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Design of a Transforming Myriapod Robot for Multimodal Locomotion

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***Abstract*—This paper describes the design and simulation verification of a multimodal locomotion system on a myriapod robot which is able to walk on uneven terrain and roll on flat ground. The proposed design aimed to reduce actuation while maintaining power efficiency on both flat and uneven terrain. A mathematical approach was utilised to determine key parameters. A simulation study was conducted to verify the kinematics and dynamics of the system, modelling the locomotion of the robot while walking and during its transformation to rolling on flat ground.**

***Index Terms*—multimodal locomotion, myriapod robot, legged locomotion, transforming robot**

I. Introduction

Multi-terrain mobile robots have increased utility when compared to traditional dedicated mobile robots [1]. However, multi-terrain robots often require complex locomotion systems with a large number of actuators, which puts constraints on size, weight, efficiency and cost. Wheeled locomotion is effective on flat terrain but struggles on uneven terrain. Legged locomotion is suited to uneven terrain but requires an increased complexity for coordinated control [2]. Myriapod robots are a form of legged locomotion based on centipedes and millipedes which have demonstrated the capacity for reduced actuation due to flexible body couplings, which allow passive adaption to the ground profile [3]. The large number of legs ensures stability without the need for complex control systems. However, myriapod systems are slow on flat terrain which makes them unsuitable for applications within buildings, homes and warehouses. Previous complex legged robots such as [4] have been able to increase their velocity on flat terrain by transforming to a wheel form, which is propelled forward by "spare" legs. The proposed design utilises this approach while maintaining the simplicity offered by a myriapod platform, utilising only 2 motors for transformation and forward locomotion both in legged form and wheeled form.

II. Kinematics Design

The Myriapod robot walks in a millipede form on uneven terrain and transforms to a wheel on flat terrain. A central drive shaft runs down the body of the millipede, powered by a single motor. Worm gears on the drive shaft transfer torque to the legs via a spur gear on the leg axle. The drive shaft is split into sections connected by universal-joints (U-joints),

Fig. 1: Partial physical prototype of the proposed myriapod.

TABLE I: Key form parameters. n=16 is the number of leg sets, c=2 is the number of legs sets contacting the ground, d=0.072 m is the distance between adjacent leg roots and s=0.01 m is safety margin distance between leg tips

Parameter	Derived Equation	Value
Maximum body section offset angle ($Q_{\max}$) in degrees	$Q_{\max} = \frac{360}{\pi}$	22.50°
Phase angle delay between adjacent legs (θ) in degrees	$\theta = c \cdot \left(\frac{360}{n}\right)$	56.25°
Vertical length of the leg (R) in meters	$R = \frac{d-s}{\left(2\sin\frac{\theta}{2}\right)\left(2-\cos\frac{Q_{\max}}{2}\right)}$	0.06 m
Length of the whole robot (L) in meters	$L = n \cdot d$	1.15 m
Wheel form diameter (D_w) in meters	$D_w = \frac{L}{\pi}$	0.37 m

allowing an offset angle between drive shaft sections which is limited by the geometry of the body casings, see Fig. 1. A cable runs through each body section and is attached to a second motor. When the cable is wound in it pulls the body into the wheel form, consecutive body cases fit into one another, securing their position. When the robot is in wheel form the legs continue to rotate propelling it forward. The legs on either side of each body sections are in phase with one another. Consecutive leg pairs are out of phase with one another by an acute phase angle. This is a metachronal walking gait which is used by millipedes [5]. In walking form this gait results in a vertical undulation of the body.

The parameters seen in Table I, were necessary to size the robot. The speed of the walking gait is characterised by [6] as

$$V_m = \frac{2R\sin\frac{\theta}{2}}{t_g} \tag{1}$$

where V_m is the velocity of the walking millipede in the direction of travel, calculated to be 0.058 m/s and t_g is the

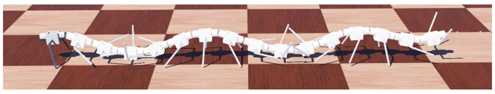


Fig. 2: The myriapod robot walking in millipede form[1].

time the leg is in contact with the ground in seconds. See Table 1 for R and θ.

III. Simulation

A motion study was conducted to validate the design and to evaluate whether rolling increased velocity on flat terrain.

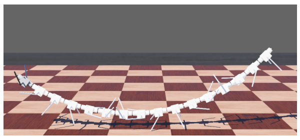
A. Simulation Setup

Webots™ from Cyberbotics Ltd was used to produce 2 simulations, one modelling the walking in millipede form Fig. 2 and one modelling its transformation from millipede to wheel form and rolling locomotion Fig. 3. Limits on computation power meant modelling simplifications were necessary. Leg rotation was modelled with a motor powering each leg set. This neglects the variation of shaft angular velocity resulting from the use of consecutive U-joints. The robot was modelled travelling forward on a flat arena, as a result there were no forces acting which would cause lateral movement. Therefore U-joints were modelled as hinge joints only allowing vertical rotation. Lateral movement of the robot would indicate simulation errors. The transformation was achieved by modelling motors at these hinges. The control code for the transformation activated these motors consecutively to replicate the behaviour of a cable wound from one end by a motor.

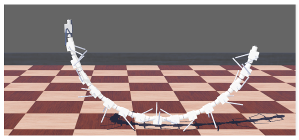
B. Results

The position of the 8^{th} body section was tracked in the x, y and z direction over a period of 35 seconds. The direction of travel is positive x, the positive y direction is the vertically upward and z is the lateral direction. In millipede form the locomotion behaved as expected, the average velocity in the direction of travel was 0.067 m/s. During the transformation to rolling simulation there are 4 main phases of movement in the recorded data see Fig. 4a. Phase 1 is the transformation period, seen in Fig. 3 with a duration of 4 seconds. Phase 2 is stable forward rolling, ending at 10 seconds. Phase 3 is rocking, a period of forward and backward rolling, causing the anomaly on Fig. 4b. Phase 3 was caused by the leg rotation which propels the roll, becoming out of phase with the rolling cycle. A protruding leg halts rotation and causing a backwards roll. Uncoordinated rocking continues until the wheel reaches a stationary position at 25 seconds and the legs begin propelling it forward again. Phase 4 is another period of stable forward rolling. The stable rolling speed was approximately 0.35 m/s this was 5.22 times faster than the walking speed of 0.067 m/s. The overall speed during the 35 seconds was 0.19 m/s. During the transformation to rolling simulation there was an unexpected displacement in the z direction, indicating computational errors in the simulation.

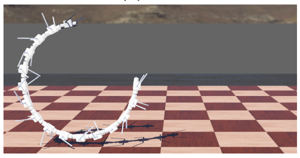
[1]Video of Fig. 2 and Fig. 3 is available at https://youtu.be/TCx6ydXqHts/



(a) 1 s



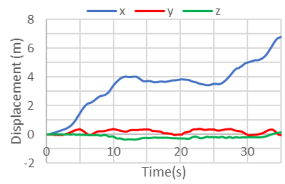
(b) 2 s



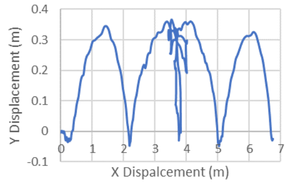
(c) 3 s

(d) 4 s

Fig. 3: The myriapod robot transforming from (a) (b), (c) to (d) rolling.



(a) Displacements in x, y, z w.r.t time.



(b) Forward displacement w.r.t vertical displacement.

Fig. 4: Displacements of the myriapod robot's 8^{th} body section from transforming to wheel form to forward rolling.

IV. Conclusion

A transforming myriapod robot has been designed with increased efficiency on flat terrain while maintaining minimally actuated systems. Simulations confirmed that rolling did increase the velocity of locomotion on flat terrain. However, the leg frequency is not currently optimised for continuous propelled rolling. To achieve this, it is necessary to determine the ideal relationship between the walking gait frequency of the millipede and the rolling cycle of the wheel form. The simulation validated the locomotion style not the transformation system. The modelling simplifications mean the simulation velocities are likely an overestimation.

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