3D Passive Dynamics-inspired Walking Actuated by Open Loop Leg Extension

Justin K. Yim, Kamal Carter, Sharfin Islam, Sarah Bergbreiter, Aaron M. Johnson

Department of Mechanical Engineering
Carnegie Mellon University
Pittsburgh, PA, USA
jkyim@andrew.cmu.edu

I. INTRODUCTION

3D passive dynamic walkers move through a combination of rocking (roll) oscillation in the frontal plane and leg swinging (pitch) oscillation in the sagittal plane. Underactuated robots inspired by passive dynamic walkers aim to excite and synchronize these oscillations with limited actuation [1]. We investigate walking actuated by leg extension in an underactuated biped robot with curved feet. Using simulation, we find that stable self-starting walking gaits can be excited by open-loop periodic leg extension across a range of extension amplitudes and frequencies.

II. METHODS

Two independent Matlab simulations describe the motion of the walker in the sagittal plane and frontal plane. The robot is modeled as a system of two extendable legs pinned together by a passive “hip” joint at the top and capped with spherical feet at the bottom. The ground is modeled as a rigid horizontal surface with a coefficient of friction of 0.5 and with which the feet make perfectly inelastic impacts. The lengths of the legs vary sinusoidally with time, equivalent to high-stiffness position control of linear actuators according to a clock. The passive hip pin joint is towards the front of the robot in order to bias the robot to walk forwards.

We simulated a 0.15 m tall robot with sinusoidal leg extension ranging from 0.40 Hz to 6.31 Hz in frequency and 3 mm to 12 mm in amplitude. We evaluated the resulting roll and pitch oscillations according to four metrics: 1) amplitude, 2) phase relative to sinusoidal extension, 3) bias (does the robot lean), and 4) consistency, measured by the standard deviation of the angle of the left leg at touchdown in the last 25% of the simulation to evaluate whether the oscillations have converged.

III. RESULTS AND DISCUSSION

Open-loop leg extension actuating a walker with a passive hip results in walking with synchronized roll and pitch oscillations that are self-starting — that is they converge to a walking gait when initialized at rest in an upright equilibrium posture. Leg extension excites both roll and pitch modes simultaneously and both simulations independently converge to foot touchdown occurring at 0 and 180 degrees of the sinusoidal leg extension.

Sagittal plane oscillations converge to forwards walking for all frequencies above 1.4 Hz with decreasing amplitude and step length with increasing frequency.

Geometry of the feet in the frontal plane is important to the range of actuation parameters that produce stable walking. Spherical feet whose centers of curvature are displaced laterally from the center line had the widest range of satisfactory walking parameters compared to spherical feet with center of curvature on the center line either with or without a gap between the feet. Feet with a centered curvature do not produce stable walking below 2 Hz where the largest steps and fastest walking in the sagittal plane occur. Furthermore, they may exhibit a steady lean biased towards the left or right more than five degrees at higher frequencies.

We are currently validating the results of the two planar simulations with a physical walker prototype.

REFERENCES