Preliminary Energetics of Tripedal and Quadrupedal Gaits Using the GARP-4 Robot

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Abstract Changes in pedality can occur in animals due to injury, congenital defects, or behaviour. Here, an attempt is made to reproduce similar conditions on a nominally quadrupedal robot upon losing functionality in one leg, rendering it tripedal. The change in walking speed and energy efficiency are examined for both quadrupedal amble and basic tripedal walking gaits.

1 Introduction

In order to study pedality changes and adaptation observed in canines, a biomechatronic quadruped robotic platform, the GARP-4, was developed at Ryerson University. Generally inspired by research examining variable morphology in primates [1] and specifically based on research conducted with three-legged dogs [2], the robot is capable of tripedal locomotion, as well as multiple methods of four-legged locomotion (amble, trot, pace). This article examines the high-level system energetics of a tripedal gait and compares it to an amble quadrupedal gait.

2 Background

The GARP-4 (Gait Adapting Robotic Platform, version 4) robot is a boom-supported quadruped robot with dimensions that approximate that of a small dog (see Fig. 1). Each leg has two actuated degrees of freedom (hip and ankle), and one passive-compliant DOF at the knee. The hips are actuated in parasaggital planes using a

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Robotis Dynamixel AX-12+ actuator. The ankle is actuated using a Futaba S3305 servo; the motor abducts and adducts the toe at the distal end of the shank. This leg design resolves the problem of toe-stubbing during protraction by abducting the toe during the forward swing phase of leg movement, and adducting the toe prior to ground contact and the stance phase. All forward-driving torque is produced at the hip by the AX-12+ actuators.

The body of the robot is a 40cm x 14.5cm planar sheet of 5mm thick acrylic. This was chosen to decrease design complexity and simplify body dynamics by providing a rigid, lightweight substrate to mount all necessary parts. The control of the robot is achieved using a National Instruments Compact RIO (cRIO) real-time embedded controller. The cRIO communicates with the AX-12+ actuators using a half-duplex serial packet communication scheme at a rate of 115 200 kbps. Communication is established with the ankle servos using a standard pulse-width modulation scheme. The control algorithm is written to approximate the behavior of a biological CPG (Central Pattern Generator, [3]). Because of the numerical nature of the Dynamixel communication packets, the control software increments and decrements goal position commands in a triangular wave pattern to achieve back and forth oscillations of each leg. Abduction/adduction of the ankle is triggered off each leg's individual wave pattern, according to specific numerical position values of each hip motor. The robot is supported by a counter-weighted boom that restricts body-roll and body-yaw. The effective mass, taking into account the counter-balance, of the robot was measured to be 650 grams.

3 Methodology

Voltage and current data were gathered for the execution of an amble gait and a tripedal walking gait. Current data was gathered using a Fluke 80i-110s current clamp over the return line of the robot. Voltage measurements were taken across the 12VDC regulated rail supply used to power the robot. The data was recorded using a National Instruments USB-6008 DAQ. Since the input of the DAQ has a maximum range of $\pm$10V, an inverting amplifier with a gain of -0.5 was used to scale and isolate the 12 VDC signal from the DAQ. The amplifier was constructed using a Texas Instruments TL071 operational amplifier.

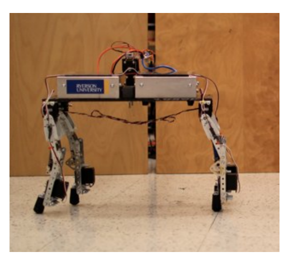

Fig. 1 The GARP-4 robot. (photo credit: Luis Fernandes).

Fifteen complete runs were recorded for each gait. For each run, the robot was made to walk in a complete circle with a circumference of 7.41m (radius of 1.18m, corresponding to the length of the boom arm). The time for each complete circle was recorded. To better understand the energetics of the system, surface temperature measurements of the outside housing of the left-hind leg Dynamixel (this being the lone-leg during tripedal walking) was taken using an IR thermometer (Optris LaserSight). Temperature measurements were taken just before and just after each trial, for both the amble and tripedal gaits.

4 Results

Both gaits, amble and tripedal, were formally conducted 15 times. A mean power consumption of 18.8 Watts and 12.1 Watts respectively, were found. Maximum power consumption values for the amble and tripedal gaits were found to be 54.7 Watts and 36.3 Watts, respectively. Average forward speed during amble was 0.29 m/s, and 0.05 m/s during tripedal walking. The energetic cost of locomotion, specific resisistance [4] is calculated as

$$\varepsilon = \frac{P}{mgv} \tag{1}$$

where ε is the unitless measure for specific resistance, P is the average consumed electrical power (Watts), m is the mass (kg), g is the gravitational acceleration constant, and v is the forward velocity (m/s), yielding 10.2 for the amble gait and 38.0 for the tripedal walk. During the tripedal walk, as shown in Fig. 2, the lone rear leg demonstrated an the average temperature increase (between start and finish of a single walk around the boom) on the housing surface of the AX-12+ was of 8.1°C. For the amble gait the average increase was only 0.1°C.

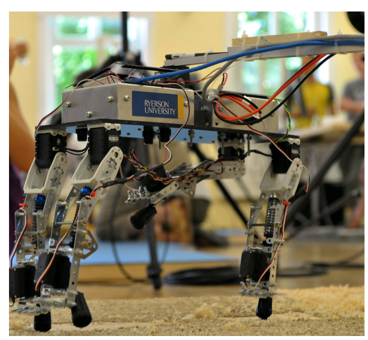

Fig. 2 The GARP-4 robot, walking tripedally during demonstrations at Friedrich-Schiller Universität Jena, Jena, Germany. Note how one of the rear legs is held far from the ground, rendering the system tripedal (photo credit: Jan-Peter Kasper, FSU-Jena).

5 Analysis

The most obvious result is that forward speed is far less during tripedal walking (0.05 m/s) than quadrupedal (0.29 m/s) walking. This is due, in large part, to a requirement to reduce step frequency of the front legs in tripedal walking. Some slip, especially in the rear leg, was seen during tripedal walking, as well. Therefore, while power consumption is less for the tripedal walk then it is for the amble, specific resistance (a measure of efficiency of transport) is almost four times as much. Furthermore, a significant rise in temperature of the lone-leg AX-12+ during the tripedal gait, when compared to the amble gait, points to the possibility of the lone leg consuming substantially more power to compensate for the unavailable fourth leg. It also indicates a vulnerability of the rear leg to overheating due to higher current usage (and, therefore, higher torque loads).

6 Conclusions

It has been shown that a quadrupedal robot can achieve tripedal gaits, mimicking behaviour found in nature. The tripedal gait was found to be slower and less efficient. One of the hip actuators was also found to have a striking increase in heat during tripedal walking. Further studies are required to better understand gait and actuator dynamics during quadrupedal and tripedal gaits.

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