Towards a Biomimetic and Dexterous Robot Avatar: Design, Control, and Kinematics Considerations

Akash Harapanahalli*, Emil Muly*, Hogan Welch*, Timothy Brumfiel*, Zhengyang Weng*, Manzano Akhtar, Ahmed R. Abouelnasr, Austin Newland, James Bunting, Kevin McGorrey, Juo Shuen Lee, Gaorong Wang, Luke Drnach, Don Jae Lee, and Ye Zhao, *Member, IEEE* (*the first five authors equally contributed)

I. Introduction

THE Athena Upper Body Robot, depicted in Figure 1, is a lightweight, 3D printed humanoid robot, built by a team of undergraduates participating in the Vertically Integrated Projects (VIP) program at Georgia Tech [1]. This project aims for low-cost robot design while achieving high-fidelity motion control performance for contact-rich manipulation behaviors. This abstract presents preliminary results on robot design, control, and kinematics. The Athena robot serves as a platform to explore both dexterous grasping of various objects and trajectory generation for agile manipulation tasks. Our long-term goal is to integrate Athena with Cassie, a bipedal robot acquired from Agility Robotics [2] and hosted in the LIDAR lab, to aim for unified locomotion and manipulation.

II. Methods

Design: Originally acquired from Youbionic [3], the robot design features an anthropomorphic upper body with five subsystems - spine, two arms, and two hands. The entire system weighs 11 kilograms and possesses 28 degrees of freedom in total. Athena employs 40 linear actuators coupled with bio-inspired design to mimic the functionality of human muscles. Generating motion with linear actuators and geometry rather than conventional rotary motors results in joint motions similar to that observed in human muscles. The linear actuators also serve to reinforce the 3D printed structure of the robot, as human muscles assist with stability and posture in the human body. To achieve such a lightweight design, the entire system is 3D printed with ABS material, and its joints are reinforced by heat-sink metal inserts to strengthen key joint connections and reduce interplay between parts.

Control: Accurate joint-level position control is fundamental in executing agile manipulation tasks. While solutions for traditional rotary joints have been well explored, rotary joints using linear actuators and geometry pose a new challenge. In particular, it is difficult to characterize the actuator's voltage-position relationship, map linear positions to joint angles, and devise a control scheme that enhances performance based on the efficiency of each joint. The Athena Control team has successfully used system identification to characterize the voltage-position relationship for each actuator. Using this characterized relationship, PID controllers were designed for the low-level control system.

The authors are affiliated with the Laboratory for Intelligent Decision and Autonomous Robots, G. W. Woodruff School of Mechanical Engineering, Atlanta, GA, USA (e-mail: ye.zhao@me.gatech.edu).

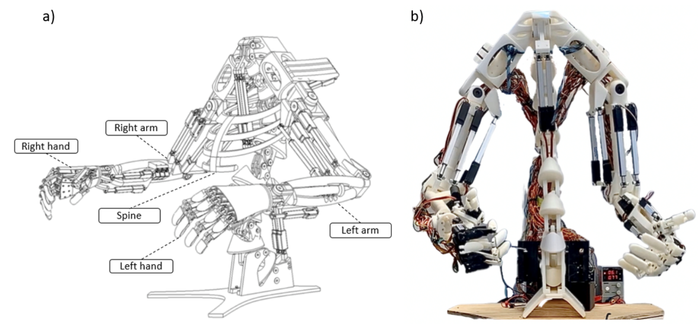

Fig. 1. a). Athena Mechanical System Architecture. b). Athena Upper Body Assembly

Kinematics: Determining Athena's range of motion is critical to perform any given task in operational space. Given trigonometric relationships of one arm's seven joint angles, the Cartesian configuration of its palm was solved by homogeneous transformation matrices. Based on a palm's desired Cartesian configuration, the optimal joint angles were solved by running a Newton-Raphson root-finding algorithm. In addition, Athena's fingers were modeled as a four-bar linkage system relating the actuator flexion/extension to the finger position. These kinematics solutions, combined with control algorithms, allow for effective operation in Athena's workspace.

III. Conclusion and Discussion

Athena serves as a proof of concept for a biomimetic and dexterous robot avatar with a high degree of accessibility due to its lightweight and low-cost design. The design combines 3D printed components with linear actuators to form the robot's limbs and muscles. Controllers are designed using a transfer function that relates each actuator's input voltage to its position. Control is achieved by mapping desired joint angles to linear positions using geometry. Desired position and orientation are converted to joint angles using an inverse kinematics root-finding algorithm. Future work will focus on (i) optimizing the mechanical design to allow for improved accuracy and motion fluidity; (ii) studying learning-based or optimal control methods; (iii) integrating a newly built Athena head robot with cameras and target vision-based grasping.

References

[1] Vertically Integrated Projects, "https://www.vip.gatech.edu/."
[2] Agility Robotics, "https://www.agilityrobotics.com/."
[3] Youbionic, "https://www.youbionic.com/."