# Haptic Interface for Hexapod Gait Execution

Digesh Chitrakar, Rahul Mitra, Kevin Huang

***Abstract*— Legged locomotion offers flexibility and maneuverability over wheeled or tracked systems. The advantages allow legged robots to traverse a wide array of heterogeneous terrains that are otherwise inaccessible. Examples of such scenarios include search and rescue, field applications, and space exploration. On the other hand, generalized autonomous walking is difficult – step planning, dynamic analysis, balance control, gait execution and adaptive foothold selection must execute in concert for successful legged locomotion. This paper presents a method for leveraging human decision making and adaptability to control legged robot walking with a haptic interface. The magnitude and direction of force feedback as well as average step size were tracked during basic locomotion. Overall robot navigation trajectory was also enhanced with haptic feedback.**

***Keywords* — telelocomotion, human robot interaction, haptic feedback**

## I. Introduction

Dynamic legged robots have vast application and are suitable for traversal in both structured and uneven or difficult environments [1], [2]. However, some significant issues with legged locomotion persist. For example, non-linear kinematics and dynamics are difficult to model precisely, and dynamic balance is difficult to achieve with numerous degrees of freedom needing to be controlled in real time [3]. To address some of these concerns, Muscolo et al. presented a biped wheeled robot with flexible legs [3], and Carpentier et al. proposed a centroidal dynamics model for multicontact locomotion of legged robots [4]. Bilateral human-in-the-loop teleoperation has been shown to improve robot task execution in complex or difficult environments [5]–[8]. The work presented here aims to alleviate several challenges associated with autonomous legged locomotion by using a bilateral human-in-the-loop architecture for gait execution of a simulated hexapedal robot.

### A. Contributions

To the best of the authors' knowledge, the work presented here is the first to detail the design and testing of a user interface that incorporates kinesthetic force feedback for the teleoperated control of a hexapedal robot's gait.

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This material is based upon work supported by the NASA CT Space Grant, Grant No. NNX15AI12H under the PTE Federal Award. Additional financial assistance was also provided by the Trinity College Department of Engineering and Trinity College Faculty Research Committee. Any opinion, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of NASA or Trinity College.

## II. Methods

*1) Robot Platform:* The robotic system used in the simulation was a Trossen PhantomX hexapod. The femur-tibia (FTi) joint of each leg was fixed; the remaining joints, the coxa-trochanter (CTr) and the thorax-coxa (ThC), are actuated for 2 DOF motion of each leg. Multiple points of contact with the ground assist the hexapod in maintaining balance control, in contrast to systems that use bipedal devices [9], [10]. Since the robot is servo-driven, dynamics can be largely ignored. Kinematics and contacts were left to the built-in physics engine of Gazebosim.

*2) Computing Systems:*

*a) Operator Workspace:* The Computer Haptics and Active Interface (CHAI3D) SDK was implemented to both gather 6DOF haptic device configuration as well as provide kinesthetic force feedback. A rosbridge node was incorporated to facilitate communication between the operator console and the simulation platform via TCP/IP.

*b) Simulation Platform:* The PhantomX hexapod ROS package provided predefined gait trajectories for translational and pivoting motion. Mapping haptic device configuration to these gaits was necessary. To that end, a walker node was written to effectively translate circular motion patterns in the haptic device configuration XZ plane to translational motion magnitude, direction and rate. Roughly circular motion in the XY plane, on the other hand, commanded the magnitude, direction and rate of the pivoting motion. This was achieved with a simple linear mapping.

*3) Haptic Device State to Robot Locomotion:*

Haptic device state includes the PHANToM Omni 6 DOF configuration.The goal is to map haptic stylus position $\vec{p}_h$ to joint state $\vec{J}$:

$$\vec{p}_h = \begin{pmatrix} x_h \\ y_h \\ z_h \end{pmatrix} \qquad \vec{J}_l = \begin{pmatrix} \theta_\text{F} \\ \theta_\text{C} \\ \theta_\text{T} \end{pmatrix}$$

for each haptic device $h$. where $\vec{J}_l$ is the joint state for leg $l$, $\theta_\text{F}$ is the joint angle for the FTi joint, $\theta_\text{C}$ is the joint angle for the CTr joint, and $\theta_\text{T}$ is the joint angle for the ThC joint. Two different mappings are developed, one for forward/backward locomotion and one for pivoting.

*a) Translational Movement:* In translational locomotion mode, $z_h$ and $x_h$ coordinates of the haptic stylus $h$ position are mapped directly to the joint angles $\theta_C$ and $\theta_T$ respectively. In other words, any user-input position can be mapped to appropriate joint angles as

$$\vec{J}_l(z_h, x_h) = \begin{pmatrix} \theta_\text{F} \\ \theta_\text{C} \\ \theta_\text{T} \end{pmatrix} = \begin{pmatrix} \bar{\theta}_\text{F} \\ \alpha_z z_h \\ \text{sgn}(\phi_{hl}) \alpha_x x_h \end{pmatrix}$$

where $\bar{\theta}_\text{F}$ is the fixed angle for joint FTi, $\alpha_z, \alpha_x$ are heuristically tuned real scalars, and $\text{sgn}(\phi_{hl})$ are direction flags for the phase of the alternating tripod gait associated with each haptic device $h$ and leg $l$.

*b) Pivoting Motion:* In pivoting motion mode, the angle of joint FTi again is fixed at $\bar{\theta}_F$. $y_h$ and $x_h$ coordinates of the haptic stylus $h$ position are mapped directly to the joint angles $\theta_C$ and $\theta_T$ respectively. In other words, any user-input position can be mapped to appropriate joint angles as

$$\vec{J}_l(y_h, x_h) = \begin{pmatrix} \theta_\text{F} \\ \theta_\text{C} \\ \theta_\text{T} \end{pmatrix} = \begin{pmatrix} \bar{\theta}_\text{F} \\ \alpha_y y_h \\ \text{sgn}\left(\psi_l\right) \alpha_x x_h \end{pmatrix}$$

where $\alpha_y, \alpha_x$ are heuristically tuned real scalars, and $\text{sgn}(\psi_l)$ is a direction flag for the phase of the pivoting gait associated with each leg $l$.

## III. Results

In a proof of concept study, input device command trajectories, time to completion, number of steps required, and robot base trajectory were recorded during a simple 3 meter straight-line traversal task, depicted below in Fig. 1c.

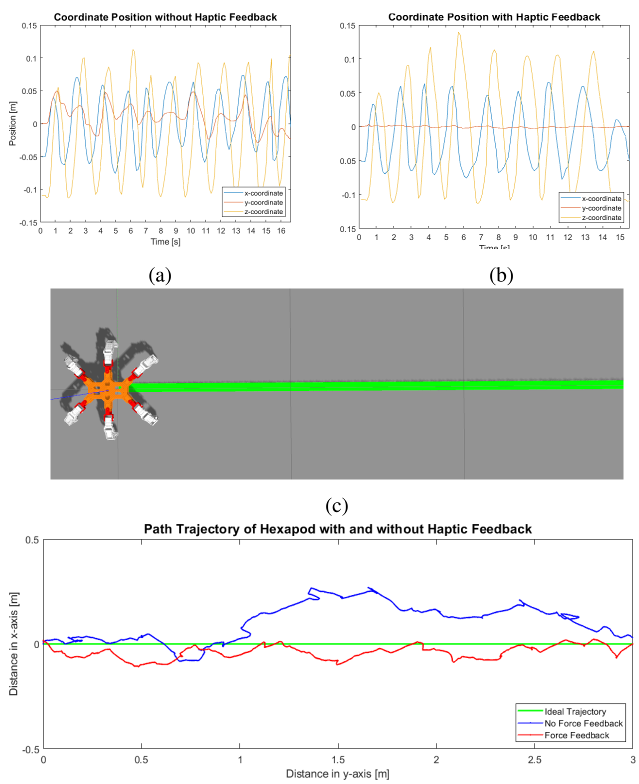


Fig. 1: Input device position command trajectories are shown in (a) without haptic feedback, (b) with haptic feedback. (c) the desired robot trajectory, a 3 m long straight path (d) hexapod base trajectory with and without haptic feedback.

The input device command trajectories during testing without and with haptic feedback are represented in Fig. 1a and Fig. 1b respectively. With haptic feedback, undesired commands in the Y component are attenuated. The mean applied haptic feedback to reduce the commanded Y component was found to be only 0.1951 N. Figure 1d shows the robot base movement. With haptic feedback, it was observed that the point to point traversal task was completed in less time and with less steps. The overall pathlength and deviation from ideal trajectory were also reduced with haptic feedback. These results are summarized below in Table I.

TABLE I: Results Table

| Feedback Mode | Times [s] | Steps | Path Length [m] | RMSE [m] |
|---|---|---|---|---|
| Haptics | 15.54 | 9 | 3.8177 | 0.0487 |
| No Haptics | 16.66 | 11 | 4.4990 | 0.1242 |

## IV. Conclusion

Real time automatic legged locomotion in challenging terrains is an unsolved challenge. In this work, the authors present a proof-of-concept haptic implementation of human-in-the-loop control of a legged proxy. The results of these preliminary experiments suggest that the incorporation of minimal kinesthetic haptic feedback might reduce unnecessary movements and increase efficiency of traversal, as measured by time to completion, path length, path error, and number of steps. Future work will include integrating contact forces into the system thereby allowing the operator even more degrees of control and also examining how the presented method can be incorporated with kinematically dissimilar input and output devices.

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