Fabrication of a 3D Printed Hexapod for All Terrain Adaptive Locomotion

Bilal Sabugar[1], Aditya Jadav[2], Archie Veera[3], Rabinder Henry[4]
[1,2,3,4]*B. Tech in AI and Robotics, Atlas Skill Tech University, Mumbai, India*

***Abstract*—This paper presents the design, fabrication, assembly and testing of a 3D printed Hexapod named "Novexa". This has been developed as an experimental platform for multi terrain adaptive locomotion. The system features six articulated legs, each providing 3 degrees of freedom, constructing a system of 18 degrees of freedom in-total. It is completely designed in CAD software and simulated; majority of the modular parts are 3D printed for cost efficiency. The controller used was an Arduino Mega as a prototype and will be upgraded to an STM32 as a final and stable build. The system consists of environmental sensors and obstacle detection sensors which includes ultrasonic for nearby detection and LiDAR for mapping the surrounding.**

***Index Terms*—Hexapod, Legged Locomotion, Bio-inspired Robotics, Gait Planning, Stability Control, Terrain Adaption, Mechatronic System Design, Autonomous Robotics, Embedded Systems.**

I. INTRODUCTION

There are many wheeled and legged rovers and robots engineered in the last 30 years for navigation through difficult terrain and exploration missions. A Hexapod, also known as a six-legged robot, is a biomimetic robot inspired by the way crabs move. The hexapod is very convenient for all terrain locomotion because they are balanced, which means they can stand or walk with a tripod gait mechanism without falling over. This makes them comparatively better than wheeled bots for walking over rugged lands and if modified they can also swim under water.

While hexapod designs are not new, the peculiarity of Novexa robot is that the entire ~1-meter body is constructed with 3D printing using Poly-Lactic-Acid making the system much more affordable and lightweight without compromising much on durability. Novexa uses a distinctive gait mechanism based on inverse kinematics, currently on Arduino Mega which assists it in making decisions on how to act and move its 18 different servos automatically to complete an assigned task autonomously. IMU sensors and compass are used to track 6-axis movement and orientations, Ultrasonic to identify nearby obstacles and LiDAR to map out surroundings allowing the robot to have complete autonomicity.

A. General Specification

Novexa is a scaled robot with a total footprint measuring approximately 1-meter in length and 0.8-meter in width and 0.4-meter in height. The entire system weighs approximately 5.5–6.0 kg. The design presents 18 degrees of freedom constructed by three independent joints in each of six legs. The robot is powered by a dual power system consisting of a logic and an actuation power rail. The combined power system is sufficient to deliver energy for 45 to 60 minutes depending on usage. Arduino Mega is used as the microcontroller for the initial prototype. A PCA9685 board is used to deliver power and control all 18 servos.

B. Structural Configuration

Novexa's body consists of 3 layers — bottom, middle and top — and six articulated legs symmetrically positioned on both sides at 30° each with an angle of 60° between both sides. Each leg has:

- Coxa joint: Horizontal (yaw) motion
- Femur Joint: Vertical (pitch) lift
- Tibia Joint: Forward (pitch) extension

This configuration is similar to the principles of the human leg and offers a large working envelope while maintaining a low center of gravity.

II. MECHANICAL DESIGN

A. CAD Modelling

The complete mechanical design and simulation was built on Autodesk Fusion360, allowing advanced parametric modelling and software-based simulations.

B. 3D Printing Parameters

Table I lists the 3D printing parameters used in the fabrication of Novexa.

TABLE I 3D Printing Parameters

Parameter	Value
Nozzle diameter	0.2mm
Layer Height	0.2mm
Infill	20~40% (Gyroid Pattern)
Material	PLA (TPU for tibia grippers)
Print Time	~70+ Hours
Filament Used	2.0~2.5 kg
Assembly	M2 Screws & Copper inserts

III. KINEMATICS AND GAIT DESIGN

A. Kinematics Model

Each leg functions as a 3-link serial manipulator with the following link lengths:

- $L1$ = Coxa length = 60 mm
- $L2$ = Femur length = 90 mm
- $L3$ = Tibia length = 110 mm

Using Denavit-Hartenberg (D-H) parameters, the position of the foot (P) in 3D space is defined as P (x, y, z) = T (θ1, θ2, θ3), where:

$x = L1\cos(\theta1) + L2\cos(\theta1 + \theta2) + L3\cos(\theta1 + \theta2 + \theta3)$

$y = L1\sin(\theta1) + L2\sin(\theta1 + \theta2) + L3\sin(\theta1 + \theta2 + \theta3)$

$z = z0$

B. Inverse Kinematics Model

Inverse kinematics determines the joint angles required to position the foot of the leg at a desired coordinate P (x, y, z) in the workspace. For the 3-link serial manipulator mechanism, the joint angles θ1, θ2, and θ3 are obtained from the geometric relationship between the link lengths and the target foot position.

The first joint angle θ1 controls the horizontal rotation of the leg and is computed from the planar projection of the foot position:

$\theta1 = \tan^{-1}(y/x)$ (1)

The distance from the coxa joint to the foot projection in the horizontal plane is:

$r = \sqrt{(x^2 + y^2)} - L1.$ (2)

The vertical distance from the femur joint is:

$d = z - z0.$ (3)

Using the law of cosines, the tibia joint angle is obtained as:

$\cos(\theta3) = (r^2 + d^2 - L2^2 - L3^2) / (2L2L3)$ (4)

The femur joint angle is then calculated as:

$\theta2 = \tan^{-1}(d/r) - \tan^{-1} (L3 \sin(\theta3) / (L2 + L3 \cos(\theta3))).$ (5)

Thus, the inverse kinematics solution provides the joint angles θ1, θ2, θ3 required to position the foot of the hexapod leg at the specified coordinate P (x, y, z) in the workspace.

C. Gait Planning

Three primary gaits were implemented:

- Tripod Gait:Tripod Gait:
- Tripod Gait: 3 legs move while 3 support the body (fast and efficient).
- Ripple Gait: Sequential leg motion (smooth, stable on rough terrain).
- Wave Gait: One leg at a time (high stability, low speed).

Each gait cycle is time synchronized using sinusoidal position functions:

$\theta i(t) = Ai \sin(\omega t + \varphi i)$ ... (6)

where Ai is the amplitude, ω is the angular frequency, and φi is the phase difference (120° offset for legs 1–3–5 and 2–4–6).

Tripod Gait Motion: The six legs are divided into two groups (1–3–5) and (2–4–6). One group performs the swing phase while the other supports the robot:

$\theta1,3,5(t) = A \sin(\omega t), \theta2,4,6(t) = A \sin(\omega t + \pi).$(7)

Ripple Gait Motion: Legs move sequentially with a constant phase shift between adjacent legs:

$\theta i(t) = A \sin(\omega t + (2\pi/6)(i-1)).$ (8)

Wave Gait Motion: Only one leg moves at a time while the other five support the robot:

$\theta_i(t) = A \sin(\omega t + (2\pi/6)(i-1))$.(9)

IV. ELECTRONICS AND CONTROL ARCHITECTURE

A. Hardware Layout

The power architecture is divided into two rails as shown in Table II.

TABLE II Power Flow Architecture

Battery (A) Nominal: 7.4V | Terminal: 8.4V	→	Logic Rail (Powers microcontroller and sensors)
Battery (B) Nominal: 14.8V | Terminal: 16.8V	→	Actuation Rail (Powers actuators and servos)

B. Components

Table III lists the key electronic components and their functions.

TABLE III System Components

Component	Function
Arduino Mega	Central controller
PCA9685	PWM and Power Rail for all 18 servos
MPU6050	IMU sensor for orientation feedback
HC-SR04	Obstacle sensing (front)
Benewake TF03 100M	LiDAR for Mapping and Path planning
Battery	Battery(A): 7.4V 2500mAh Battery(B): 14.8V 5000mAh
Servos	MG995 (9 kg·cm)

C. Control Software

The control system is distributed in a layered architecture:

- Low-Level (Firmware): Generates PWM signals for servos and sensors.
- Mid-Level (Gait engine): Computes phase offsets and trajectories.
- High-Level (Autonomous Layer): Obstacle avoidance and IMU stabilization.

A basic PID loop stabilizes roll and pitch using the IMU feedback. The equation used for stabilization is:

$\Delta\theta = K_p \cdot e + K_i \cdot \int e + K_d \cdot (de/dt)$ (10)

V. SENSOR INTEGRATION

A. Sensor System

The following sensors are integrated in the Novexa platform:

- IMU (MPU6050): Provides 6-axis orientation data.
- Ultrasonic Sensor (×2, HC-SR04): Measures front obstacle distance.
- Environmental Sensors: Temperature, Moisture, and CO_2 (NDIR) sensors for environmental sensing.
- LiDAR (Benewake TF03 100M): Long-range mapping and path planning.

The assembled prototype is shown in Fig. 1.

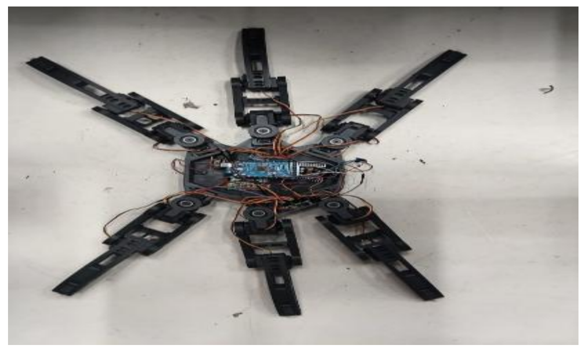

Fig. 1. Assembled Prototype of Novexa Hexapod.

VI. FUTURE WORK

Future development of Novexa will focus on the following areas:

- Integration of ROS2 for autonomous terrain mapping.
- Implementing Neural Gait optimization using TinyML.
- Upgrading servos for more stability and torque.
- Developing a modular sensor pod for environmental mapping.
- Adding solar-assisted charging for outdoor missions.
- Improving design with a detachable leg for advanced operations.

VII. CONCLUSION

This paper presented Novexa, a 3D printed hexapod robot designed for adaptive locomotion across multiple terrain types. The system demonstrates the feasibility of using low-cost PLA fabrication combined with inverse kinematics-based control and multiple gait strategies to create a capable and affordable all-terrain robotic platform. Future work will focus on autonomous navigation, enhanced sensing, and neural gait optimization to further improve the robot's adaptive capabilities.

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