Variable Impedance Actuation to Increase the Behavioural Diversity of Legged Robots

Derek Leach, Nandan Maheshwari, Fabian Günther and Fumiya Iida

Biologically Inspired Robotics Lab, Swiss Federal Institute of Technology Zurich, Switzerland
(E-mail: [derek.leach, nandan.maheshwari, fumiya.iida]@mavt.ethz.ch)

Abstract: A single leg hopping robot has been constructed which includes a clutch in series with the hip motor and a prototype Linear Multi-Modal Actuator (LMMA) at the knee. The single leg will be used to test how the different actuation methods can improve the behavioural diversity of the robot.

Keywords: Multi-Modal Actuator, clutch, brake, Variable Impedance Actuator, dynamic legged locomotion, behavioural diversity

1. INTRODUCTION

The desire to develop fully autonomous, deliberative, mobile robots that can competently sense and interact with their environment (human or hostile), manipulate objects and traverse challenging terrain, fuels much of the research in the robotics field.

For operating in diverse environments and over difficult terrain, legs are the best means for locomotion, however conventional legged robot locomotion has a very high energetic cost of transport [1]. Furthermore, intrinsic to a robot's autonomy is its ability to ambulate whilst supplying its own power, current power supply technology and energy storage greatly constrict the performance of the robot in this regard.

Consequently much of the focus in legged robot locomotion research has concentrated on using passive elements to make legged locomotion as efficient as possible [2, 3] and using compliance to allow legged robots to traverse rough terrain whilst reducing control effort and improving stability [4, 5]. The robots that have been designed to operate most efficiently can often only do so in a single mode and a narrow performance range. Hosoda et al [6] showed how variable compliance allowed for many more modes, however their pneumatic actuation is not conducive to a robot's autonomy.

In this paper we introduce a new actuator and actuation method that we hope will go some way to increasing the behavioural diversity of the robot whilst maintaining efficient locomotion. The power will be supplied electrically so that these methods can eventually be implemented in autonomous robots.

Goal Our goal is to implement actuation into a robot leg such that there are several different modes of operation. It will be able to travel efficiently and stably in steady state locomotion at a range of speeds and it will be able to switch to fully controllable actuated mode for precise leg movements.

Challenge Each of these operational modes requires a different set of mechanisms. Efficient and stable locomotion requires springs to store the energy and free swinging movement of the leg, whilst position output will require precise control of the leg and so high impedance. A mechanism is needed to change the impedance to suit the required task.

Solution We present a new means of actuating a robot leg utilizing brakes and clutches which will provide many different modes of operation.

2. THE ROBOT

To validate our actuation methods, they will be tested on a two segment hopping leg robot attached to a boom. This configuration has successfully been able to test leg performance and dynamic locomotion [7] and so will provide our first means of evaluation.

2.1 The Leg

We have designed a 2 segment leg, with a thigh and a shank each 60 cm long. The leg can be seen in Fig. 1.

Fig. 1 Two segment hopping leg robot attached to a test rig with a passive spring in place of the actuator.

The hip has one rotary degree of freedom actuated by a Maxon RE65 DC motor with 25:1 planetary gear reduction. The motor is connected in series with a magnetic clutch to the leg. With the clutch engaged the motor has full positive drive of the leg, with the clutch disengaged the leg swings freely.

The knee joint also has one rotary degree of freedom and will be powered by the Linear Multi-Modal Actuator (LMMA), mounted to the thigh at one end and the shank at the other.

2.2 The Linear Multi-Modal Actuator (LMMA)

Fig. 2 shows the prototype Linear Multi-Modal Actuator (LMMA), the actuator is 670 mm long, has a range of 120 mm and weighs 4.5 kg. The actuator's frame consists of two guide rails along which three blocks can slide. Each block has a brake mechanism that can fix it to brake rails—which run parallel to the guide rails—and prevent it from sliding. From Fig. 2, the Spring and Middle-Block are connected by a spring and the Middle and Motor-Block are connected by a ball screw driven by a DC motor.

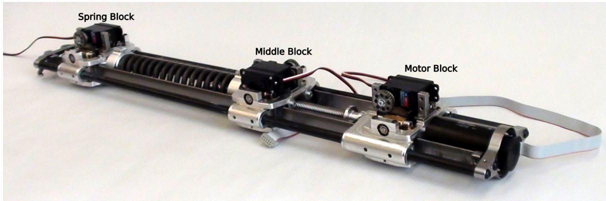

Fig. 2 Linear Multi-Modal Actuator.

To reduce the number of components and simplify the mechanism, early prototypes used the guide rails as the brake rails, however this did not provide sufficient braking force so in this prototype we have included dedicated flat brake rails to maximize the braking area.

2.3 Modes of the LMMA

Applying the correct brake configurations allows the actuator output to: slide freely; become completely rigid; provide direct position control from the motor; or become a series elastic actuator. Furthermore the spring can be charged by the DC motor and discharged. With a charged spring, an instantaneous power output can be supplied greater than the motor alone can provide.

When used to power a leg joint, these modes will allow for different behaviours. For dynamic hopping and running the LMMA can be used in the series elastic configuration to exploit the compliance in the spring for efficiency. Direct actuation removes the bandwidth limit of the spring and allows high impedance and accurate position control of the joint.

For the single hopping leg, applying the brakes of the LMMA during push off can arrest the release of the spring and so produce a short hop. Whilst in the flight phase, the stored energy in the spring can be dissipated, kept or charged more for a higher hop. In this way different hopping patterns can be produced for traversing obstacles.

Just as humans lock their knee joint when standing, this actuator will be able to use its rigid mode to fix the length of the leg. Furthermore the brake mechanism in each block is not back drivable, so once applied no extra energy is consumed.

3. CONTROL OF DYNAMIC LOCOMOTION

Actuating passive dynamic walkers so that they overcome energetic losses can provide for very efficient locomotion, Kuo [8] showed how hip actuation and toe-off provide different performance characteristics for this gait. We similarly aim to actuate the leg to return it to a stable passive forward hopping state using the hip and knee actuators.

Our hopping robot will be developed in stages. Currently a passive spring is connected to the knee joint in place of the LMMA (Fig. 1) and the hip is directly connected to the motor. With this configuration open loop hopping control is possible with a sinusoid position input at the hip. Next we will include the hip clutch to explore how this can improve the energy efficiency of the leg. Once the hip actuation has been developed the LMMA will be mounted in place of the passive spring at the knee and its modes will be explored. At first the series elastic mode will be utilized to improve the dynamic performance of the hopping gait with just the passive knee.

For both the hip and knee actuator a control architecture will be developed to cope with and exploit their discrete nature.

ACKNOWLEDGEMENTS

This work was supported by Swiss National Science Foundation, Grant No. PP00P2123387/1.

This research was funded by the Swiss National Science Foundation through the National Centre of Competence in Research Robotics.

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