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DESIGN AND DEVELOPMENT OF SIX LEG SPIDER ROBOT

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ABSTRACT

Ants are six-legged insects that can carry loads ten times heavier than their body weight. Since having six-legs, they are intrinsically stable. They are powerful and can carry heavy loads. For these reasons, in this paper a new parallel kinematic structure is proposed for a six-legged ant robot. The mechanical structure is designed and optimized in Solidworks. The mechanism has six legs and only two DC motors actuate the six legs so from mechanical point of view the design is an optimal one. The robot is light weight and semiautonomous due to using wireless modules. This feature makes this robot to be suitable to be used in social robotics and rescue robotics applications. The transmitter program is implemented in supervisor computer using LabVIEW and a microcontroller is used as the main controller. The electronic board is designed and tested in Proteus Professional and the PCB board is implemented in Altium Designer. Microcontroller programming is done in Code Vision.

I. INTRODUCTION

Autonomous robots can be divided into manipulators and mobile robots. Based on locomotion on the ground, mobile robots can be further divided into wheeled robots and legged robots. Legged robots are characterized by the number of their legs. Among legged robots, six legged robots have an important place since they are compliant and stable. This class of legged robots draws special attention from the researchers all over the world, because of its fascinating nature. Most six-legged robots are inspired by insects whose legs have four degrees of freedom. However most six-legged robots' legs possess three or less degrees of freedom that reduces their mobility. Using four DOFs for each leg enlarges the workspace of the leg and makes it redundant. Ant is one of the creatures that can carry loads ten times heavier than its body weight. This paper demonstrates design, mechanical simulation and implementation of a new six legged robot called AntBo t I inspired by ants. Initially mechanical design and simulation of the robot using Solid works is presented and mechanical parameters of the robot are extracted. The new proposed kinematic structure has parallel mechanism. The actuators are chosen based on the maximum torques required. The two actuators drive the six legs, so from mechanical point of view the design is optimal. Afterwards mechanical implementation and electronic implementation are presented. The electrical circuit and Printed Circuit Board (PCB) of the robot are designed and tested using Proteus Professional and Altium Designer respectively. To make the robot autonomous, two wireless modules are used and the transmitter's program is programmed and tested using LabVIEW software.

II. LITERATURE REVIEW

The concept of a six-legged spider robot has garnered significant attention due to its potential applications in various fields, including search and rescue, military surveillance, and environmental monitoring. The research on multi-legged robots, particularly spider like robots, explores various aspects, such as kinematics, control systems, locomotion strategies, and design techniques.

- **Locomotion and Gait Planning:** A crucial aspect of multi-legged robots is their ability to move in complex environments. Researchers have proposed various gait algorithms inspired by biological systems. These gaits, like walking, running, or climbing, enable the spider robots to move efficiently across uneven terrains. Most studies focus on the design of stable and energy-efficient gaits, such as the tripod gait (using three legs at a time) or wave gait (alternating leg movements).
- **Kinematics and Dynamics:** The kinematics of six-legged robots involves the design of a body structure and leg movements that ensure stability while walking. Several studies have explored inverse kinematics (IK) and forward kinematics (FK) models to determine leg positions and motions based on the robot's body frame. Dynamic control approaches also help handle real-time external disturbances and forces, such as those encountered during locomotion on different surfaces.

- **Design and Control Systems:** The mechanical design of spider robots often involves lightweight materials to maintain stability while carrying payloads. Leg design, including actuators, joints, and materials, is crucial for achieving effective locomotion. Most robots use servo motors or hydraulic actuators to control the movements of the legs. In terms of control, algorithms ranging from simple open loop controls to advanced machine learning-based approaches are used to manage locomotion, obstacle navigation, and environmental interaction.
- **Applications:** Various applications are driving the development of spider robots. For example, in search and rescue operations, a six-legged robot can maneuver in environments where traditional wheeled robots cannot, such as rubble or rocky terrain. In the military, spider robots are used for reconnaissance, as they can avoid detection and traverse diverse environments. Spider robots can navigate tough terrain to collect data in remote locations.

III. METHODOLOGY

The development of a six-legged spider robot typically follows a structured methodology involving the design, simulation, prototyping, and testing phases. Below is an outline of the methodology

1. Design Phase:

Mechanical Design:

- **Leg Design:** Design each leg with multiple joints (typically three or four degrees of freedom per leg), using lightweight materials such as carbon fiber or plastic for structural components. Each leg must have actuators (e.g., servo motors) that control its movement.
- **Body Structure:** Design the body to be lightweight but stable enough to support the actuators and any sensors/payloads. The body should have a central processing unit (CPU), battery compartment, and mounting points for sensors.
- **Sensor Integration:** Integrate sensors like cameras, proximity sensors, gyroscopes, or LIDAR to aid in navigation, obstacle detection, and environmental awareness.

2. Kinematic Modelling: ‘

- **Inverse Kinematics (IK**): Develop the inverse kinematics model to calculate the necessary leg joint angles to reach a desired foot position.
- **Forward Kinematics (FK):** Develop the forward kinematics model to determine the position of each foot based on given joint angles.
- **Trajectory Planning:** Plan the paths that each leg must take during movement, considering the robot's gait and the terrain. This often involves real-time calculations based on sensory data.

3. Control System:

- **Gait Generation:** Implement gait generation algorithms (such as tripod, wave, or ripple gaits). Each leg moves in a coordinated manner to ensure stability and efficient motion.
- **Stability Control:** Develop stability algorithms that dynamically adjust the gait based on feedback from sensors, ensuring the robot maintains balance in the face of external disturbances.
- **Motion Control:** Use techniques like PID controllers or more advanced machine learning-based controllers to manage the precise movement of each leg.

4. Prototyping:

- **Hardware Development:** Manufacture or 3D print the robot's body and legs, ensuring that all components fit together properly and can withstand the mechanical loads during movement.
- **Actuators and Motors:** Install servo motors or other actuators, ensuring they can provide enough torque for the legs to move efficiently and precisely.
- **Sensor Integration:** Integrate sensors to provide feedback on position, orientation, and external obstacles.

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Design and Implementation

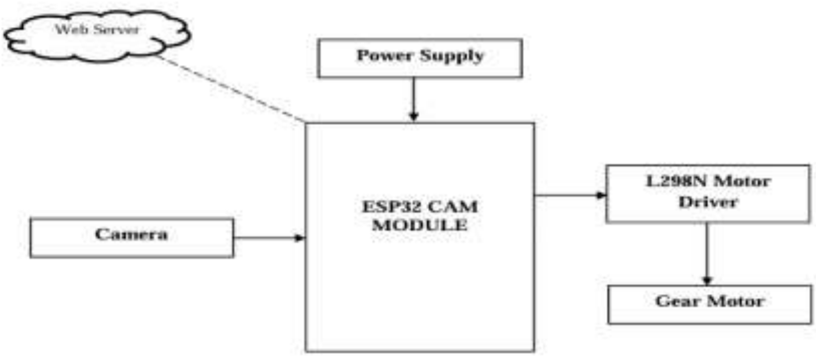
The six-legged robot (also known as a hexapod) is inspired by the movement of real spiders or insects. Each leg moves independently, which allows for high mobility and stability. The design will consist of several key components:

- **Body Frame:** Holds all components together.
- **Legs:** Six legs with multiple joints, typically using actuators for movement.
- **Actuators**: Motors or servos used to control the movement of each leg.
- **Sensors:** To help with navigation, obstacle avoidance, or feedback (e.g., cameras, infrared sensors).
- **Controller:** A microcontroller or processor that processes input and sends commands to the actuators.

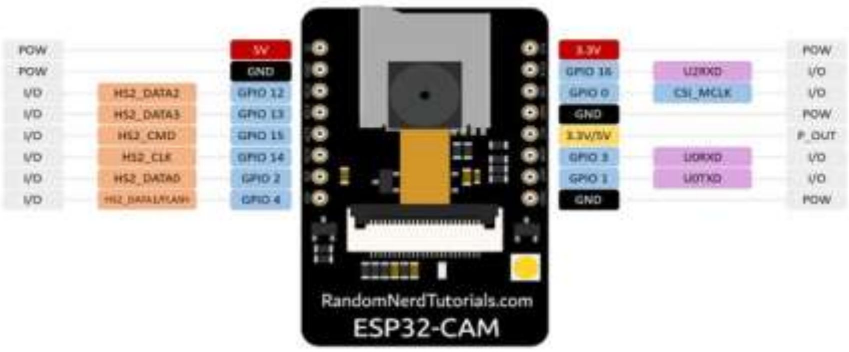
Description Hardware

- Esp32 Cam Module
- L293d Motor Driver
- Battery Operated Gear Motor
- Rechargeable Battery

Block Diagram



ESP32 Cam Module



The ESP32-CAM module is a low-cost, powerful microcontroller with integrated Wi-Fi and Bluetooth capabilities, designed for applications that require both video and wireless communication. It is primarily used for image capture and video streaming but can also be applied in other IoT (Internet of Things) projects.

Specifications of ESP32-CAM Module

- **Microcontroller:** ESP32 (Dual-core 32-bit CPU)
- **Camera:** OV2640 camera module (2MP resolution)
- **Wi-Fi:** IEEE 802.11 b/g/n
- **Bluetooth**: Bluetooth v4.2 BR/EDR and BLE
- **Operating Voltage**: 5V (through the 5V pin)

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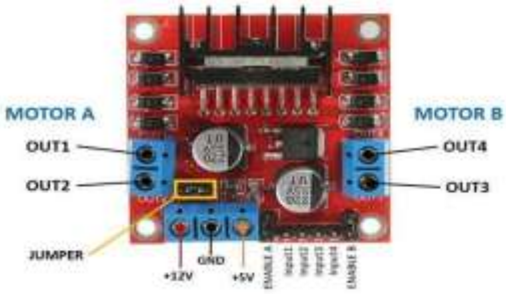
- **GPIO Pins:** 9 GPIO pins available for input/output
- **Storage:** External micro SD card support (up to 4GB)
- **Programming Interface**: USB to serial interface for uploading programs
- **Audio:** Not supported directly (requires external components)
- **Camera Features:** Supports various image capture modes (JPEG, BMP, etc.)
- **Power Consumption:** Low power consumption in deep sleep mode
- **Dimensions:** Compact size (approx. 27mm x 40mm)
- **Support for I2C, SPI, UART:** For interfacing with external sensors and peripherals

L293D Motor Driver



The L293D motor driver works by using an H-Bridge configuration, which allows the current to flow in either direction, thus enabling the motor to rotate in both directions. It has two channels, each capable of driving a single motor. By controlling the input pins, you can change the direction, speed, and enable/disable the motor.

L293D Motor Driver Specifications

- **Logic Supply Voltage (VCC):** 4.5V to 5.5V
- **Motor Supply Voltage (VM):** 4.5V to 36V
- **Continuous Output Current per Channel:** 600mA
- **Peak Output Current per Channel:** 1.2A (for short periods)
- **Input Pins:** Four pins (IN1, IN2, IN3, IN4) for controlling motor direction
- **Enable Pins:** Two pins (Enable 1 and Enable 2) for motor activation
- **Operating Temperature Range:** -40°C to 85°C
- **Output Voltage:** Up to 36V for motor operation
- **Package Type:** Available in 16-pin DIP or SMD
- **Protection Features:** Thermal shutdown and overload protection

BATTERY OPERATED GEAR MOTOR

The 5V BO gear motor operates by converting electrical energy from a 5V DC supply into mechanical energy through a motor and a built-in gearbox. The motor turns at a high speed, but the gearbox reduces the speed and increases the torque. This makes it suitable for applications that require controlled, slower movement with higher force, such as driving wheels, actuators, or small mechanical systems.

- **Motor Input:** 5V DC power.
- **Gearbox:** Reduces the speed of the motor while increasing torque, making it ideal for low-speed, high-torque applications.

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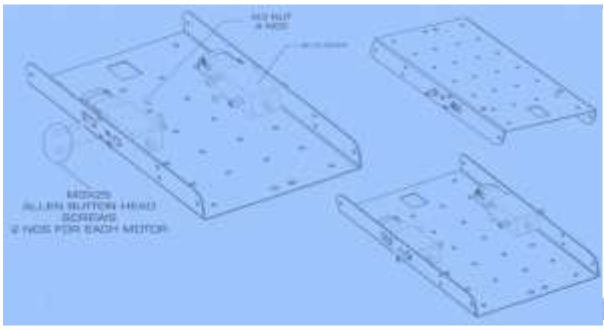
- **Output Shaft:** The rotating output shaft drives mechanical parts, like wheels or gears.

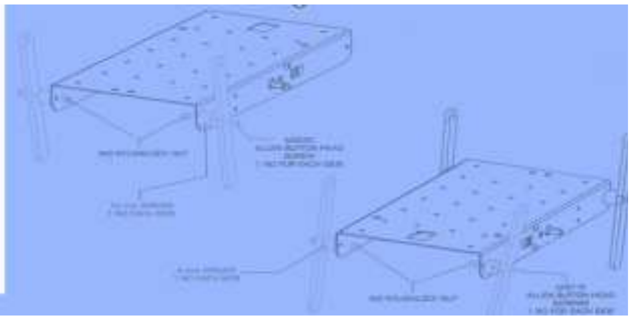
RECHARGEABLE BATTERY

A 2000mAh 3.7V rechargeable battery is a common type of lithium-ion or lithium polymer battery used in various electronic applications such as robotics, drones, portable devices, and power banks. The battery provides a balance of capacity and voltage, making it suitable for medium-power devices that require a stable power source.

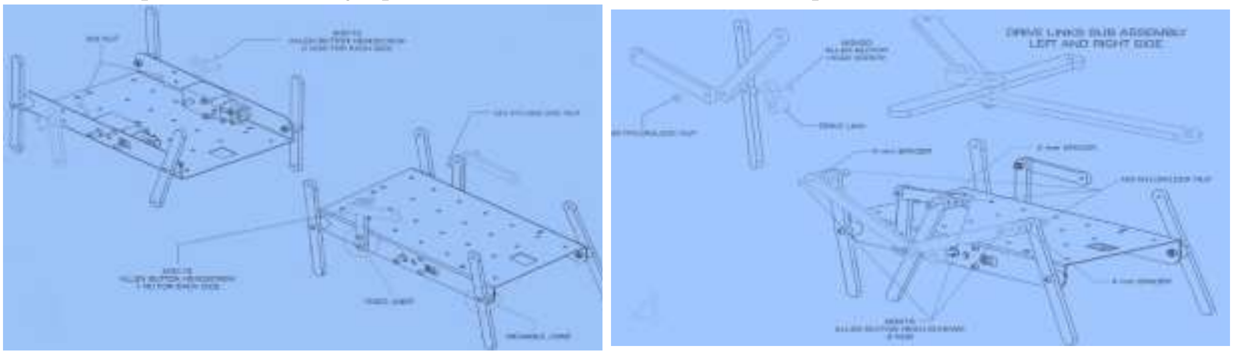
Mechanical Design and Simulation



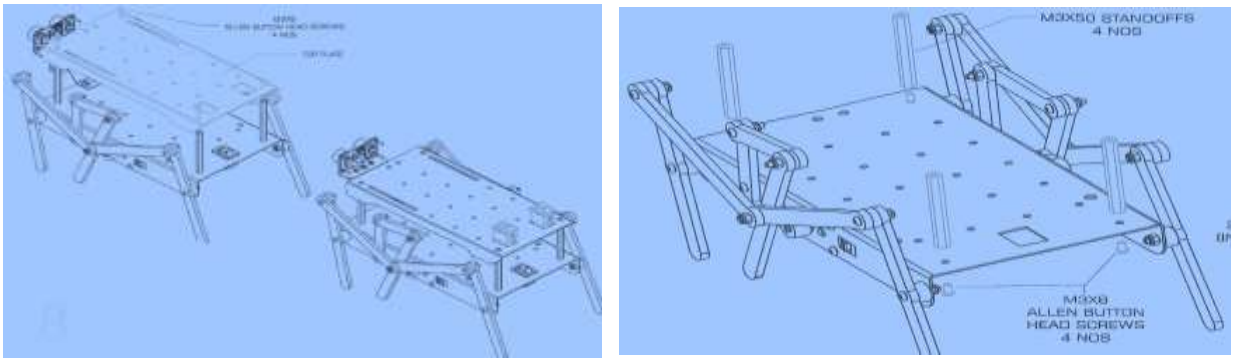
Chassis plate with battery operated motor



Chassis plate with kinematic link



Assembly 01



Assembly 02

Choosing Chassis and Legs Material

- The chassis and legs of the robot can be made from different materials. Wood, plastic, fiberglass and aluminum are good candidates for chassis and legs material.
- After studying the properties of these materials, the chassis and legs of the robot are chosen to be aluminum due to its light weight, low cost and corrosion resistance.
- To provide friction under legs of the robot and to make the locomotion of the robot smoother and easier and also to smoothen under legs and obstacle avoidance, interfacial adhesive is used
- To mount IR sensor or camera, a head is also designed for the robot. The head can also be used to mount a manipulator.

IV. RESULTS AND DISCUSSION

The result of implementing a 6-legged spider robot (hexapod) will depend on various factors such as design, functionality, and performance. However, after successfully designing, constructing, and programming the robot, the expected outcomes can be summarized in the following areas:

1. Physical Movement and Gait Patterns
2. Stability and Mobility
3. Control and Coordination
4. Applications and Potential Features

Top View

Side View

Final Assembly

Front View

V. APPLICATIONS

- **Search and Rescue:** They can move over rubble or rough terrain to find people.
- **Exploration:** Useful for exploring other planets or caves where wheels can't go.
- **Military**: Used for spying or carrying equipment in tough areas.
- **Inspection:** Checking pipes, bridges, or other hard-to-reach places.
- **Agriculture:** Monitoring crops or soil in uneven fields.
- Boiler inspection and maintenance

VI. ADVANTAGES

- Can work with lower sound
- Stronger to work in bad terrain
- Can move more freely on irregular surface
- More efficient movement mechanism
- This linkage structure allow to provide all direction motion to combination of 6 legs
- Climbing ability

- Mobility and flexibility

VII. DISADVANTAGES

- Hard to build: Six legs are tricky to design.
- Uses more power: More legs mean more energy needed.
- Big and heavy: Six legs make it less portable.
- Expensive: Costs more to make.
- They need maintenance to keep them running
- Robot need a supply of power

VIII. CONCLUSION

The development of a six-legged spider robot involves a comprehensive approach that combines mechanical design, advanced control systems, and robust testing methodologies. The goal is to create a robot capable of autonomous operation in challenging environments, with potential applications ranging from rescue missions to military surveillance and environmental monitoring. Each stage, from design to testing, plays a critical role in ensuring that the robot performs its tasks effectively and efficiently. In this paper, design, simulation and implementation of a new six-legged ant robot was proposed. The kinematic structure of the robot was parallel and only two motors were used to actuate the six legs. The mechanical structure was designed using Solidworks. The robot can walk and turn and because of using wireless modules it is semiautonomous. The transmitter program was implemented using LabVIEW on the supervisor computer and five modes of operation were defined for the robot. The robot is light weight and can mimic the ant.

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