AN EMBODIED MOVEMENT INSPIRED BIPEDAL ROBOT DESIGN WITH CORE-LOCATED ACTUATION

Umer Huzaifa, Catherine Maguire, and Amy LaViers

Abstract— **From embodied movement analysis, such as the Basic Six in Bartenieff Fundamentals, Thigh Lift, Forward Pelvic Shift, and Lateral Pelvic Shift play a major role in walking. Inline with this understanding, we have designed a biped model with two mechanical links acting as legs and a mass acting as core at the hip, that can move forward and backward along the direction of travel in accordance with the Forward Pelvic Shift. For the simplified model, gait is generated using feedback linearization giving a stable walk. The alignment of the biped model to the human movement strategies may be beneficial as a form of bio-inspired design. Moreover, variable gait synthesis in a bipedal model, the ultimate goal of this work, may be essential to incorporating robots in dynamic, human-facing environments, where systems need to modulate motion profile for appropriate nonverbal communication.**

I. INTRODUCTION

Human gait can be analyzed from an embodied perspective where externally experienced principles of movement and internally perceived body connections are examined, including those as articulated in Irmgard Bartenieff's Fundamentals (BF). In particular, her Basic Six movement sequences [1] are designed to create a supportive relationship between body organization and movement intention. All of these movements are related to accessing efficient and effective fundamental body connections in any activity, but three of these sequences, namely, Thigh Lift (TL), Forward Pelvic Shift (FPS), and Lateral Pelvic Shift (LPS), are particularly useful lenses through which to describe walking. The isolated action of these has been shown in Fig. 1.

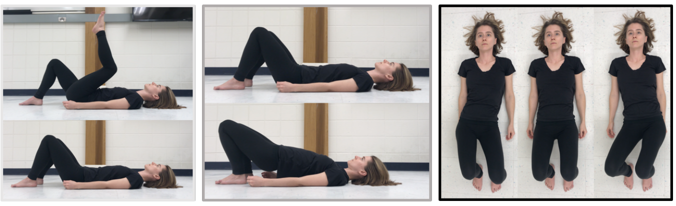

Fig. 1: Three exercises within Bartenieff's Basic Six. Thigh Lift in the left panel; Forward Pelvic Shift in the middle; and an exaggerated Lateral Pelvic Shift, both sides (right and left), in the right, are shown.

Inspired from this understanding of human walking, a robot design is proposed [2] that incorporates core-located actuation. This design emulates the effect of the human pelvis with a tray structure allowing a heavy ball to roll on a curved path. The tray structure is attached to a bipedal robot platform. The ball rolls in the channel from one end to the other by the rotation of the tray about the pitch axis Y, thus replicating the effect of pelvic shift.

II. SIMPLIFIED PLANAR BIPED MODEL FOR CORE-LOCATED ACTUATION

A planar model simplification of the bipedal robot from [2] is presented. As shown in Fig. 2, to model the core in humans, the planar model has a piston mechanism moving a heavy mass forward and backward using a force actuator. The orientation of this mechanism is fixed at a right angle with the vertical. In the swing phase, the biped acts as a three link planar robot fixed at the stance leg foot. The Euler-Lagrange equation for this phase give the following equations of motion:

$$D_s \ddot{q_s} + C_s(q_s, \dot{q_s})\dot{q_s} + G_s = \Gamma_s, \tag{1}$$

where $q_s = [q_{st}, q_{sw}, d_t]^T$ is the set of generalized coordinates. This phase is active until the swing leg impacts the ground. Resultantly, an update in the joint positions and joint velocities occurs. At this moment, the two leg joint angles simply exchange their roles while the core mass displacement from the hip remains the same. The joint velocities, on the other hand, are determined using the assumptions of impact without a slip and rebound.

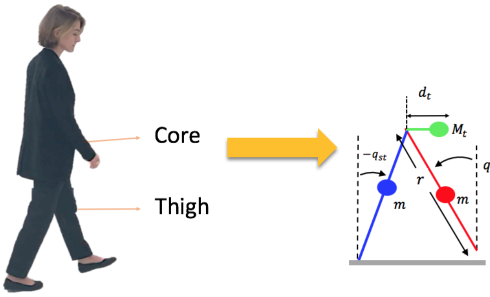

Fig. 2: Human-inspired planar biped model with core-located actuation. Core is replicated by a prismatic joint moving the mass M_t forward and backward by displacement d_t. The thighs are imitated as two mechanical links of mass m rotating about the hip.

Corresponding authors, Umer Huzaifa and Amy LaViers are with Department of Mechanical Science and Engineering, University of Illinois at Urbana-Champaign, IL 61801, USA. (email: {mhuzaif2, alaviers}@illinois.edu)

Catherine Maguire is affiliated with Laban/Bartenieff Institute of Movement Studies (LIMS), Brooklyn, NY 11217, USA. (email: cat-maguire@embarqmail.com)

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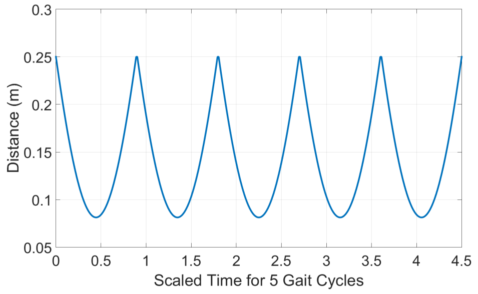


Fig. 3: Desired virtual constraint for torso mass against the swing leg joint angle over 5 gait cycles. Namely, this plot shows d_t versus q_{st}.

III. CONTROLLER DESIGN

The control system for this robot has been designed using the concept of virtual constraints detailed in [3]. The stable walking controller is generated through use of feedback linearization and a Poincare return map. For modeling, we have extended the compass walker model to include an actuated core, emulating the effect of the forward propulsion of the robot [4].

In order to generate the desired walking, we define output:

$$y_s = h(q_s) - h_d(\theta_s) \tag{2}$$

where θ_s is a strictly monotonically increasing function of the joint configuration variables (in our case, that is q_{st}, the joint angle of the stance leg). Feedback linearization is used to drives y asymptotically to zero, thus making $h(q_s) \rightarrow h_d(\theta_s)$. The virtual constraints used include a to and fro motion for the torso mass, shown in Fig. 3.

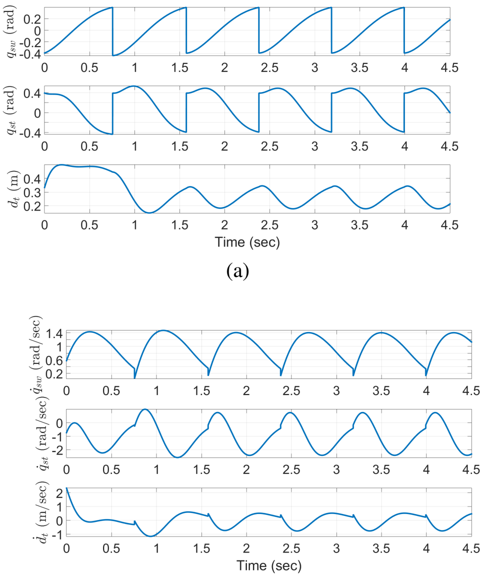
To meet the virtual constraints, following control signal is generated:

$$u(\theta_s) = (L_g L_f h(\theta_s))^{-1}(v - L_f^2 h(\theta_s)). \tag{3}$$

This control signal ensures that the robot structure remains on the virtual constraint surface. The Lie derivatives $L_g L_f h$ and $L_f^2 h$ are for linearizing the system while the signal v is an additional control signal to make the resulting double integrator asymptotically stable. The resulting joint position and velocity trajectories are shown in Fig. 4

IV. TOWARDS EXPRESSIVE BIPEDAL ROBOTS

This work has leveraged a description of walking via Forward Pelvic Shift and Thigh Lift from Bartenieff's Basic Six, modeled as a planar biped controlled through feedback linearization. This high-level description may allow for movement to be parametrized in terms closer to how humans describe movements to each other. The presented model covers only two of the three specified movements in the Basic Six and covers a simplified representation of the three dimensional robot proposed in [2] (shown in Fig. 5). Future work will explore generation of different gait styles by variations in the movement of the core mass using an iterative, descriptive design cycle incorporating observation from Certified Movement Analysts and evaluation by lay viewers. Furthermore, another direction of research can be the investigation of the advantages of drastic change in the center of mass of the robot because of varying movements of the core mass.



(a)

(b)

Fig. 4: Periodic waveforms of joint positions and velocities for nearly five walking steps of the planar model.

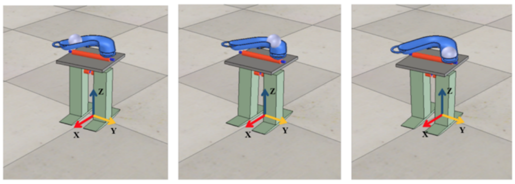


Fig. 5: Perspective view of the proposed robot design at different instants during a walking step [2]. A coordinated movement of the legs and the pitching motion of the tray give a stable gait.

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