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.

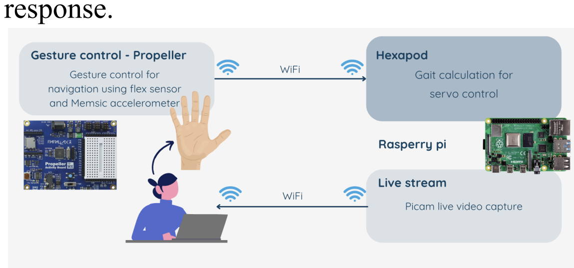
Gesture-Controlled Hexapods have been designed using ATOM ESP32 Pico and IMU modules to detect and interpret hand movements. A user-friendly interface is provided making the human machine interaction naturally acquirable and hence reducing the users learning curve. In addition, since the design is wireless, 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.

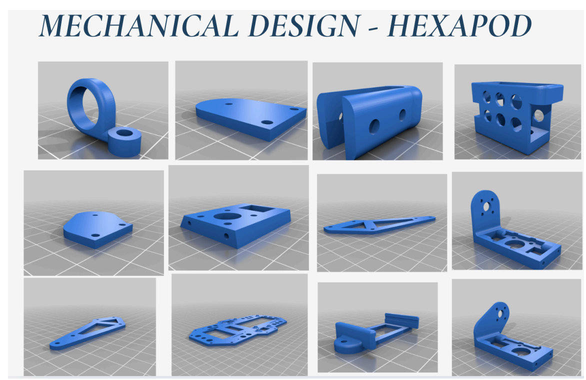
Intel's CEO demonstrated a hexapod that could be controlled using wearable devices. These wearable devices use accelerometers and gyroscopes to provide an ergonomic interface for real-time user interaction. Nevertheless, real-time performance was compromised due to latency in gesture recognition. The 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 uses the Propeller microcontroller to capture the gesture input and sends navigation instructions over WiFi to the Raspberry Pi on the hexapod, which carries out the gait calculations for synchronized servo actuation. The Raspberry Pi microcontroller is also attached with a PiCam that provides real-time video streaming with object detection, so the user can 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 Raspberry Pi connected with 2 servo drivers to control the 18 servos, 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 over WiFi. The system calculates the required movement patterns and controls the servos in response.



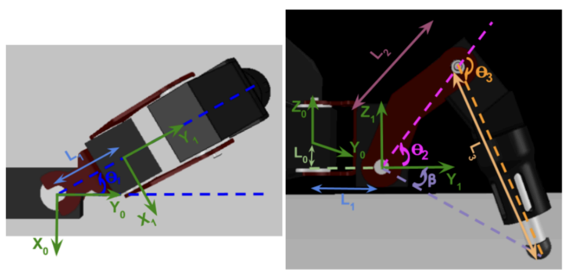


Mathematics

Inverse kinematics is used to calculate the precise joint angles required for each of the robot's 18 servos (three per leg) to position the feet at desired coordinates in space. Each leg’s movement is typically modeled as a serial kinematic chain.

The angle of rotation of Joints 1, 2, and 3 are:

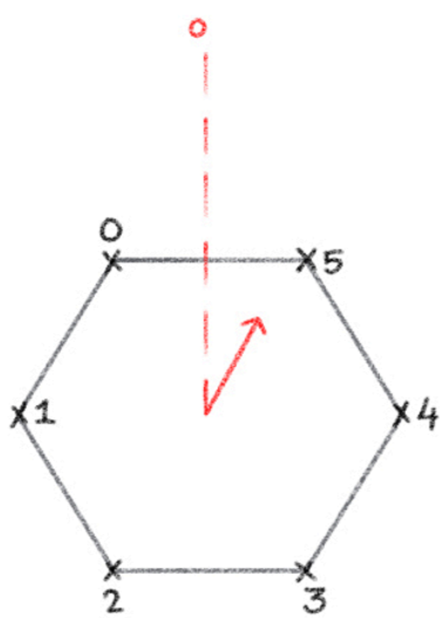
- $\theta 1 = \arctan\left(\frac{Y_0}{X_0}\right)$
- $\theta 2 = \arccos\left(\frac{-L3^2+L2^2+X_0{}^2+Y_0{}^2+Z_0{}^2}{2*L2*\sqrt{X_0{}^2+Y_0{}^2+Z_0{}^2}}\right) + \arctan\left(\frac{Z_0}{\sqrt{X_0{}^2+Y_0{}^2}}\right)$
- $\theta 3 = -(\pi - \beta) = -\arccos\left(\frac{X_0{}^2+Y_0{}^2+Z_0{}^2-L2^2-L3^2}{2*L2*L3}\right)$



(a) Top view. (b) Side view.

Algorithm

The six legs are divided into two alternating groups of three: at any given time, three legs (the front and back legs on one side, and the middle leg on the opposite side) are in contact with the ground supporting the body, while the other three are lifted and swung forward to take the next step. This alternation creates a stable triangular support polygon, ensuring that the robot maintains static stability throughout the gait cycle.

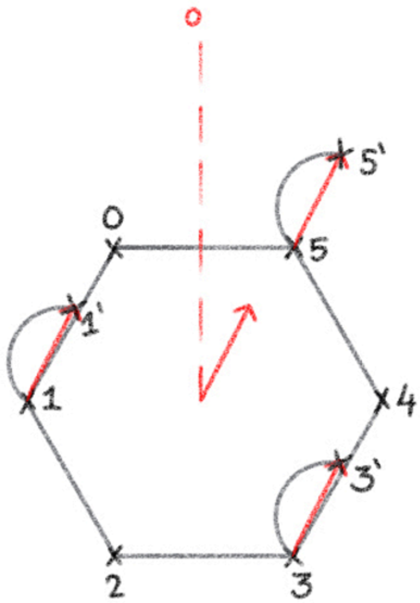


Define LEG_GROUP_A = [Leg 1, Leg 3, Leg 5] ***// e.g., left front, right middle, left rear***
Define LEG_GROUP_B = [Leg 2, Leg 4, Leg 6] ***// e.g., right front, left middle, right rear***

Loop while walking:
  // Step 1: Move Tripod A
  Lift LEG_GROUP_A
  Move LEG_GROUP_A forward (swing phase)
  Lower LEG_GROUP_A to ground (stance phase)
  Move LEG_GROUP_B backward to propel body (stance phase)

  // Step 2: Move Tripod B
  Lift LEG_GROUP_B
  Move LEG_GROUP_B forward (swing phase)
  Lower LEG_GROUP_B to ground (stance phase)
  Move LEG_GROUP_A backward to propel body (stance phase)

  // Repeat
End Loop



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)

Hardware Design

- Hexapod Structure: A six-legged robotic platform with 18 degrees of freedom (DOF) for enhanced mobility.
- Actuators: MG996R servos enabling movement and gait patterns.
- Sensors and Communication:
  - PiCam for live video streaming.
  - Raspi and desktop for WiFi communication.
  - Propeller board for gesture control.
- Power System:LIPO batteries 1800mAh, 7.4V.

Software Design

- User Control: a C code is used to take different gestures as an input to the desktop and is sent to raspberry pi over the internet using a python script.
- Navigation Algorithm: Implements a gait algorithm dividing legs into two groups for stable movement.
- Video Streaming: PiCam streams live footage via localhost with object detection algorithms.
- Servo Control Logic: PWM signals control movement, and specific formulas govern speed and angles.

Prototyping

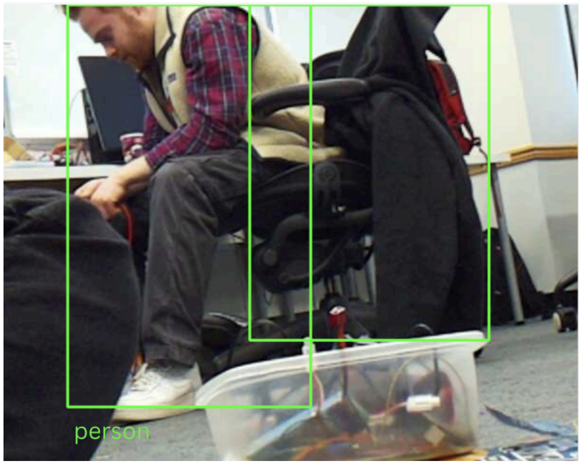
Component	**Cost**
Raspberry Pi + PiCam	$50
MG996R Servo motors x 18	$120
Propeller	$80
Flex sensors and IMU	$30
Servo shields	$12
Buck converters	$6
LiPo batteries	$40
Miscellaneous	$50
Total prototype cost	**$388**

Bill of material

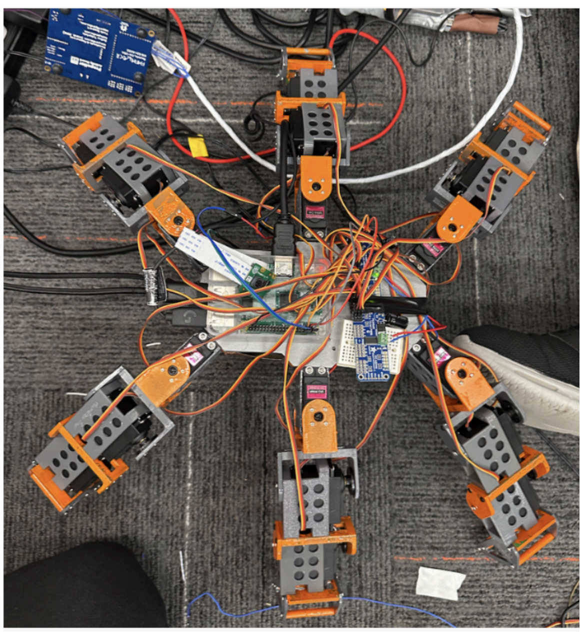
Results

Live Streaming Performance: PiCam had a consistent video stream with accurate detections. User Control Responsiveness: Users gesture inputs were accurately processed and transmitted.

Hexapod movement is still being tested, and challenges were observed due to the complexity of the robot.

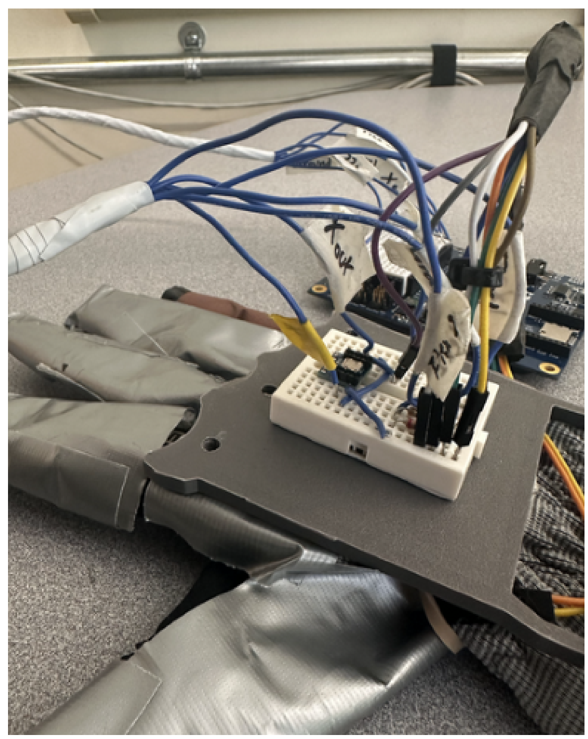


Final set up



Hexapod

Gesture Controller



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.

References

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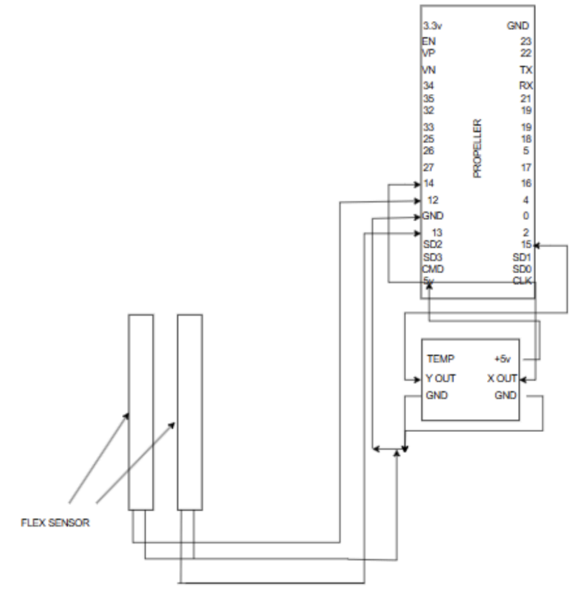
https://randomnerdtutorials.com/raspberry-pi-mjpeg-streaming-web-server-picamera2/



Appendix

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