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A Centipede Inspired Robot

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Abstract - This project details the engineering of a four-segment, centipede-inspired modular robot designed for stable navigation and real-time data acquisition. By transitioning from a monolithic frame to a decentralized Robo Kit Chassis architecture, the system achieves a balance between structural rigidity and modular flexibility. Each module is constructed from a modified industrial-grade chassis, providing a consistent mounting platform for propulsion, power, and computational components. The propulsion system utilizes a distributed drive array consisting of six high-torque DC gear motors managed by three L298N H-bridge drivers. To ensure real-time responsiveness, the control architecture is split into a Master-Slave hierarchy. A Raspberry Pi 4 handles high-level processing, including the NoIR Camera stream and sensor fusion, while an ESP32-C6 manages low-level pulse-width modulation (PWM) signals to the motor drivers. This configuration ensures that computational heavy-lifting does not interfere with the precise timing required for synchronized movement across the four segments. A critical feature of the design is the dual-rail power strategy, utilizing two 2200mAh LiPo batteries distributed across Modules 2 and 4. This approach isolates inductive motor loads from sensitive logic components, significantly reducing the risk of brownouts or signal noise. The third module serves as the Intelligence Hub, housing the Pi 4 and ESP32-C6. To further protect these components from mechanical vibration and electrical interference, this module utilizes passive free-spinning wheels, decoupling the primary processing units from the torque-heavy propulsion segments. The resulting improvised centipede robot offers a robust solution for exploring confined environments. The combination of distributed DC propulsion, Wi-Fi 6-enabled microcontrollers, and localized power regulation creates a platform that is both computationally powerful and mechanically resilient.

Keywords: Modular Robotics, Distributed Propulsion, L298N Motor Control, ESP32-C6, Raspberry Pi 4, Power Isolation

INTRODUCTION

The field of mobile robotics has seen a significant shift toward bio-inspired designs, moving away from rigid, monolithic structures in favour of articulated, multi-segmented systems. Among these, centipede-inspired robots represent a unique category designed to navigate complex, confined, and hazardous environments where traditional wheeled or tracked platforms often fail. This project details the design, implementation, and optimization of an improvised modular centipede robot, engineered specifically for high-torque propulsion and real-time environmental monitoring. By utilizing a decentralized architecture and a master-slave computational hierarchy, the robot achieves a level of mechanical resilience and data-processing capability suitable for industrial exploration.

Historically, the primary challenge in modular robotics has been the trade-off between mechanical complexity and power stability. Large, multi-segmented robots require significant torque to move, which in turn demands high-current power sources. However, the electromagnetic interference (EMI) and voltage fluctuations generated by heavy-duty motors often lead to brownouts or signal corruption in sensitive microcontrollers. This project addresses these issues through a strategic four-module design that prioritizes the physical and electrical isolation of computational logic from inductive motor loads.

The structural foundation of the robot consists of four modular body segments derived from an industrial-grade Robo Kit Chassis. In a move toward structural consistency and cost-efficiency, the chassis plates are modified by bisecting them, creating uniform modules that provide a stable mounting surface for all internal components. This rigid aluminium chassis allows for more precise alignment of the propulsion system, which is critical when coordinating six independent gear motors across multiple segments.

The propulsion and power distribution are spread across the modules to ensure a balanced centre of gravity and redundant drive capabilities. Module 1 (the front) and Module 2 each house a pair of DC gear motors driven by L298N H-bridge drivers, providing the initial pulling force for the robot.

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Module 4 serves as the rear drive unit, pushing the frame forward to prevent dragging on high-friction surfaces. To power this energy-intensive array, the system utilizes a distributed dual-battery strategy. Two 2200mAh 2S LiPo batteries are positioned on Modules 2 and 4, respectively. This arrangement allows the robot to draw from separate high-discharge pools, ensuring that the motor drivers can pull the necessary current for climbing obstacles without depleting the voltage required for the brain of the system.

At the heart of the robot lies a sophisticated computational hub located on Module 3. This module is uniquely designed with free wheels, meaning it lacks active propulsion. This intentional decoupling serves to isolate the Raspberry Pi 4 and the ESP32-C6 microcontroller from the mechanical vibrations and electrical noise generated by the drive motors. In this hierarchical setup, the Raspberry Pi 4 acts as the Master, managing high-level tasks such as the NoIR Camera stream and complex sensor data processing. The ESP32-C6 serves as the Slave, dedicated to real-time motor control and low-level pulse-width modulation (PWM) to the L298N drivers. The inclusion of the ESP32-C6 is particularly advantageous due to its Wi-Fi 6 capabilities and RISC-V architecture, which ensure low-latency communication and efficient multitasking when reading environmental sensors like the MQ-2 and MQ-135.

Ultimately, this project demonstrates that an improvised approach utilizing modified chassis components and high-current buck converters can produce a robust robotic platform capable of surviving the rigors of hazardous environment exploration. By separating vision, power, and logic into distinct modular segments, the design achieves a level of stability and redundancy that exceeds traditional single-chassis robots.

RELATED WORK

A significant source of inspiration for this project comes from the work of Ground Control Robotics, particularly their serpentine and multi-legged inspection robots. Their products, like the SCUTTLE, are engineered for durability and reliability in harsh industrial environments, such as crawling through long stretches of pipe for inspection. The key takeaway from their philosophy is the emphasis on creating a robust, practical tool rather than just a laboratory prototype. This project will adopt their focus on sealed, durable segments to protect the internal electronics from dust and moisture—a critical feature for rescue and industrial applications. Furthermore, their approach to creating powerful, high-traction locomotion in a slim profile directly informs the goal of making this centipede robot capable of navigating real world, challenging environments effectively

PROPOSED SYSTEM

The evolution of autonomous exploration requires robotic platforms capable of traversing non-linear, unpredictable, and often hazardous terrains. Conventional single-body wheeled robots frequently encounter limitations in high-friction or confined spaces, such as industrial pipelines or collapsed structural environments. To address these challenges, the proposed system introduces a multi-segmented, centipede-inspired modular robot. This system leverages a decentralized hardware architecture, a dual-rail power strategy, and a hierarchical control network to provide a robust solution for real-time environmental monitoring and navigation.

The physical foundation of the robot is built upon a modular philosophy, utilizing four distinct body segments designed for both structural rigidity and articulated flexibility. This system utilizes a modified Robo Kit Chassis. By bisecting standard industrial chassis plates, the design produces uniform, heavy-duty modules that offer a consistent and stable mounting environment for internal electronics.

The distribution of these modules follows a strategic functional mapping. Module 1 serves as the lead unit, housing the primary visual sensors. Module 2 and Module 4 act as the primary power and propulsion hubs. Module 3 is designated as the Logic Centre, intentionally isolated from the mechanical strain of propulsion to protect the primary computational units. This segmentation allows the robot to snake through narrow apertures while maintaining a low centre of gravity across its entire frame.

Locomotion is achieved through a distributed drive array consisting of six high-torque DC gear motors. Unlike standard servo-driven walking gaits, this system utilizes a continuous-drive approach managed by three L298N H-bridge drivers. These drivers are strategically placed: one on Module 1 to provide pulling torque, one on Module 2 for mid-section stability, and one on Module 4 to provide pushing force from the rear.

A critical design choice is the implementation of free-spinning wheels on Module 3. By removing active propulsion from the module carrying the central processing units, the system effectively decouples the brains of the robot from the intense vibrations and electromagnetic interference (EMI) generated by active DC motors. This mechanical isolation ensures that the high-frequency oscillators within the microcontrollers remain stable, preventing system-wide crashes or sensor data corruption during high-torque maneuvers.

The nervous system of the proposed robot follows a Master-Slave hierarchy designed to balance high-level

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processing with real-time hardware execution. The Raspberry Pi 4 (Module 3) serves as the Master node. It is responsible for managing the high-bandwidth NoIR Camera feed and performing complex data fusion from the environmental sensor suite, which includes MQ-2, MQ-135, and Oxygen sensors.

The ESP32-C6 acts as the Slave controller, dedicated exclusively to the low-level management of the L298N drivers via pulse-width modulation (PWM). The selection of the ESP32-C6 is pivotal; its Wi-Fi 6 capabilities and RISC-V architecture allow for ultra-low latency communication with the Master node. This ensures that when the operator issues a movement command, the ESP32 can adjust the speed of all six motors simultaneously, maintaining the synchronized forward momentum required for a multi-segmented vehicle.

To sustain a payload and six independent motors, the system employs a sophisticated dual-rail power strategy. Power is sourced from two 2200mAh 2S LiPo batteries. LiPo battery powers the L298N drivers on Modules 1 and 2. The second LiPo battery powers the Raspberry Pi 4, the ESP32-C6, and the L298N on Module 4 through high-efficiency buck converters. A 5A Buck Converter provides a steady 5.1V to the computational hub. A Common Ground is established across all four modules to provide a consistent reference for the I2C and Serial data signals, while the positive rails remain strictly separated to maintain electrical purity for the logic sensors.

The robot's ability to perceive its environment is driven by a specialized sensor array located at the head of the centipede. The NoIR Camera provides high-definition video feedback, even in low-light industrial environments. Because the Pi 4 is on Module 3 and the camera is on Module 1, the system utilizes an extended 50cm CSI ribbon cable, which is shielded to prevent EMI from the nearby gear motors. Complementing the visual feed is a chemical detection suite. The MQ-2 sensor monitors for flammable gases like LPG and Propane, while the MQ-135 tracks air pollutants such as Ammonia and CO2. By analyzing the delta between these two sensors, the system can distinguish between a fire hazard and general air toxicity, providing critical data to the remote operator.

The user interface is facilitated through a Triple-Node Communication link. To ensure stability, a laptop serves as a local host server. The Raspberry Pi 4 streams video and sensor data to the laptop via a Wi-Fi 6 link. The laptop then transcodes this data and serves it to a Mobile Application. This app serves as the operator's Command Center, featuring a virtual joystick for movement and live gauges for gas concentrations and battery health. By using the laptop as a bridge, the system gains the ability to log massive amounts of mission data for post-exploration analysis without taxing the Raspberry Pi's limited storage resources.

The proposed modular centipede robot represents a comprehensive synthesis of mechanical engineering and IoT integration. By utilizing a bisected chassis design, a hierarchical control system, and isolated power domains, the robot overcomes the traditional failures associated with high-weight, multi-motor platforms. This improvised yet highly engineered system provides a scalable, resilient model for the next generation of exploration and rescue robotics.

WORKING

The hardware operation of the modular centipede robot represents a sophisticated mechanical ballet, where electrical energy is systematically converted into high-torque locomotion and real-time environmental awareness. The system's physicality is defined by its four-segment Robo Kit Chassis, which provides the structural rigidity required to support a payload while maintaining the flexibility of an articulated multi-segmented frame.

At the heart of the robot's movement is a distributed array of six DC gear motors managed by three L298N H-bridge drivers. The hardware logic follows a Push-Pull methodology. The L298N drivers on Modules 1 and 2 receive Pulse Width Modulation (16M) signals from the ESP32-C6 to engage the forward four motors, effectively pulling the robot. Simultaneously, the driver on Module 4 engages the rear motors to push the frame, ensuring that the 4-module assembly does not buckle or drag during high-friction maneuvers.

The L298N drivers function as high-current gatekeepers. They take 3.3V logic pulses from the microcontroller and translate them into a 6.0V to 7.4V output capable of driving the gear motors. By varying the duty cycle of these PWM signals, the hardware allows for precise speed control and differential steering, enabling the centipede to navigate tight industrial corridors

A critical aspect of the hardware's working is the dual-rail power isolation strategy. Utilizing two Pro-Range 2200mAh 30C LiPo batteries, the system separates the noisy motor power from the clean logic power.

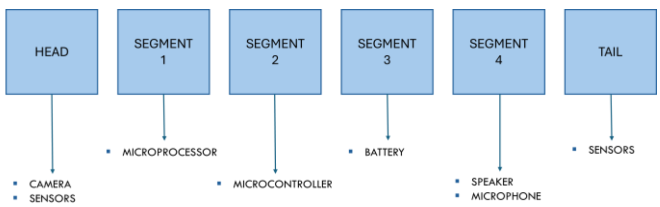

Fig1: Block Diagram of System Architecture

Finally, Module 3 serves as the stabilized Nervous System. By utilizing passive free-spinning wheels, this module remains physically decoupled from the intense vibration of the drive motors. This ensures that the physical hardware of the Raspberry Pi**,** particularly its sensitive SD card slot and GPIO pins remains mechanically secure throughout the mission.

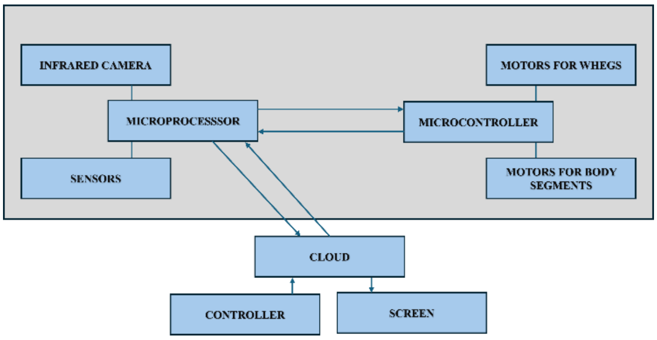

Fig2: Work Flow of the System

The software framework of the centipede robot functions as a sophisticated, multi-layered digital nervous system that orchestrates the interaction between high-level artificial intelligence and low-level hardware execution. Operating primarily on a Raspberry Pi 4 (Master) and an ESP32-C6 (Slave), the software utilizes a Python-based asynchronous model to ensure that the robot remains responsive while performing intensive tasks such as real-time object detection and high-definition video streaming.

SCOPE OF THE PROJECT

This project possesses a broad scope, with its core strength lying in its ability to access and operate in environments that are inaccessible or too hazardous for humans and conventional robots. One of its most immediate and impactful applications is in Search and Rescue operations. Following disasters like earthquakes, the robot's slender, flexible body can navigate through small gaps in rubble that are impossible for larger robots to enter. Equipped with a night vision camera, it serves as a remote set of eyes for rescue teams, locating survivors and assessing structural stability from within without risking further collapse or human life.

In the industrial sector, the centipede robot is a powerful tool for preventative maintenance. Its form factor is perfectly suited for crawling through pipelines, ventilation systems, or the intricate interiors of large machinery to inspect for cracks, blockages, or wear. Furthermore, the robot can operate in hazardous environments, such as pipes containing toxic residue or extreme temperatures, providing a much safer inspection solution than sending in human workers.

The robot's design is also ideal for environmental monitoring and scientific exploration. It can be deployed to map unexplored cave systems, navigate fragile ecosystems with minimal disturbance, or collect data from hazardous zones like abandoned mines or radioactive sites. By equipping it with specialized sensors for air quality, temperature, or radiation, it becomes an autonomous data-gathering platform.

For security and surveillance, the robot offers a unique platform for stealthy reconnaissance. Its low profile and quiet movement make it suitable for patrolling perimeters, inspecting the undercarriages of vehicles, or conducting surveillance inside buildings without being easily detected.

The future scope of this project is heavily tied to advancements in AI and swarm intelligence. By integrating object detection models like YOLO, the robot can transition from a remotely operated device to a fully autonomous agent capable of executing missions like 'explore and map' or 'find heat signatures' without human intervention.

ADVANTAGES

The development of the modular centipede robot represents a significant advancement over traditional monolithic robotic platforms, particularly for applications in industrial exploration and hazardous environment monitoring. By synthesizing a decentralized mechanical architecture with a hierarchical software control system, the project achieves a level of mechanical resilience, electrical stability, and computational intelligence that is often unattainable in single-chassis designs. The following analysis details the specific strategic advantages offered by this improvised yet highly engineered platform.

The primary advantage of the four-segment articulated chassis is its ability to navigate complex, non-linear environments. Traditional rigid-frame robots frequently encounter high-centering or wedging issues when traversing uneven debris or tight industrial pipelines. In contrast, the centipede-inspired design allows the mass to be distributed across four independent modules linked by flexible pivot points. This allows the robot to snake through narrow apertures, maintaining continuous contact with the ground even on irregular surfaces.

Furthermore, the distributed propulsion system utilizing six independent DC gear motors provides a high degree of mechanical redundancy. In standard four-wheeled robots, the failure of a single motor or the loss of traction on one corner can lead to a complete mission failure. In this modular system, the push-pull force is spread across three distinct segments (Modules 1, 2, and 4). If a motor in the front segment encounters an obstacle or suffers a mechanical stall, the remaining four motors in the middle and rear segments provide sufficient torque to propel the entire frame forward or facilitate a safe extraction.

The decision to utilize a Master-Slave computational architecture between the Raspberry Pi 4 and the ESP32-C6 offers a critical advantage in processing efficiency. In many hobbyist builds, a single controller is tasked with managing high-level AI, video streaming, and low-level motor timing simultaneously, often leading to jitter or system crashes under heavy loads. In this proposed system, the Raspberry Pi 4 is dedicated exclusively to high-bandwidth tasks, such as running the YOLOv8 real-time object detection model and hosting the Flask web server. Meanwhile, the ESP32-C6, powered by its high-performance RISC-V core, handles the time-critical reflexes of the robot, including pulse-width modulation (PWM) for the six motors and real-time analog polling of the MQ-2 and MQ-135 sensors. This division of labor ensures that the robot's locomotion remains instantaneous and smooth, even while the primary processor is performing intensive visual analysis of the environment.

One of the most profound technical advantages of the project is the implementation of a dual-rail power isolation strategy. By utilizing two separate 2200mAh 30C LiPo batteries, the system physically separates the noisy inductive loads of the motors from the clean logic signals of the microcontrollers. This configuration effectively eliminates voltage sags the sudden drops in power that occur when a motor stalls which are the leading cause of unexpected reboots in autonomous vehicles.

This isolation, supported by a common ground reference and high-current buck converters, ensures that the NoIR Camera stream remains flicker-free and that the gas sensors provide accurate, drift-free data. The resulting signal integrity allows the robot to operate at maximum torque without compromising the stability of its digital nervous system.

Finally, the Triple-Node Communication link (Robot to Laptop to Mobile App) provides the operator with unparalleled situational awareness. By utilizing a laptop as a host bridge, the system offloads heavy data logging and video transcoding from the robot's onboard processors, preserving thermal headroom and battery life. The integrated Heads-Up Display (HUD) merges live video with real-time chemical and thermal data, allowing an operator to identify invisible hazards, such as a methane leak detected by the MQ-2 while simultaneously navigating visually through the NoIR feed. The addition of Telegram Bot integration serves as a final strategic layer, ensuring that high-resolution evidence of detected hazards is transmitted to off-site supervisors instantly, creating a robust, multi-layered surveillance network.

CONCLUSION

The development of the modular centipede robot confirms the viability of distributed, multi-segmented architectures for complex exploration tasks in hazardous environments. By synthesizing a robust mechanical frame with a sophisticated Master-Slave computational hierarchy, the project successfully demonstrated that a modular approach provides superior maneuverability and electrical stability compared to traditional monolithic designs. The mechanical success of the platform was rooted in the strategic modification of a bisected aluminum chassis. A critical engineering milestone was the isolation of the Raspberry Pi 4 and ESP32-C6 on a passive, free-spinning module, which effectively protected the sensitive logic from the mechanical vibrations and electrical noise of the propulsion system. Electrically, the project validated the dual-rail power isolation strategy. The use of separate 2200mAh 2S LiPo batteries for the motor and logic domains proved essential in maintaining signal integrity. This configuration eliminated the risk of voltage sags during high-torque maneuvers, ensuring that the NoIR Camera and MQ-series gas sensors provided stable, drift-free data to the remote operator. Software integration further elevated the project's utility through the implementation of a Triple-Node Communication link. By leveraging the YOLOv8 framework and a Flask-based Heads-Up Display, the robot transformed raw environmental data into an intuitive, actionable interface. Ultimately, this project provides a scalable blueprint for the next generation of low-cost, high-performance exploration robots. The successful synchronization of multiple modules, isolated power rails, and AI-driven vision proves that sophisticated robotic capabilities can be achieved through the strategic integration of accessible hardware. This platform stands as a resilient solution for industrial monitoring and search-and-rescue missions, where the ability to navigate the unpredictable is the ultimate measure of success.

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