User Controlled Hexapod with live stream for rescue operations

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Abstract

The increased frequency of natural disasters poses new challenges to traditional search-and-rescue (SAR) operations. This article presents a six-legged robot platform, "Rescue-Feet," that enhances mobility across difficult terrain and provides live streaming for remote inspection. The system integrates a hexapod motion mechanism, remote user control, and real-time video streaming to provide an effective SAR device.

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Introduction

Search-and-rescue missions require mobility solutions that can navigate complex environments safely and efficiently. Traditional methodologies are generally limited by hazardous conditions, which render them less efficient. The proposed hexapod robot addresses these limitations through stability, real-time observation, and remote gesture control, allowing for improved disaster response operations.

Problem Statement

With the increase in natural disasters, it becomes increasingly difficult for SAR teams to access the victims in remote regions. Traditional methods are time consuming, dangerous, and require significant labor. This hexapod robot offers an exciting solution with the provision of instant feedback and enhanced mobility through an efficient robot system.

Related work

There have been a number of research efforts towards creating search-and-rescue (SAR) operations through robotic technology. Autonomous flying robots, such as drones equipped with sophisticated algorithms, can navigate disaster sites on their own and feed first responders real-time data. Soft biologically inspired robotics enhance adaptability in coping with challenging terrain, which allows for enhanced mobility in hazardous settings. Cooperative multi-robot systems leverage ground and aerial vehicles to work together, enhancing the general efficiency of SAR operations. Bio-inspired mechanisms, such as moose-hoof robots, also enhance mobility and stability within challenging terrain. These advancements combined counteract the limitations of traditional SAR methods, resulting in more efficient and safer disaster responses.

Gesture controlled robots have gained significant popularity in today's world. Our research shows the different ways of coupling human machine interaction for intuitive control and smooth movement. Here we review the different works on gesture controlled hexapods along with their benefits and drawbacks.

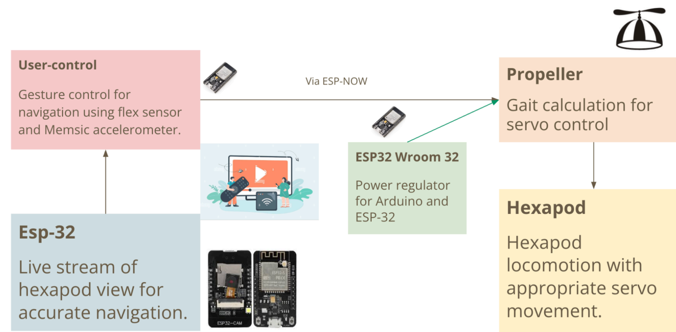
Gesture-Controlled Hexapods have been designed using ATOM ESP32 Pico and IMU modules to detect and interpret hand movements. A user-friendly interface is provided making the human machine interaction naturally acquirable and hence reducing the users learning curve. In addition, since the design is wireless, user mobility and operational flexibility is improved. However, this method has reported that the technology is susceptible to signal interference and so makes it difficult to achieve accurate gesture recognition. This inturn impacts system reliability and control.

Intel's CEO demonstrated a hexapod that could be controlled using wearable devices. These wearable devices use accelerometers and gyroscopes to provide an ergonomic interface for real-time user interaction. Nevertheless, real-time performance was compromised due to latency in gesture recognition. The gesture set was also limited, restricting the range of functionalities.

Other advancements in hexapod control use new algorithms for improved stability and autonomous behaviour. However the concern of energy consumption and high processing power remains.

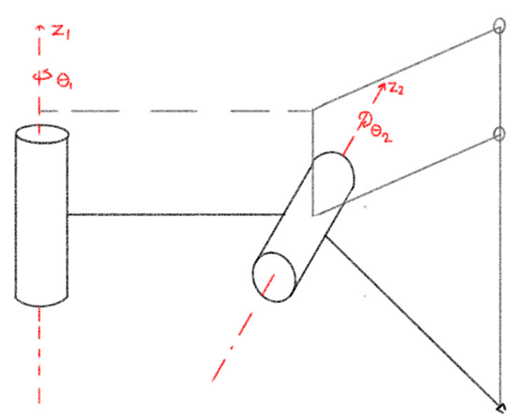
Design and working principle

The hexapod robot is an organized mechanical and electronic system for stable movement. The human control is facilitated by a gesture control device that sends navigation instructions via ESP32 Wroom module to the Propeller, which carries out the gait calculations for synchronized servo actuation. The Propeller microcontroller is also attached to an ESP32 Wroom module to receive instructions from the gesture control device. The ESP32-CAM module provides real-time video streaming, with the user being able to see the immediate surroundings for successful navigation. The modularity enhances reliability, and the hexapod becomes a valuable resource for SAR operations. The hexapod actuators are supplied by PWM-controlled servos from the Propeller, and therefore smooth movement is permitted and guaranteed under stability. The operation entails a controlled control and communication method where controls from the user through the gesture control device are fed into the controller system through using ESP-NOW protocol. The system calculates the required movement patterns and controls the servos in response.



Mechanical Design - Hexapod

Mathematics



Kinematics of hexapod limbs,

$$^{0}T_1 = \begin{bmatrix} cos(\theta_1) & sin(\theta_1) & 0 & a_1cos(\theta_1) \\ sin(\theta_1) & -cos(\theta_1) & 0 & a_1sin(\theta_1) \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^{0}T_2 = \begin{bmatrix} cos(\theta_1)cos(\theta_2) & sin(\theta_2)cos(\theta_1) & sin(\theta_1) & (a_2cos(\theta_2)+a_1)cos(\theta_1) \\ sin(\theta_1)cos(\theta_2) & sin(\theta_1)sin(\theta_2) & -cos(\theta_1) & (a_2cos(\theta_2)+a_1)sin(\theta_1) \\ -sin(\theta_2) & -cos(\theta_2) & 0 & a_2sin(\theta_2) \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

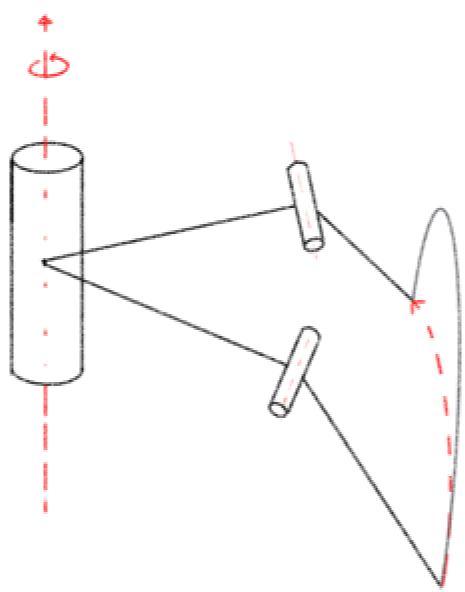
Giving end effector cylindrical coordinates in the frame of the leg,

$$r = a_2cos(\theta_2) + a_1$$

$$\theta_{local} = \theta_1$$

$$z = a_2sin(\theta_2)$$

Each leg is a 2-DOF manipulator. Thus, the equations are over-defined. The angle and height equations are chosen for inverse kinematics of the leg.



Swing θ_{local} in the direction of motion with,

$$\theta_{local} \propto cos^{-1}\left(\frac{direction\ of\ travel}{direction\ of\ leg\ normal}\right)$$

Allowing for omnidirectional gait.

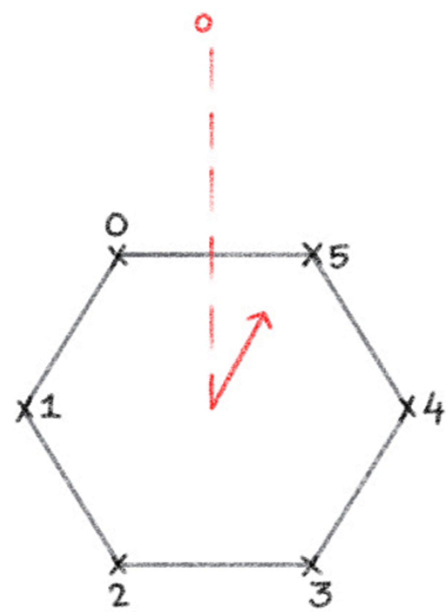
Encoding State values for hexapod sequence

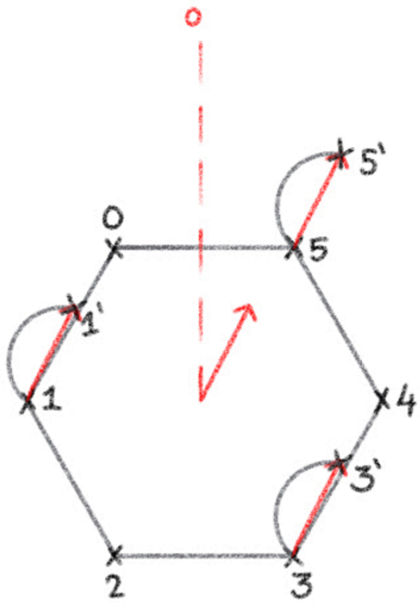
flex_index_sign = 0 or 1 (not flexed, flexed)
flex_mid_sign = 0 or 1 (not flexed, flexed)
x_sign = 0, 1 or 2 (left tilt, neutral, right tilt)
y_sign = 0, 1, or 2(up, neutral, down)

sense_state = (flex_index_sign * 18) + (flex_mid_sign * 9) + (x_sign * 3) + (y_sign)

Algorithm

The legs are divided into two groups P and Q, for example,
P = {1, 3, 5}
Q = {0, 2, 4}





Loop{

1. Group P starts swing
2. Group Q assumes base
3. Group P ends swing
4. Group Q starts swing
5. Group P assumes base
6. Group Q ends swing

}

Hardware Design

- Hexapod Structure: A six-legged robotic platform with 12 degrees of freedom (DOF) for enhanced mobility.
- Actuators: 9g micro servos enabling movement and gait patterns.
- Sensors and Communication:
  - ESP32-CAM for live video streaming.
  - Two ESP32 Wroom modules for communication.
  - Propeller board for processing movement commands.
- Power System: BS-2 microcontroller regulating power distribution.
- ESP32 Wroom is also used for the gesture control device.

Software Design

- User Control: A Python-based interface allows users to control the hexapod remotely using keyboard inputs.
- Navigation Algorithm: Implements a gait algorithm dividing legs into two groups for stable movement.
- Video Streaming: ESP32-CAM streams live footage via an HTTP server.
- Servo Control Logic: PWM signals control movement, and specific formulas govern speed and angles.

Prototyping

Component	**Cost**
Parallax propeller	$80
9g Servo motors	$45
3D print	$14
Flex sensors and IMU	$30
ESP32 with camera	$10
ESP32 Wroom 32	$30
Miscellaneous	$15
Total prototype cost	**$224**

Bill-of-material

Cost analysis for mass production

A. Direct Costs
   a. Materials (structural, electronical, manufacturing)
   b. Labour (Assembly line, quality control)
B. Indirect costs (factory overhead, packaging, shipping, storage, marketing and distribution)
C. Research and Development costs
D. Tooling and equipment costs (3D printing, molds, custom tools)

E. Compliance and Certification (regulatory approval and safety certifications)
F. Manufacturing costs, operational costs, quality assurance

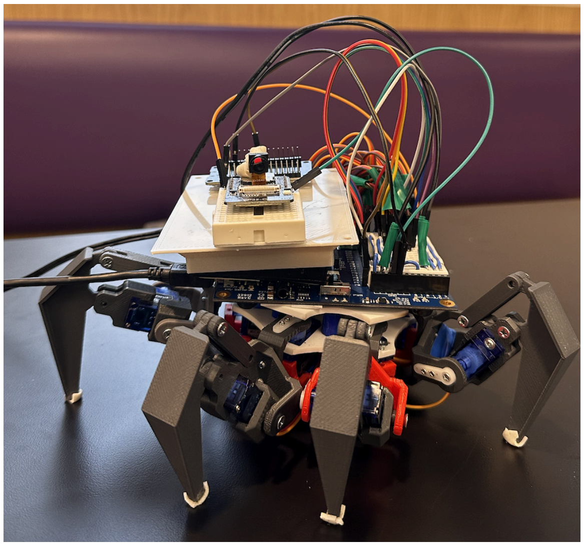
Cost component	**Cost**
Materials	$10,000
Actuators and sensors	$8,000
Manufacturing Labour	$7,000
Tooling	$5,000
Compliance and testing	$3,000
Software development	$5,000
AI and Computer Vision	$5,000
Communication Systems	$2,000
Marketing and distribution	$2,000
Shipping and Packaging	$1,000
Overhead	$5,000
Total	**$53,000**
Safety & Rescue Robot market price	**$50,000-$150,000**

The estimated cost of this solution is on the lower end of the SAR robots in today's market, but our solution provides more features for a better price.

Results

The prototype underwent testing under varying conditions:
Mobility in Uneven Terrain: The hexapod moved easily across bumpy grounds.
Live Streaming Performance: ESP32-CAM had a consistent video stream.
User Control Responsiveness: Wireless inputs were accurately processed.

Final set up



Next Steps

Future enhancement includes utilization of an 18-DOF model for better stability, with more sensors used for increased efficiency.

Conclusions

The Rescue-Feet hexapod is shipped with an excellent solution for search-and-rescue missions. Live monitoring, remote control, and stability make it ideal for moving through hazardous ground.

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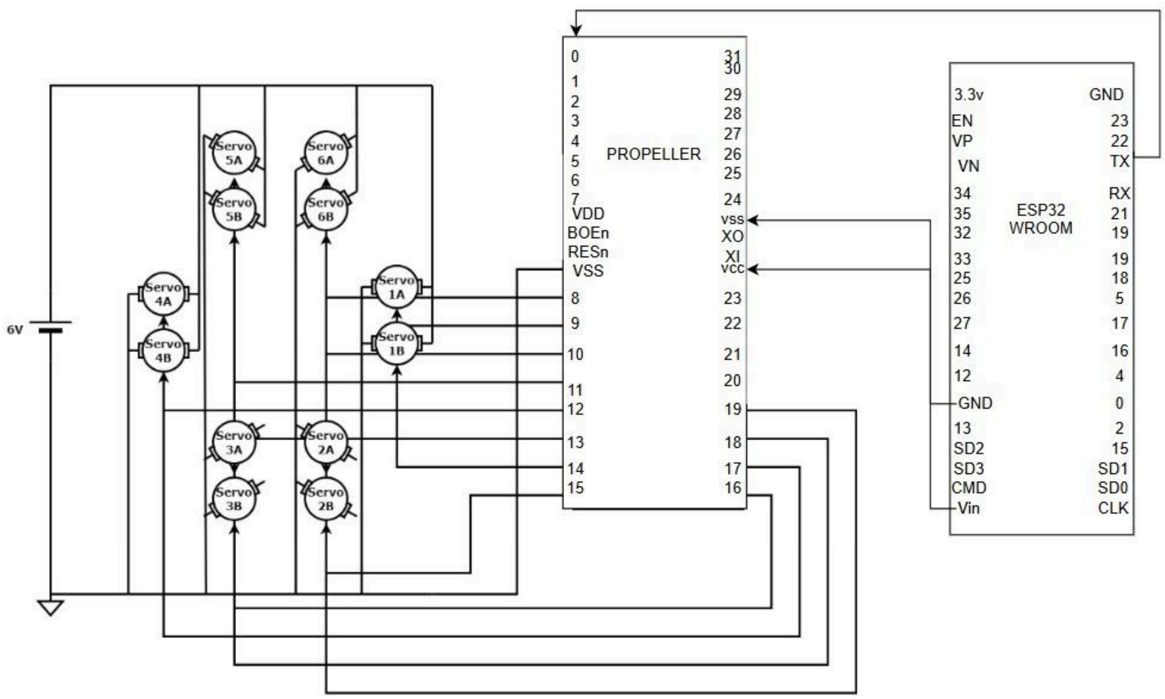
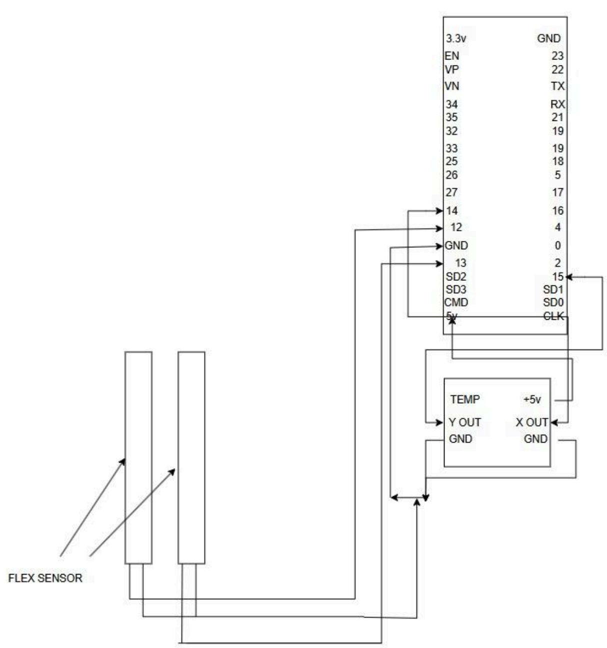
Appendix

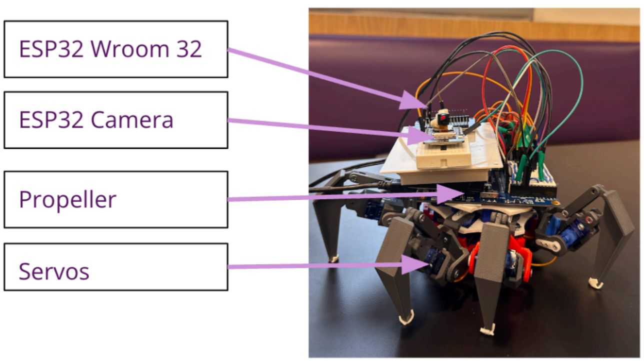
Circuit diagram (1: Hexapod, 2: Gesture control)

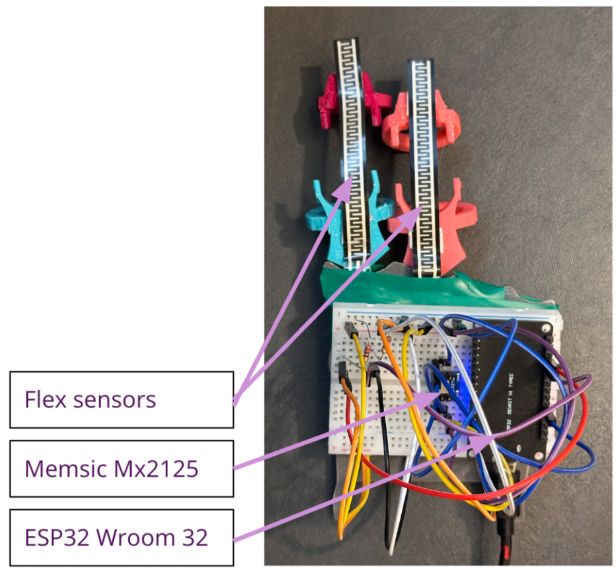




Labelled Set up

Hexapod integration





Gesture control