Major Build 1 - Hexapod kinematics design

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1. Motivation and bioinspiration

The field of bio-inspired robotics draws inspiration from natural organisms to design and create robots that mimic their locomotion, behavior, and adaptability. One fascinating example to generate locomotion actively is the hexapod spider robot, which emulates the movement of spiders. The main motivation for using hexapod robots rather than the traditional wheeled robots is for their Versatility, Efficiency, adaptability and stability which makes them suitable for tasks requiring robust locomotion. These hexapods are heavily bioinspired for their biomechanical design which draws inspiration from the exoskeletons of insects and gait optimization. As seen in [1], the most common gaits for controlling the swing and stance of a leg during a forward motion are- tripod gait, wave gait and ripple gait. The video[2] visualizes all the possible gait patterns of a hexapod. Since for our project we only need simple movements we've chosen a tripod gait.

[1]https://hackaday.io/project/21904-hexapod-modelling-path-planning-and-control/log/62326-3-fundamentals-of-hexapod-robot
[2]https://www.youtube.com/watch?v=6T8NDrmyjwc

2. Kinematic profile

To generate the kinematic profile for both the walking gait and rotation without translation, we utilized a step-based approach. For the walking gait, we define the desired step parameters such as step length, step height, and walking speed. Based on these parameters, we calculate the joint angles for each leg at each step to achieve the desired trajectory while maintaining stability. This method involves determining the leg positions relative to the body frame and calculating the corresponding joint angles using geometric relationships.

Similarly, for rotation without translation, we adjust the leg positions and joint angles to achieve the desired rotation while keeping the body stationary. By coordinating the movement of the legs and adjusting the phase difference between them, we can achieve smooth and stable rotation.

This method can be adapted to different requirements and gaits by adjusting the step parameters and optimizing the trajectory. For instance, by modifying the step length and timing, we can switch between different gaits such as a triangular gait, wave gait, or alternating tripod gait.

The triangular gait is a common choice for hexapod robots due to its simplicity and stability. In this gait, the robot moves three legs at a time while maintaining a tripod configuration. The other three legs remain stationary, the robot alternates between two sets of legs: 1, 3, and 5 (active legs) and 2, 4, and 6 (static legs). Initially, legs 1, 3, and 5 lift off the ground, while legs 2, 4, and 6 provide support. Next, legs 2, 4, and 6 become active, lifting off the ground, while legs 1, 3, and 5 touch down. This alternating sequence creates a stable triangular base. By varying the timing of leg movements, the robot can rotate around its central axis. The triangular gait ensures that the robot remains stable during the turn. The angles at which each leg moves are critical for stability. The robot’s body pitch, roll, and yaw are controlled by adjusting leg angles. Coordination between legs ensures smooth transitions during gait changes. While the triangular gait provides stability, it has limitations such as the robot’s speed is relatively slow due to the tripod movement, turning 360 degrees is efficient, but lateral movement is restricted.

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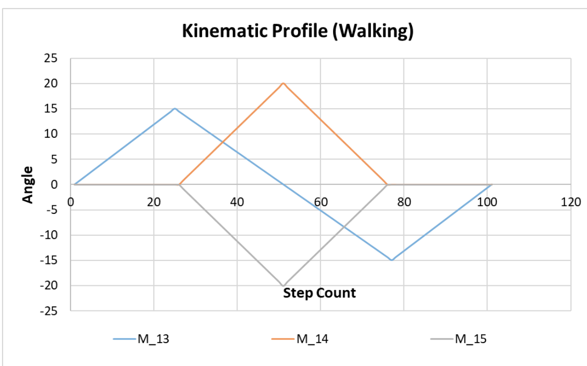
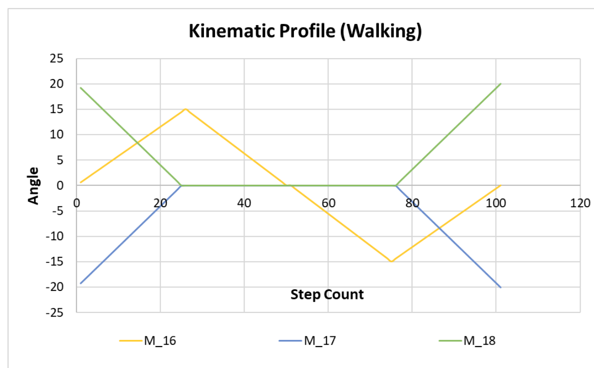
<tr><td>
</td><td>
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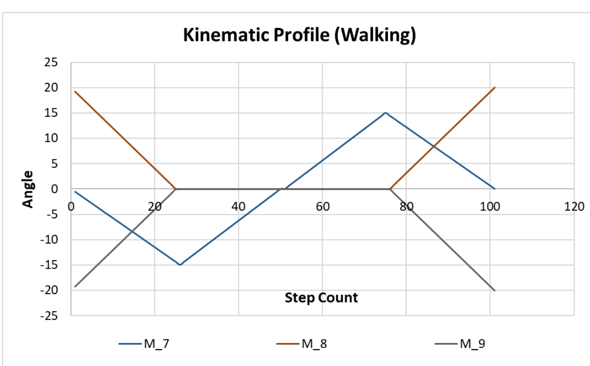
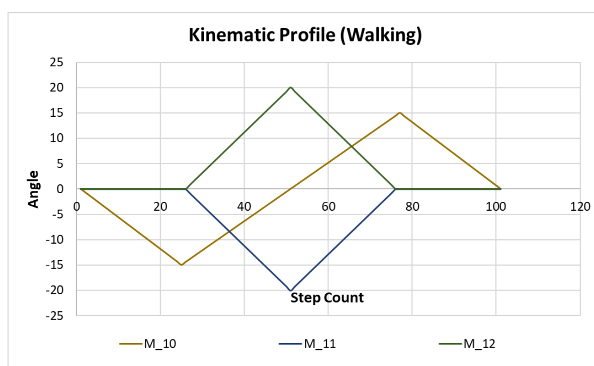
<tr><td>
</td><td>
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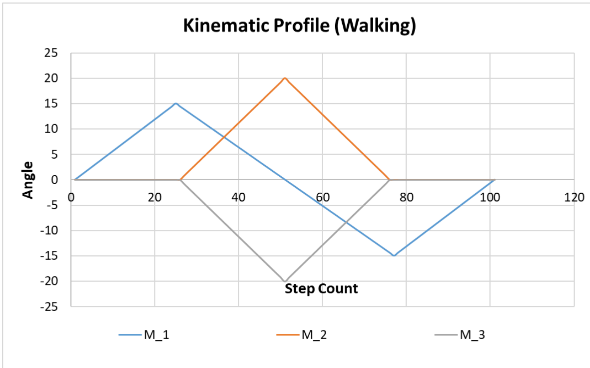

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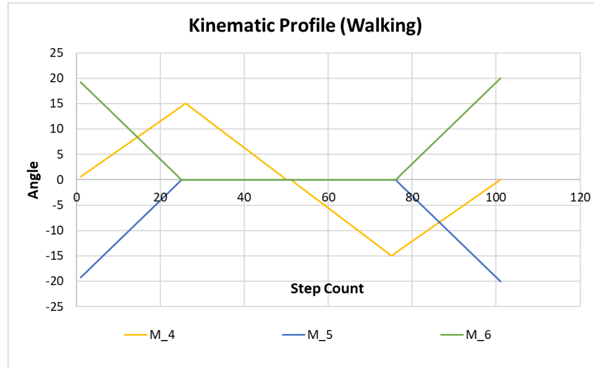
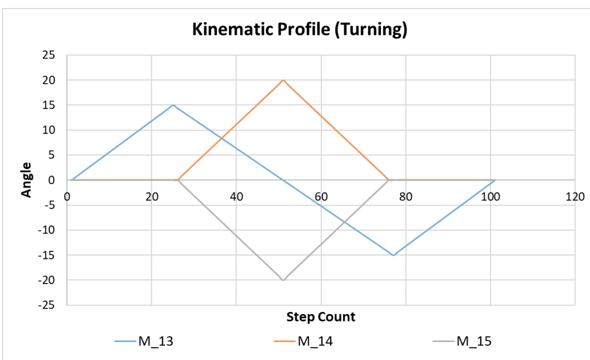


Left_3

Turning Gait

Right



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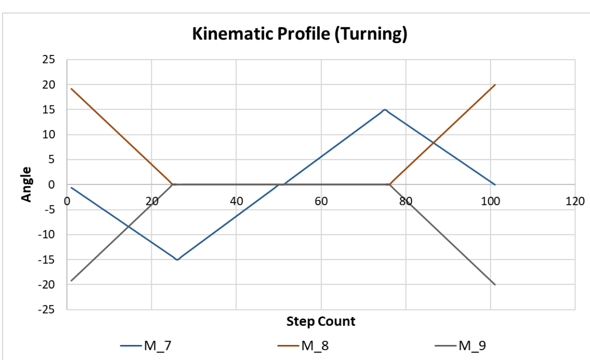

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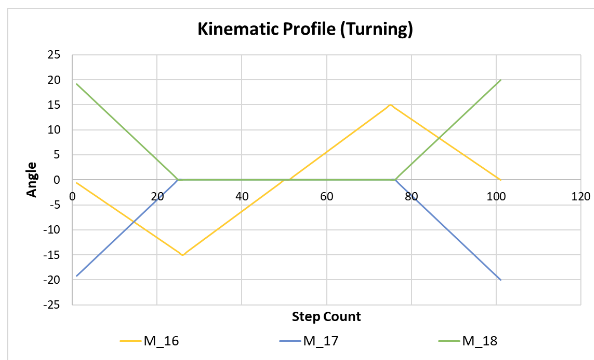

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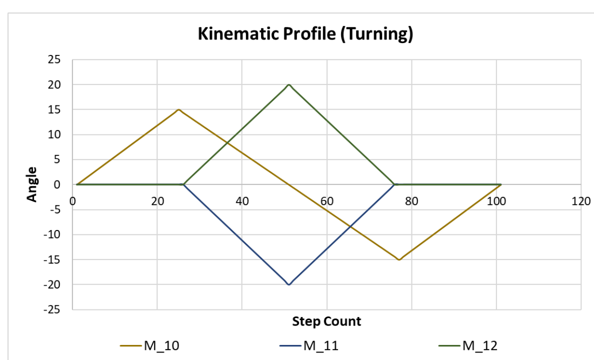

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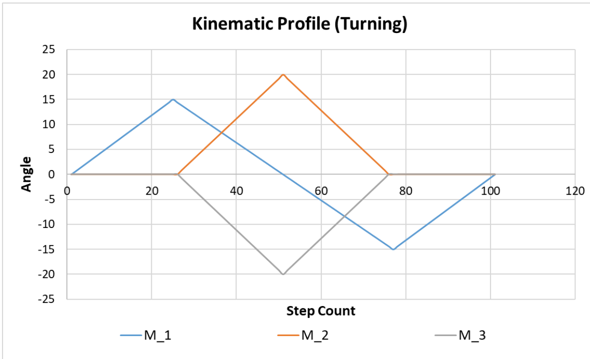

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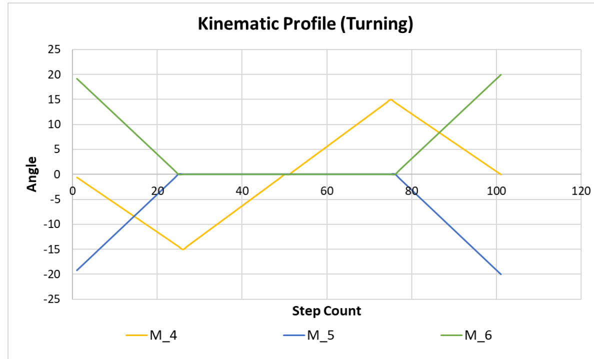

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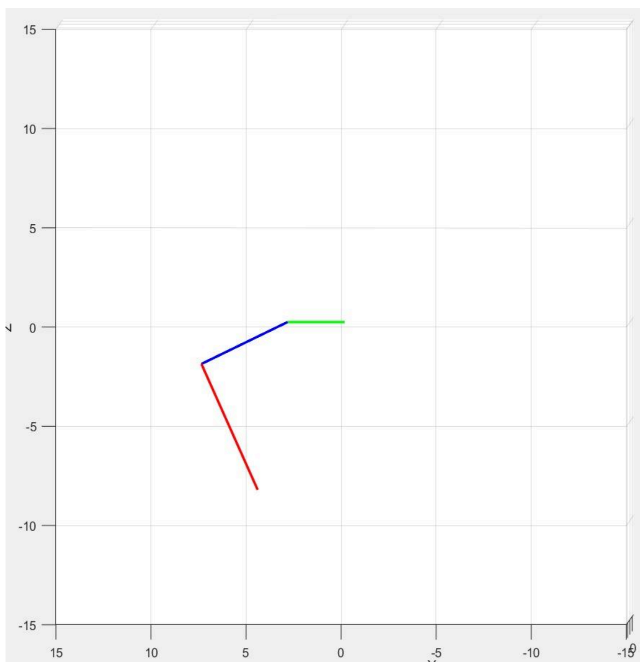
3. Simulated environment:



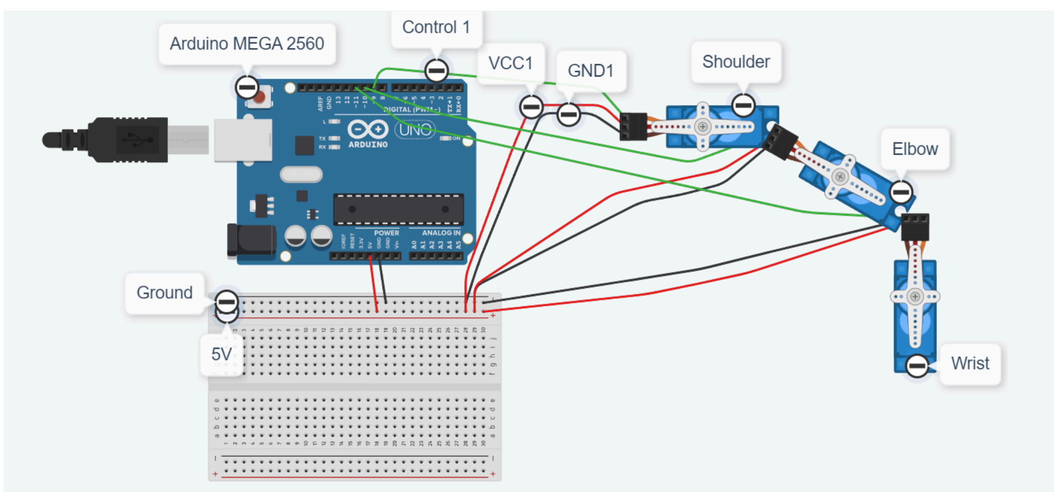
Simulation environment figure

We have used MATLAB for simulation of the orientations (or inclinations) of three motors regulating the motion of a single leg on a hexapod robot. These motor orientations are stored as distinct variables. Initially, we conducted a simulation of a walking mechanism using a range of angles to explore the behavior and limitations of the single leg. Rather than referring to these angles as random, they were systematically varied to observe their effects on leg movement. This allowed us to understand the range of motion and performance characteristics of the leg.

Later we modified our code in MATLAB, which provides us with a CSV file containing information about the positions of the motors controlling leg movements. We compared these simulated positions with the angles used during benchtop testing to ensure consistency and accuracy in the simulation results.

The simulation process involved converting motor orientations from degrees to radians for mathematical operations, considering the constant lengths of leg segments representing physical dimensions. Using trigonometric expressions, we computed the 3D coordinates of the leg joints based on the motor orientations and segment lengths.
It visualizes the leg in 3D by drawing lines connecting the base (where the leg is attached to the body) to the first joint, from the first to the second joint, and from the second to the third (terminal) joint. These lines are depicted in distinct colors (red, green, and blue) to facilitate the differentiation of leg segments.
It configures the 3D plotting environment by defining axis limits, appending labels to the axes, and exhibiting a grid.
Throughout the simulation, a brief pause was introduced between iterations to regulate animation speed, allowing for better observation of leg movement.
Upon completion of the loop, it effectively generates an animation portraying the leg's movement through a full rotation, based on the motor orientations retrieved from the CSV file.

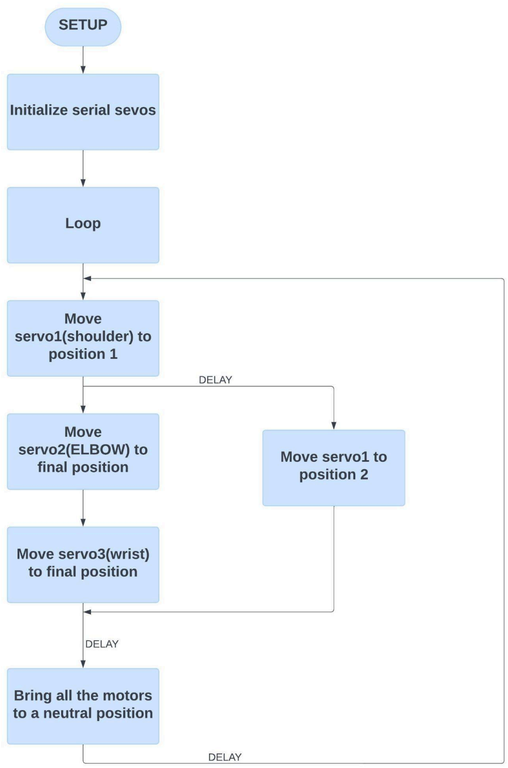
4. Mechatronics description



Wiring diagram figure for a single leg.

The mechatronics of a single leg in the robot involves the integration of mechanical components with electronics and control systems to achieve coordinated movement. In this context, each leg comprises three servo motors: one at the shoulder joint, one at the elbow joint, and one at the wrist joint.

The operation begins with the control signals sent to the servo motors from the microcontroller unit (arduino in our case) . These signals determine the position and speed of each motor, allowing precise control over the leg's movement. The wiring diagram illustrates the connections between the servo motors, power supply (5V), ground, and control pins (connected to pins 9,10, 11 on the microcontroller).



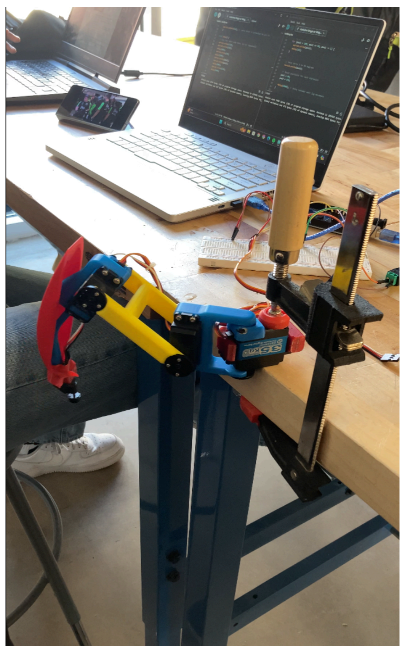
Flow chart of pseudo code logic

Here is a flow chart of the logic we tried to implement to get a step motion using the three motors. The code initiates with all motors set at a 90-degree angle. Subsequently, Motor 1 (shoulder) transitions to 105 degrees, while Motor 2 (elbow) and Motor 3 (wrist) remain at a neutral 90-degree position. Following this, Motor 2 moves to 110 degrees(final position), while Motor 3 shifts to 70 degrees(final position). In the meanwhile, Motor 1 moves from 105(pos1) to 75(pos 2) degrees. Following a specified delay, all motors revert to their neutral positions at 90 degrees.And this cycle is repeated, giving it the motion of a walking leg. The angles here are changed accordingly as per how far the leg moves in each step.

5. Benchtop and field testing

During our hexapod spider robot development, we conducted benchtop testing on a single leg and field tests involving all six legs. Initially, our Arduino IDE and Tinkercad-based code provided movement for one leg, but the displacement was excessive as seen in figure below. Through iterative adjustments—varying angles incrementally—we achieved the desired movement. The triangular gait, with angle replication across three legs, simplified both walking and rotation.

Field tests on all six legs were successful, although we encountered a discrepancy in negative and positive displacement. By reversing angle signs, we resolved the issue, achieving smoother motion with smaller leg movements.

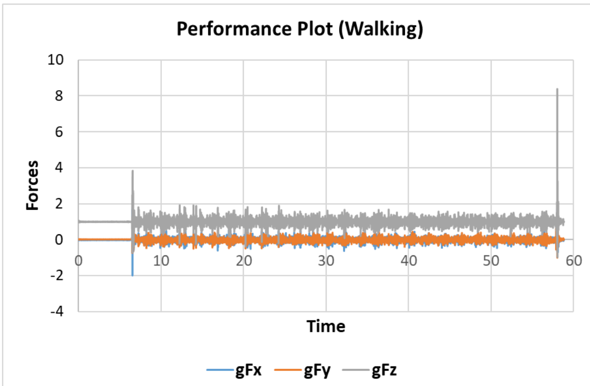


Benchtop Testing of single leg

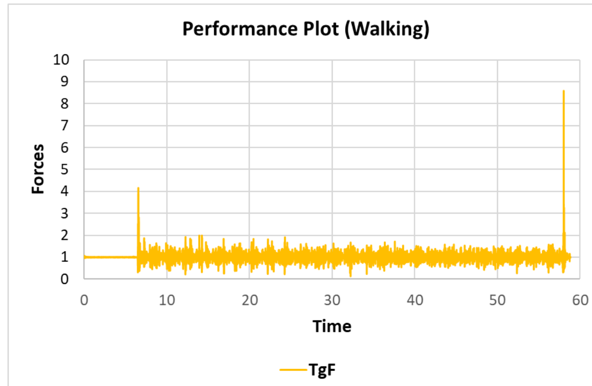
6. Performance and Discussion

During the final performance, the hexapod spider robot encountered deviations while walking on the black line. The observed lateral movement 35 inches off the intended path over a 60-inch distance suggests an asymmetry in leg movements. Uneven leg motion, with one side moving less than the other, leads to translational drift. Additionally, inadequate surface friction contributes to leg slippage, causing unintended displacement. The uniform forces recorded during walking indicate consistent leg-ground interactions but fail to counteract slipping.

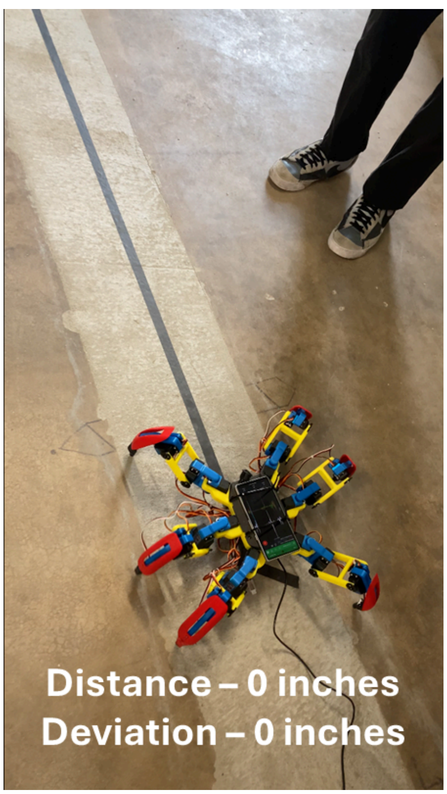
In contrast, rotation exhibited minimal deviation (only 3 inches after a complete turn), attributed to stable and smooth motion supported by uniform forces. Addressing leg symmetry, surface friction, and optimizing force distribution will enhance the robot's performance by increasing the stability during any kind of maneuvers. All the plots and figures are shown below.

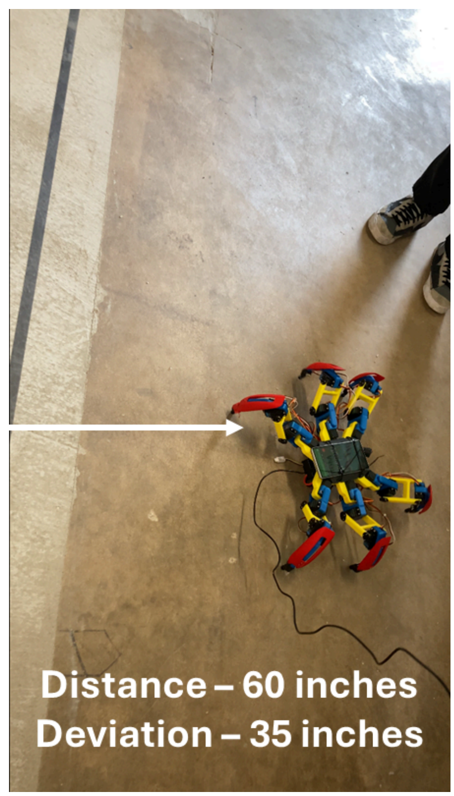


Walking force plot in cartesian coordinates



Total forces during walking





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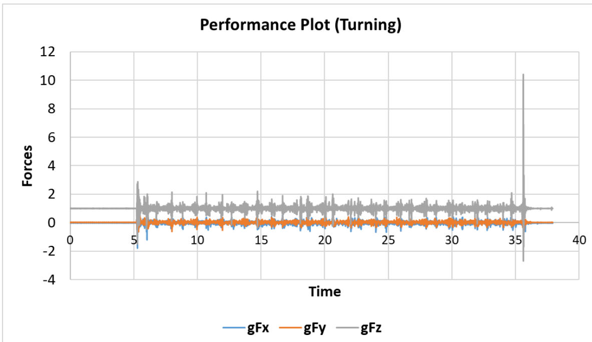
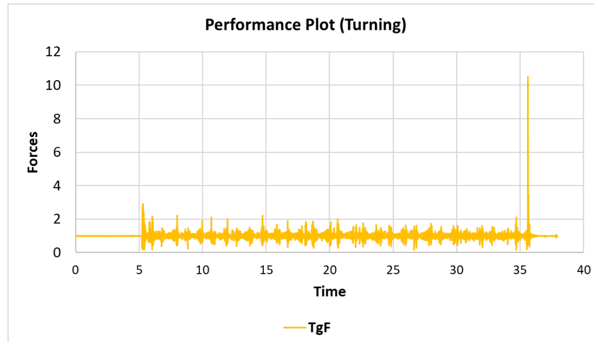
<tr><td>
</td><td>
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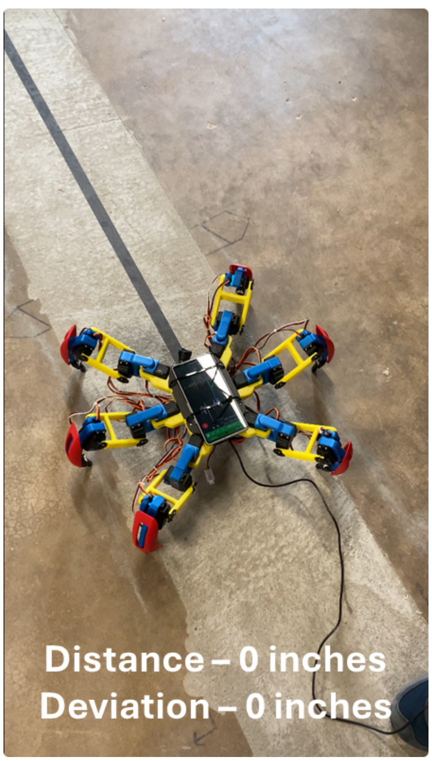
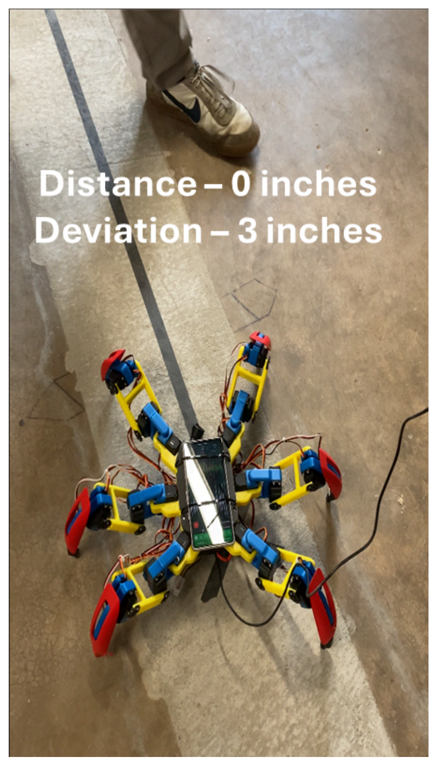
<tr><td>Rotation force plot in cartesian coordinates</td><td>Total forces during Rotation</td></tr>
<tr><td>
</td><td>
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<tr><td>Rotation - Initial Position</td><td>Rotation - Final Position</td></tr>
<tr><td colspan="2">Performance Plots and Pictures during the performance testing</td></tr>
</table>

7. Looking forward

In our hexapod spider robot project, we conducted benchtop and field testing. While the triangular gait provided stability, lateral deviations occurred during black line tracking. To address this, we need to fine-tune leg movements, optimize surface interaction, and integrate sensors for real-time feedback. Reflecting on the project, iterative prototyping and systematic calibration would be valuable. Bioinspired locomotion, such as metachronal gaits, can enhance future designs. Hexapods outperform conventional technology in search and rescue, exploration, and agriculture. Adding force/torque sensors, IMUs, vision sensors, and environmental sensors will make the hexapod more versatile and useful.

8. Contribution statement

Uday Kiran Balaga: Performance analysis, field testing, Plotting kinematic profiles, force plots and explanation of the obtained results. Helped in writing sections 6 and 7 of the report.

Sujith Yeluru: Background research on kinematic profiles, generating kinematic profiles, CSV file generation for the angles we finalized in the bench top testing, Assisted in writing sections 1, 2 and 4 of the report.

Ravi Teja Kolli: Arduino Coding for single leg bench top testing, ran simulations for single leg in MATLAB, helped in understanding the mechatronics of the robot, Assisted in writing sections 3 and 5 of the report.