Flexible spine modeling for quadruped robot

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1 Introduction

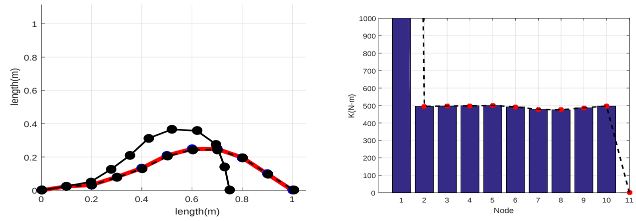
The work is motivated by four-legged animals which can carry large loads on their back and also navigate through rough terrains which are inaccessible to wheeled mobile robots. Several such legged robots have been designed and built – one of them is cheetah-cub (Sprwitz et al. (2013)). Most of these robots have a rigid central structure along its primary axis, which reduces the flexibility of their body. The lack of flexibility reduces maneuverability and stride length. In recent work, flexibility of the spine has been introduced in robots such as Lynx (Eckert et al. (2015)). Three different model has been presented with their own benefits and limitations. In this work we propose an optimization problem which can generate a flexible spine structure satisfying our desired criteria. Using the idea developed in field of structural optimization(Xu and Ananthasuresh (2003),Zhou and Ting (2008)) we developed a formulation to determine the shape and stiffness of the aticulated spine.

2 Mathematical modeling and numerical simulation

A structural optimization process is used to obtain designs of a flexible spine which can be used in a quadruped robot to generate stable bounded gait. We consider the spine consisting of N rigid links connected by one-degree-of-freedom rotary joints with springs and dampers at the joints. The assembly is subjected to a transverse loading and additionally there is an axial displacement δ_d at the free end. The assembly is a redundant system as the assembly can assume infinite number of shapes due to the external loading. We minimize the strain energy generated due to self loading of the quadruped robot and put the desired flexibility of the spine as a constraint under actuated condition. The optimization problem can be stated as follows:

$$\begin{aligned}
&\min_{\theta_0, C_K^{-1} K_v} && \mathcal{J} = \frac{1}{2}\sum_{i=1}^{N+1} K_i(\Delta\theta_{1,i} - \Delta\theta_{1,i-1})^2 \\
&\text{Subjected to:} && \mathbf{K}_m(\vec{\theta_1} - \vec{\theta_0}) - \mathcal{P}(\vec{\theta_1}) = 0 \\
& && \mathbf{K}_m(\vec{\theta_2} - \vec{\theta_0}) - \mathcal{P}(\vec{\theta_2}) = 0 \\
& && \sum_{i=1}^{N} L_i \sin\theta_{j,i} = 0; \quad j = 0,1,2 \\
& && \sum_{i=1}^{N} L_i(\cos(\theta_{2,i}) - \cos(\theta_{0,i})) - \delta_d = 0 \\
&\text{Data:} && (K_{initial}, \theta_{initial}, K_{boundary}, L_x, \delta_d)
\end{aligned} \tag{1}$$

In the above, K_i is the nodal stiffness of the ith node, $\theta_{j,i}$ denotes the orientation of ith rigid link under jth loading condition. The third and the fourth equality constraint represent the zero transverse displacement of the end and the axial displacement δ_d. The optimization problem was solved numerically using *fmincon* available in MATLAB (2015a) and the results for a particular loading is shown in figure 1. The primary use of the flexible



(a) (b)

Figure 1: (a,b) Structure and nodal stiffness obtained from the optimization process with, vertical loading -5 N per node and axial loading -400 N

spine is to generate a periodic end point motion while supporting the body weight and other forces generated due to locomotion. The axial force in the model is applied as a tension using a DC servo motor and this tension results in a deformation of the flexible multi-body structure. We have observed via multiple simulations

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and experiments that the inertia of the body does not have a visible influence if the system is over damped. The deformation or the shape of N rigid links models the flexibility in the spine in a quadruped.

3 Hardware design

The quadruped robot is designed with a pantograph leg which have some compliance which is known to result in more energy efficiency Eckert et al. (2015). The parameters of the designed robot is given in Table below.

Parameter	Value
Mass	2.1 Kg
Standing height	270 mm
Width	200 mm
Length	370 mm
RC servo motor	Makeblock digital servo (8x)
	Vega analog servo (1x)
Control board	Raspberry Pi 3b
Communication	USB connection to with VNC viewer

The robot is controlled with the help of on-board central pattern generator(Sprwitz et al. (2013)) in an open loop manner – there is no feedback to the controller from the legs. Eight coupled nonlinear oscillator generate the pattern which enables the quadruped robot to move in trot(figure:5), canter and with bounded gait. Two

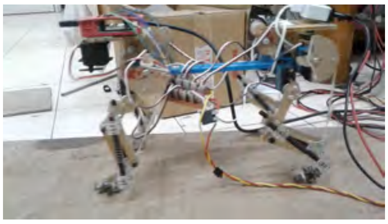

Figure 2: Quadruped with rigid spine

Figure 3: Two rigid spine segment connected by a flexible strip

multi-segmented spines were used. Figure 4 shows the robot with a rigid spine made of acrylic segments and figure 3 shows a spine made of more flexible polypropylene. An accompanying video shows the quadruped

Figure 4: Quadruped with flexible spine

with rigid spine moving on a flat surface with trot gait and figures 5 shows snapshots of the moving quadruped with the rigid spine.

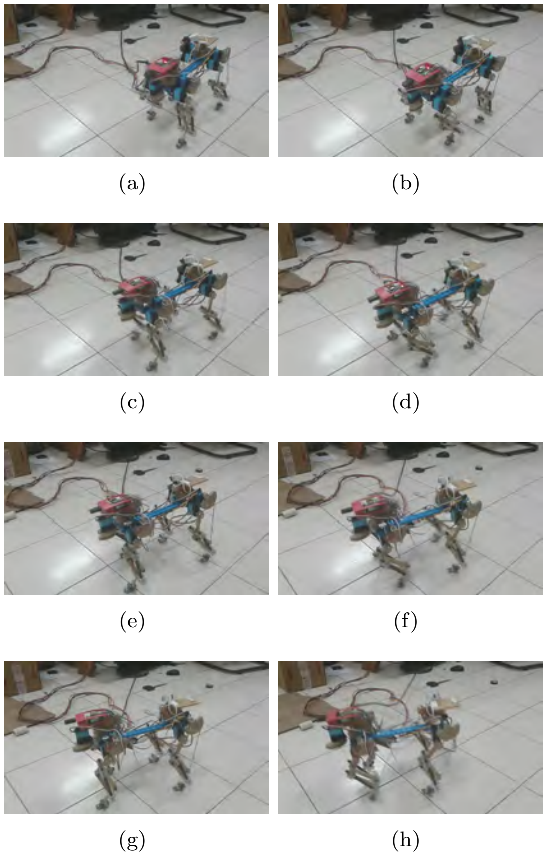

Figure 5: Rigid spine quadruped locomotion in trot gait

4 Future work

We are in the process of developing the hardware with a quadruped with the flexible spine shown above. We hope to demonstrate that the robot with a flexible spine gives better performance and more natural looking motions.

5 Acknowledgment

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6 Presentation format

We would be presenting our finding in form of a short talk with a video.

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