

Dynamic Bipedal Walking while Carrying an Unknown Time-Varying Load

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1 Introduction

In recent years, there has been tremendous interest in employing legged and humanoid robots for dangerous missions in disaster and rescue scenarios, requiring robots to operate swiftly and stably while dealing with high levels of uncertainty and large external disturbances. One such practical example is using a legged robot to carry and manipulate large and heavy objects whose mass is not known a priori. Most prior work only considers constant static loads. For instance, traditional controllers for dynamic bipedal walking, such as in [2], fails when the unknown mass exceeds 15% of the robot mass. Results in [1] demonstrate robust adaptive control to adapt to an unknown load of 16 % of robot weight. The problem of carrying large loads while maintaining dynamic walking on a nonlinear, underactuated and hybrid dynamical system is challenging. The limitation of current research, as well as the demand of practical requirement, motivates our research on using adaptive control for dynamic bipedal walking while carrying large unknown time-varying load.

2 Results

The continuous-time dynamics of a bipedal robot is $\dot{x} = f(x) + g(x)u$, where $x \in \mathbb{R}^n$ and $u \in \mathbb{R}^m$ are the states and controls. Walking gaits can be formulated through virtual constraints expressed as outputs $y(x) \in \mathbb{R}^m$. Input-output linearizing controllers can be developed resulting in the closed-loop linear output dynamics $\dot{\eta} = F\eta + G\mu$ where $\eta = [y, \dot{y}]^T$. If we consider uncertainty in the dynamics and assume that the functions, $f(x), g(x)$, are unknown, we then have to design our controller based on nominal functions $\tilde{f}(x), \tilde{g}(x)$. The closed-loop system now takes the form $\dot{\eta} = F\eta + G(\mu + \theta)$, where

$$\begin{aligned} \theta &= \Delta_1 + \Delta_2\mu \\ \Delta_1 &= L_{\tilde{f}}^2 y(x) - L_g L_{\tilde{f}} y(x) (L_{\tilde{g}} L_{\tilde{f}} y(x))^{-1} L_{\tilde{f}}^2 y(x), \\ \Delta_2 &= L_g L_{\tilde{f}} y(x) (L_{\tilde{g}} L_{\tilde{f}} y(x))^{-1} - I. \end{aligned} \quad (1)$$

Building off our recent work on L1 Adaptive Control for Bipedal Walking in [3], we apply the control scheme onto the problem of carrying unknown mass on torso. Our approach is not only able to handle up to load of 94% robot weight, but also deal with under-actuated robot and tracking the entire walking gait. Fig.1 shows the first 5 steps in the simulation of carrying randomly unknown mass [0:30] kg.

References

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- [2] Kevin Galloway, Koushil Sreenath, Aaron D. Ames, and Jessie W. Grizzle. Torque saturation in bipedal robotic walking through control lyapunov function based quadratic programs. *IEEE Access*, to appear, 2015.
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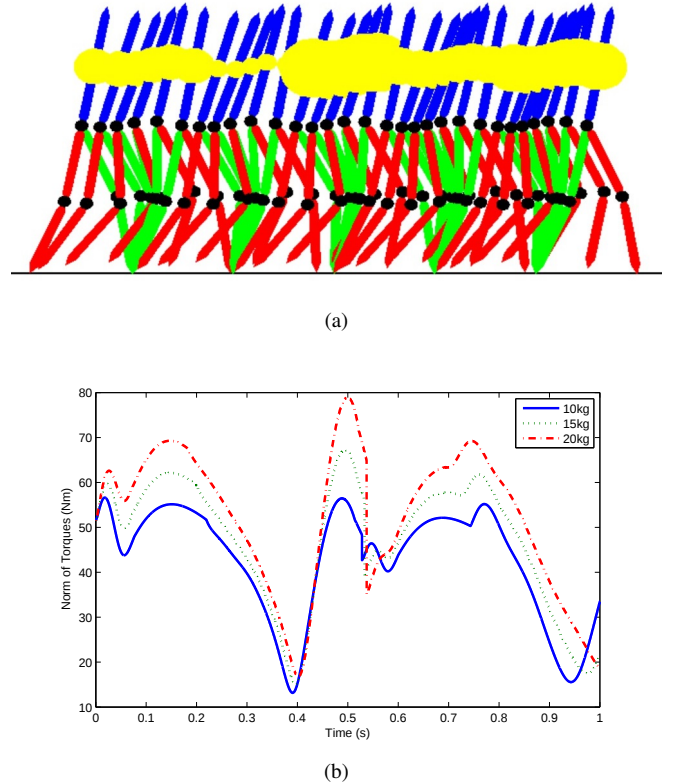


Figure 1: (a) Dynamic bipedal dynamic walking while carrying an unknown load whose mass randomly varies between 0-30 Kg on every step. (b) Norm of control torques for dynamic walking while carrying 10, 15, and 20 Kg unknown masses.