Bio-Inspired Heterogeneous Step Sizes for a Six-Legged Walking Robot

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Abstract: The stick insect *Carausius morosus* uses non identical step sizes while walking with its six legs. As a consequence, the step size differences create a systematic mechanical tension between these legs during the stance phase. In this work, we implemented a step size adaptation for the walking robot LAURON, which allows us to create heterogeneous step sizes. Experiments with different step size configurations show the effects of this systematic mechanical tension on the walking performance of a six-legged walking robot.

Keywords: bio-inspired robotics, stick insect, step size, hexapod, six-legged walking robot

1. INTRODUCTION

Biologically-inspired robots with a natural appearance are fascinating and usually come along with a big public interest. On the one hand, following the design and control rules of Nature increases the acceptance by the public and on the other hand these design principles can help to develop energy efficient, fast, robust and reliable robots. Especially, walking robots are typical examples for bio-inspired robots. The six-legged walking robot LAURON was inspired by the stick insect. In a recently published work we focused on the creation of a biologically-inspired free gait walking pattern [1]. Although this work concentrated on gait generation and coordination of the legs we noticed that the step sizes of our stick insects varied significantly from one leg to the other.

Our extraction of the stick insect's step sizes is based on video analysis and was carried out by hand, which makes this method very time consuming. We could see a trend in our data to different step sizes for certain leg groups, but the data basis was too small.

In literature, we found several works, which include more reliable data on the step sizes of the stick insect. The step sizes for the left and right leg are equal in most cases. Therefore, the step sizes are only distinguished for the front, middle and rear leg. In this work we will focus on the relative differences between the step sizes. The step size of the middle leg will be used as reference value. All ratios have the form (front:middle:rear). In the work of Holk Cruse the step sizes of the stick insect *Carausius morosus* are equal on a narrow path $(1.0 : 1.0 : 1.0)$, but are unequal when walking on a flat terrain $(0.8 : 1.0 : 1.1)$ [2]. Straight walking stick insects also have different step sizes in the work of M. Gruhn [3]. Here, we found a ratio of $(1.4 : 1.0 : 1.1)$. Baessler does not give exact values for the AEP and PEP, but gives ranges for these two values. These ranges do not allow us to determine an exact ratio. However, the published ranges show non identical step sizes for the front, middle and rear legs [4]. Another example verifying our observations can be found in the work of B. Diederich [5]. In this work detailed experiments have shown that the sick insect adapts its step sizes when climbing uphill $(1.1 : 1.0 : 0.96)$ or downhill $(0.8 : 1.0 : 0.8)$.

Fig. 1 LAURON IVc: Fourth generation of the bio-inspired (stick insect) walking robot LAURON.

Similar to previous observations, the step sizes on a flat terrain are different for the front, middle and rear legs $(0.94 : 1.0 : 0.96)$. With non identical step sizes, the stick insect creates a systematic mechanical tension between its legs. A possible explanation for this behaviour is the improvement of its walking capabilities and the adaptation to certain situations.

In this work, we will investigate the effects of non identical step sizes on the walking process of a six-legged walking robot. We do not know of any six-legged robot trying to use non identical step sizes. But these bio-inspired heterogeneous step sizes might create a more biological locomotion with a reduced energy consumption and an increased stability based on systematic mechanical tension. We will discuss and demonstrate the effects of heterogeneous step sizes based on the results of real experiments with LAURON IVc (see Fig. 1).

2. APPROACH

Our approach is evaluated with the fourth generation of the six-legged robot LAURON. Its kinematic structure is a simplified version of the morphology of the stick insect *Carausius morosus*. Each leg has three degrees of freedom and is equipped with many sensor systems.

LAURON is controlled by a behaviour-based control system. Due to the modular structure of this control system the step size adaptation only needed to be implemented in a single behaviour. The steering behaviour creates the AEP and PEP for each leg. Then the corresponding trajectories are created by the independent swing and stance behaviours. In this work we use the step size of the two middle legs as reference value. The step sizes of the front and rear legs can be varied as a ratio of the middle legs' step size and independently from each other. The swing, stance period and the duty factor (ratio of these two values to each other) are dependant on the desired walking velocity and the current gait. All legs have the same swing and stance time. Therefore, an increased step size of one leg pair will result in a slower stance velocity and create a mechanical tension between this leg pair and the others. In contrast, a smaller step size creates a faster stance movement, which induces an opposite mechanical tension. The adaptation of the step size ratios between the front, rear and middle legs enables us to create many different mechanical tension configurations. Now, we are able to transfer the observations made with the stick insects to the walking robot LAURON IVc.

3. RESULTS AND EXPERIMENTS

After implementing the step size adaptation, we conducted several experiments with different step size ratios between the front, middle and rear legs. The first effects were not as visible as expected. But, walking with certain ratios made a more stable and smoother impression than with others. These subjective and personal impressions were analysed with the help of the joint torques, number of step cycles and energy consumption.

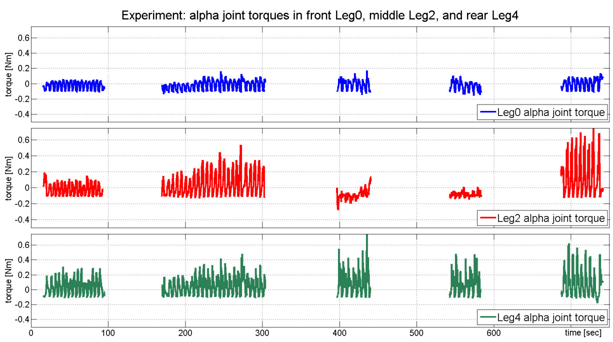

Fig. 2 Experiment: heterogeneous step sizes with effects on joint torques, chronology: R_1, R_7, R_8, R_8, R_9.

All experiments were conducted under the same conditions. LAURON walked a fixed distance with a fixed velocity in its tripod gait. Only the step size ratio and the step size of the middle legs was changed from one experiment to the other. In Fig. 2 we have illustrated the alpha joint torques of the front (top), middle (middle) and rear leg (bottom). The used step size ratios in these five experiments were as follows: R1, R7, R8, R8 and R9 (see Table 1). In the last experiment the step size of the middle legs was increased from 100mm to 200mm. The data shows that the torque distribution changes together with the ratio. With ratio R8 the joint torques in the middle leg are the smallest. The walking performance during this experiment was very good and even made a better impression than with identical step sizes (R1).

More experiments can be found in Table 1. The tested ratios were inspired by the natural ratios of the stick insect found in literature. The number of cycles shows how effective each ratio was (lower value = better). Although R8 and R9 almost have the same number of step cycles the consumed energy is significantly higher with R9. It is very difficult to evaluate all effects of the heterogeneous step sizes on the walking process. But our experiments show clearly that a systematic mechanical tension can have a positive effect on the walking process of a six-legged walking robot.

exp. no.	ratio	width	cycles	energy
R_1	1.0 : 1 : 1.0	100	15	6249
R_2	0.8 : 1 : 1.1	100	12.5	6390
R_3	1.4 : 1 : 1.1	100	7.5	3257
R_4	1.1 : 1 : 1.4	100	7.5	4131
R_5	1.0 : 1 : 1.0	140	6.5	3312
R_6	0.9 : 1 : 0.9	100	12	5508
R_7	0.5 : 1 : 0.5	100	23.5	12411
R_8	1.5 : 1 : 1.5	100	7	3151
R_9	0.5 : 1 : 0.5	200	8	4884

Table 1 Experiments showing the effects of different step size ratios: width := step size of middle legs [mm], cycles := step cycles, energy := needed energy [J].

4. CONCLUSION AND FUTURE WORK

We were able to show that the joint torques, walking velocity and walking efficiency can be influenced in a positive way by using non identical step sizes while walking with a six-legged robot. In this ongoing work we are currently verifying this positive effect and investigating the effects of a systematic mechanical tension for walking up slopes. In the future, we want to improve LAURON's walking capabilities by using specialised step size ratios for different scenarios.

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