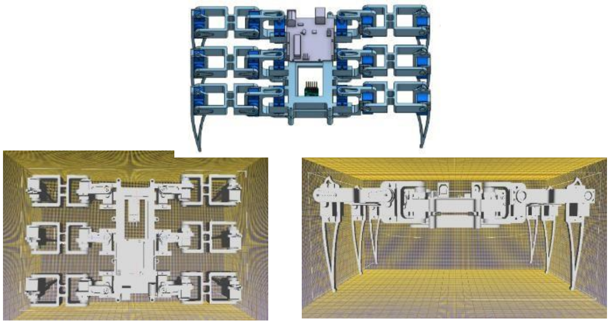

Fig-4.2.6: Overall Design of Lower model

C) Block Diagram (Lower Part):

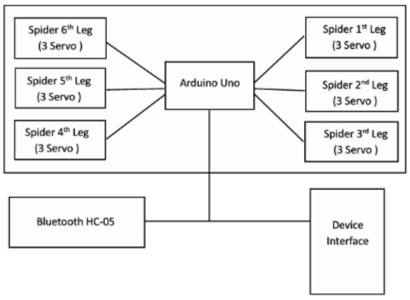

Fig-4.2.7: Block Diagram of lower model

D) Material: Select the appropriate metal to draft certain part of hexapod robot which provide the perfect stability to the robotic draft. for demonstration we use nylon filament.

Strong 3D Parts | Well As Light Weight | Freely Move

E) Connection Diagram (Lower Part): The hexapod plan highlights six legs organized in a hexagonal design, which gives adjusted stability and flexible movement capabilities. The legs should be equally divided into the central body to guaranteed uniform weigh

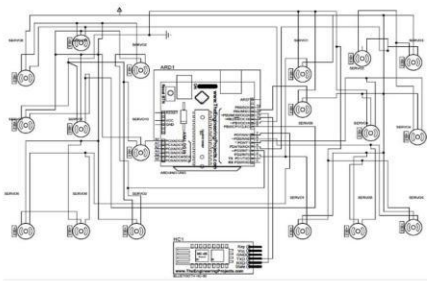

Fig-4.2.8: Connection Diagram

F) Overall Look (Lower Part):

Fig-4.2.9: Overall Look

2. **Upper Part:**

A) Overall Design of Model:

Fig-4.2.10: Overall Design of Upper model

Monitoring dangerous conditions is improved by equipping a hexapod robotic spider with an ESP32-CAM, gas sensor, and humidity sensor. Remote surveillance is made possible by the ESP32-CAM's real-time Wi-Fi video streaming capabilities. While the humidity sensor monitors moisture levels, which are essential for fire detection and air quality evaluation, the gas sensor picks up dangerous gases including CO, methane, and LPG. This mechanism makes the hexapod perfect for environmental monitoring, industrial safety, and rescue missions by allowing it to navigate hazardous locations either remotely or independently.

B) Block Diagram (Lower Part):

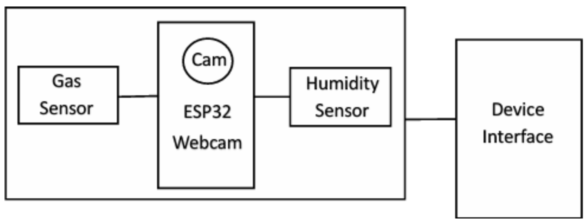

Fig-4.2.11: Block Diagram of Upper model

This block diagram represents the monitoring system of a hexapod robotic spider using an ESP32-CAM, gas sensor, and humidity sensor. Which help to build the hexapod robotic spider

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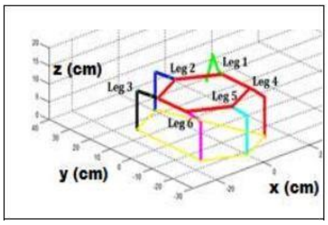
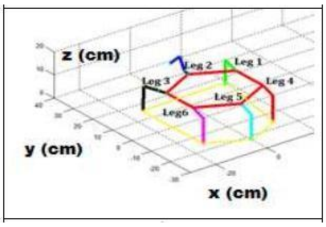
5. MODIFICATION CLASICAL STABILTY MARGINS:

Analysis of the stablility margins above for three gaits (ripple,wave and three pod) are simulated for each gait within the steps has below :

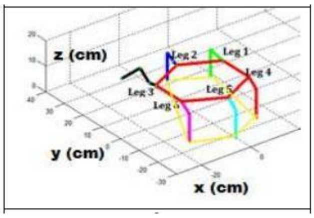
1. The Wave gait cases

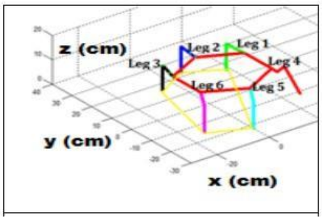




The hexapod robot's initial configuration can be seen in the first image (top left), with the legs numbered Leg 1 through Leg 6. While keeping the other legs grounded,

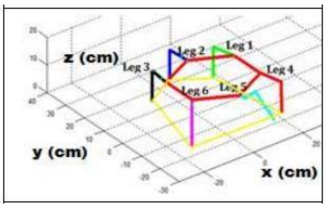
The robot begins to move its first leg (Leg 1) in the second image (middle left). Additionally, the movement is wave-like, with each leg moving repeatedly.

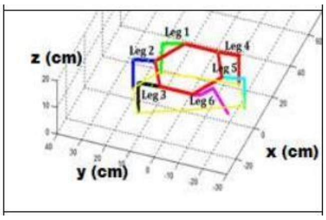




Leg 2 is raised while Leg 1 is lowered in the third image (bottom left).Legs 1 and 2 are already in place, but Leg 3 continues the movement by lifting in the fourth image (top right).

Stable and controlled locomotion is ensured by this sequential movement.

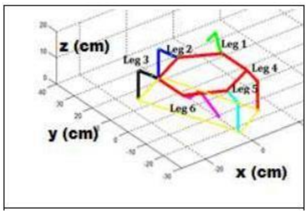


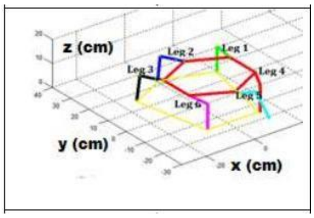


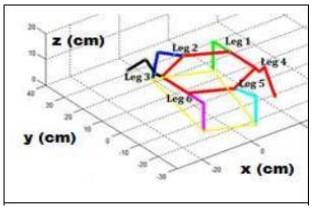
Leg 4's movement can be observed in the fifth image (middle right), which follows the same pattern as the preceding steps. The structure is now securely supported by legs 1, 2, and 3. Legs 5 and 6 finish their movement in the sixth image (bottom right),

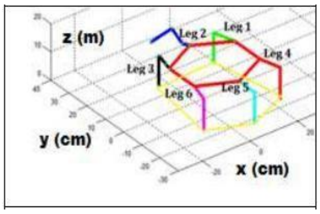
Which is the last phase of the wave gait pattern. Now that it has finished one complete wave gait cycle, the robot can walk steadily and smoothly.

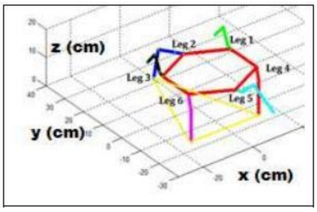
2. The ripple gait cases

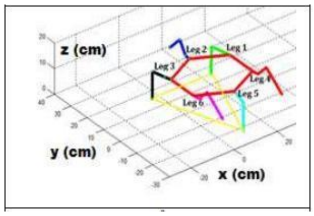












6. HISTORY OF ROBOTIC SPIDER

In 2012, Matt Denton and his company, Micro magic Systems built Mantis a huge robotic spider. That robot can move around on any surface and carry a single human.The robot is 9.18 feet (2.80 meters) tall, weighs 4,188 pounds (1,900 kg), and is pulled by a 2.2 liter, 50-horsepower Perkins Engines Turbo Diesel motor that controls the hydraulic system

Fig-6.1: Huge Robotic Spider

It can walk because of several sensors surrounding it. The robot's hydraulic solenoid in its legs is managed by Hex Engine software, which is operated on a computer running the Linux operating system.Its inventors are spending to triple the speed. Currently, the vehicle can travel 5 kilometres (3.1 mi) on a 4.5 imperial gallons (20 L) diesel tank, and it is driver-operated by joysticks within a cockpit.To overcome from that, in 2024 Todays IOT based generation The robotic spider plays on advance feature.

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7. IMPROVEMENT OF ROBOTIC SPIDER

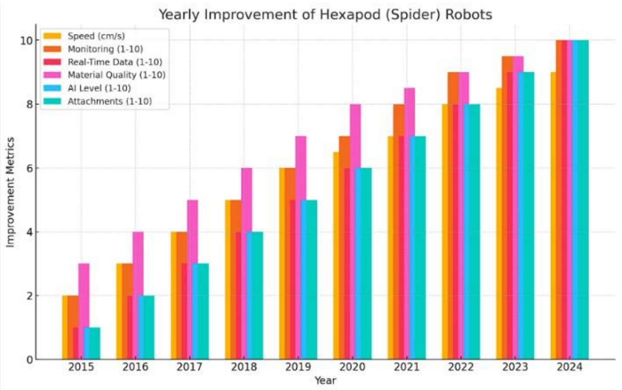

Fig-7.1: Improvement Of robot as per year

While AI and attachments are still in their early stages, hexapod robots saw incremental advancements in speed, monitoring, and material quality between 2015 and 2017. The efficiency and adaptability of the robot were increased by 2018–2020 due to notable advancements in real-time data processing, artificial intelligence capabilities, and structural quality. They became more dependable for hazardous environments in 2021 and 2022 thanks to AI-driven autonomy, quicker movement, and improved monitoring systems. All measurements, including attachments and real-time data, achieved almost maximum levels by 2023–2024, demonstrating state-of-the-art robotics technology for sophisticated applications.

8. ADVANTAGE OF ROBOTIC SPIDER

6.1) Fully Based on IOT: Relate This enables users to operate the robot from any location to monitor its status and examine performance information. The robot's functionality is improved by IoT integration, which makes it possible for automatic tasks, data logging, and communication with other smart equipment.

6.2) Small In Size: Relate with Small Size it allows Spider to do multiple Activity and Increase Movement Speed Larger robots cannot function.well in complex situations, which is why robotic spiders are used. Due to its small size, it can manoeuvre and carry out jobs in tight regions, such searching for and rescuing people, checking machinery, and investigating small spaces.

6.3) Comfortable Operating: It may operate a hexapod robotic spider in multiple ways: using a computer interface for comprehensive programming and adjustments, a mobile app via Bluetooth or WiFi for convenient control from a smartphone, or a remote-control device for real-time manual operation.

6.4) More Balancing Efficiency: Because of its six legs, which offer stability and redundancy, a hexapod robotic spider has higher balancing efficiency. With six legs, the robot can stay balanced even if one or more of them fail or run into obstacles because the other legs can make up for it.

Ability	Hexapod Robotic Spider	Automatic Car
Adaptability	Traverses rough,uneven terrain.	Limited to smooth, planned surfaces.
Webcam View	Stable view on any surface due to leg structure.	Unstable view on rocky surfaces.
Direction Change	Can change direction instantly (0-degree turn radius).	Slower direction changes.
Balancing	Maintains stability on all surfaces, including rocky areas.	Less stable on uneven terrain.
Climbing & Breaking	Can climb rocks and break hollow objects wih sharp legs.	Cannot climb or break objects.

Fig-7.1: Comparison among another model

9. WHY ROBOTIC SPIDER REALLY REQUIRED

There is the huge question for hexapod robotic spider, there are already automatic car and other devices are launched for those operations at critical places then why only robotic spider is needed why not other devices. At a critical area or place we can't be known properly how that surface be going on? What is the texture of soil? We all knows as like that places

very harmful animal or object are present that can be attract on our device and can be harm the device component so that our useable device destroyed.These are many problems were going to barrier in certain operation or task of our devices for overcoming from all that problem the hexapod robotic spider is launched

The six legs on a hexapod robotic spider allow for stability and flexibility, making it an excellent choice for traveling on slippery surfaces. The leg's ability to individually adapt to irregular surfaces helps the body stay balanced and distribute weight efficiently. This capacity makes the robot extremely useful for activities involving exploration and difficult terrain where wheeled or tracked robots could find it difficult to navigate and manoeuvre over obstacles and irregularities in the landscape.

Fig-9.1: Final Output Hexapod Robot

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10. IMPACT OF THE SOLUTION :

1. Industrial Safety and the Identification of Hazards
2. Observation of the Environment
3. Intelligent Farming
4. Military and Monitoring
5. Real-Time Data Collection
6. Disaster Response & Rescue
7. Workplace Safety in Factories & Chemical Plants

11. CONCLUSION :

Using its ESP32 webcam module, gas sensors, and humidity sensor, the hexapod robotic spider offers a reliable way to monitor in hazardous conditions in real time. It is appropriate for industrial, disaster relief, and environmental monitoring applications due to its multi-legged design, which guarantees stability and adaptability over uneven terrain. While the integrated sensors provide vital real-time data on gas levels and humidity, enhancing situational awareness and safety, the ESP32-based camera offers a live video feed, allowing remote supervision.

This experiment shows how including human safety or user safety we can monitoring at that places where human existence cannot be possible. To cover all that places we build that robot. It monitoring that place and sends real time data to user on server. Improved Mobility: Compared to conventional wheeled or tracked robots, the hexapod design enables better agility in rugged and uneven terrain. That thing unable the robot walks at any surface and make it different than other.

Collecting Data & Alerts in Real Time: By combining gas and humidity sensors, environmental hazards can be promptly detected, enhancing safety protocols which leads to enhancing durability and Check survivors for human and it provide the accurate reading of sensors data again and again until the user want

After Combining All that feature an advantage. It acts as a Super robot, which can perform multiple activity like broken Anything. He performs multiple activity among the Spider Legs. Hence, we can consider this robot is the best example for the Hazardous environment. Which monitor the critical issues, Early detection of any hazardous thing with avoiding Any harm to human being It have well known legs for Adjust According Environment or place and let it consider as big and most important part of that hexapod robotic spider.

12. REFFERENCE :

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