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 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.

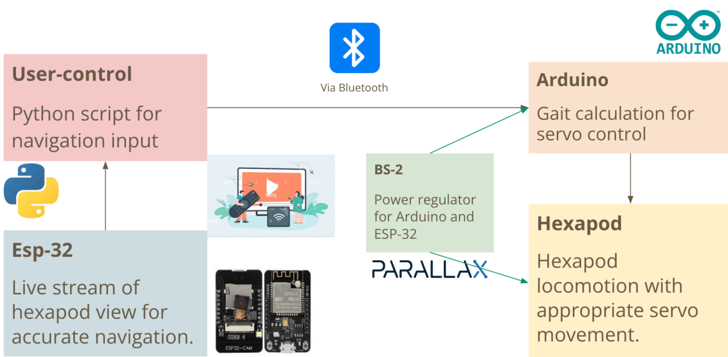
Related work

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.

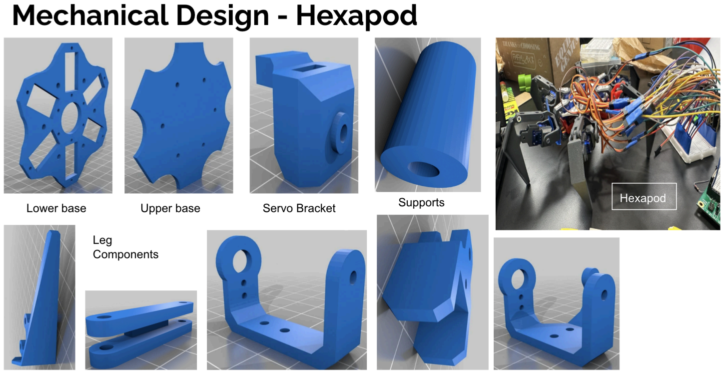
Design and working principle

The hexapod robot is an organized mechanical and electronic system for stable movement. The human control is facilitated by a Python program that sends navigation instructions via Bluetooth to the Arduino, which carries out the gait calculations for synchronized servo actuation.

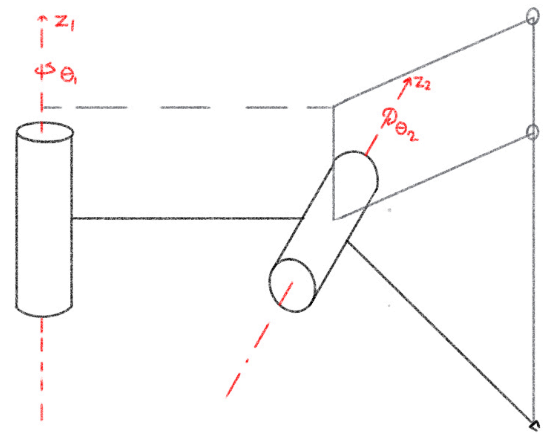
The ESP32-CAM module provides real-time video streaming, with the user being able to see the immediate surroundings for successful navigation. The BS-2 power stabilizer offers stable supply to the Arduino and ESP-32 boards. The ESP32-CAM provides continuous live video for navigation assistance, and the BS-2 regulates power to prevent oscillations. 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 Arduino, and therefore smooth movement is permitted and guaranteed under stability. The operation entails a controlled control and communication method where inputs by the user through a keyboard are fed forward into the controller system through a Bluetooth interface for feeding commands to the Arduino board. The system calculates the required movement patterns and controls the servos in response.



Mechanical Design - Hexapod



Mathematics



Kinematics of hexapod limbs,

$$ {}^{0}T_1 = \begin{bmatrix} cos(\theta_1) & sin(\theta_1) & 0 & a_1 cos(\theta_1) \\ sin(\theta_1) & -cos(\theta_1) & 0 & a_1 sin(\theta_1) \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ {}^{0}T_2 = \begin{bmatrix} cos(\theta_1)cos(\theta_2) & sin(\theta_2)cos(\theta_1) & sin(\theta_1) & (a_2 cos(\theta_2) + a_1)cos(\theta_1) \\ sin(\theta_1)cos(\theta_2) & sin(\theta_1)sin(\theta_2) & -cos(\theta_1) & (a_2 cos(\theta_2) + a_1)sin(\theta_1) \\ -sin(\theta_2) & -cos(\theta_2) & 0 & a_2 sin(\theta_2) \\ 0 & 0 & 0 & 1 \end{bmatrix} $$

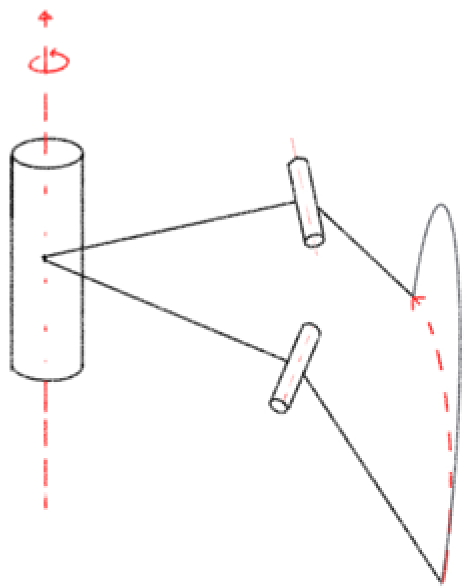
Giving end effector cylindrical coordinates in the frame of the leg,

$$ r = a_2 cos(\theta_2) + a_1 $$

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

$$ z = a_2 sin(\theta_2) $$

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,

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

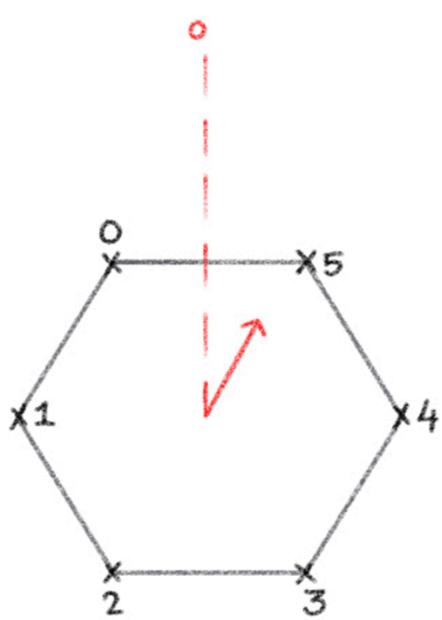
Allowing for omnidirectional gait.

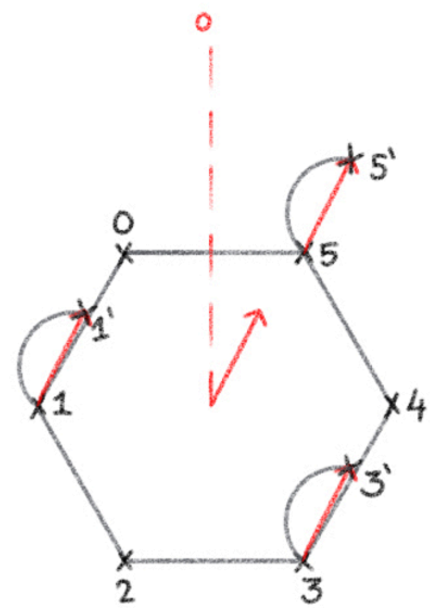
Algorithm

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.
  - AT-09 Bluetooth module for wireless control.
  - Arduino Uno for processing movement commands.
- Power System: BS-2 microcontroller regulating power distribution.

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**
BS2 with Board of education	$100
9g Servo motors	$45
3D print	$14
Arduino uno	$30
ESP32 with camera	$10
Bluetooth Module	$10
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

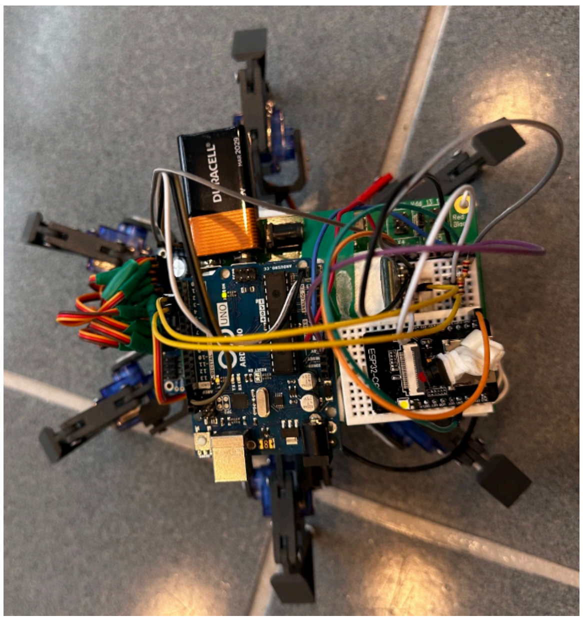
Cost component	**Cost**
Materials	$10,000
Actuators and sensors	$8,000
Manufacturing Labour	$7,000
Tooling	$5,000
Compliance and testing	$3,000
Software development	$5,000
AI and Computer Vision	$5,000
Communication Systems	$2,000
Marketing and distribution	$2,000
Shipping and Packaging	$1,000
Overhead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

The estimated cost of this solution is on par with advanced wheelchairs in today's market, but our solution provides more features.

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: Bluetooth inputs were accurately processed.
Power Consumption: The system was effective in power use, although there is potential to optimize power management.

Final set up



Next Steps

Future enhancement includes gesture controls for input and the 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.

References

https://ieeexplore.ieee.org/document/10434325

https://amprius.com/rescue-robots/#:~:text=Ability%20to%20access%20hard-to,victims%20in%20otherwise%20unreachable%20places.

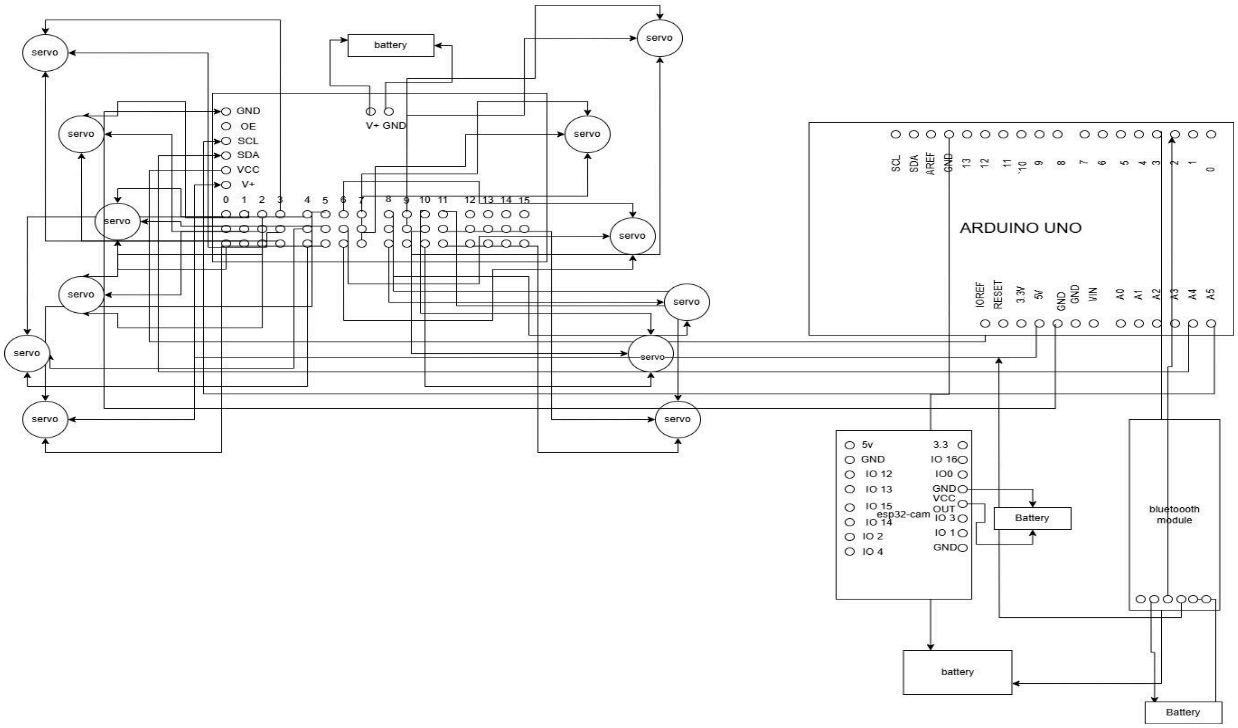
https://www.marketresearchfuture.com/reports/search-and-rescue-robots-market-10599#:~:text=Search%20and%20Rescue%20Robots%20Market%20Size%20was%20valued%20at%20USD,period%20(2024%20%2D%202030).

https://randomnerdtutorials.com/esp32-cam-video-streaming-face-recognition-arduino-ide/

https://ieeexplore.ieee.org/document/7041375

https://groups.csail.mit.edu/robotics-center/public_papers/Posa13.pdf

Appendix



Circuit diagram

Labelled Set up