Motion Hacking
–Toward Control of Insect Walking–

Dai Owaki\textsuperscript{a}, Volker Dürr\textsuperscript{b}, and Josef Schmitz\textsuperscript{b}
\textsuperscript{a}Dept. of Robotics, Graduate School of Engineering, Tohoku University, Japan
owaki@tohoku.ac.jp
\textsuperscript{b}Dept. Biological Cybernetics, Faculty of Biology, Bielefeld University
\{volker.duerr,josef.schmitz\}@uni-bielefeld.de

1 Introduction

Insects adapt their locomotor behavior in response to changes in environment and context by altering both inter- and intra-leg coordination. Past studies have investigated the adaptivity of coordination using neurophysiological, electrophysiological [1, 2], neurotheological [3, 4], or synthetic approaches that were based on computer simulations [5] or physical robots in the real world applications [6]. However, the detailed mechanism still remains unknown.

To elucidate the mechanisms, we apply an external and precise method of interference with neural motion control, based on the electrostimulation of leg muscles. Here, we propose the method, called “Motion Hacking (Fig. 1)” [7,8], based on engineering techniques.

First, we investigated externally controlled joint torques induced by stimulating one out of three leg muscles (protractor, retractor, and levator) in the stick insect \textit{Carausius morosus}. For a given parameter set of a burst of pulse-width modulated electrostimulation, we found a piecewise linear relationship between the burst duration and the generated joint torque. Linearity holds for a burst duration range between 100 and 500 ms, corresponding to the typical values of swing and stance durations of walking in stick insects. The result suggests that the extent and timing of movement generated by joint torques of a single leg can be controlled. This is a necessary prerequisite for hacking the motion of a leg via external muscle stimulation in free walking insects.

2 Materials and Methods

We tested 20 adult female \textit{C. morosus} from our laboratory colony at Bielefeld University. We selected three leg muscles (protractor, retractor, and levator) in the middle-right leg for electrostimulation. When stick insects walk, they use the protractor muscle to swing the leg forward during swing phase, the retractor muscle to move the leg backward during stance phase, and the levator to initiate a swing phase [1,4,5]. Thus, we selected these muscles to effectively control of walking of the stick insects.

For the electrostimulation of these muscles, we developed a “hand-made” electrostimulator. We designed an extension circuit board for Raspberry Pi 3 B+ (Raspberry Pi Foundation), including isolated 4 channel pulse width modulation (PWM) signal outputs. The stimulator can flexibly change the parameters of the stimulation PWM signals, e.g., frequency (1–120Hz), duty factor (0–100%), amplitude (output voltage, 0–18V), which enables the investigation of the effect of these parameters on motion generation due to muscle stimulation.

As a first step towards the control of stick insect walking, we investigated externally induced joint torques generated by stimulating one out of the three leg muscles in the stick insect. Figure 2 shows the experimental setup for the electrostimulation. We measured the corresponding joint torques when we stimulated one muscle in the middle-right
Figure 3: Linear relation between stimulation burst duration and generated joint torque in protractor muscle. The warm to cold color gradient of plotted points indicates the sequence numbers of stimulations, suggesting that we did not find muscle fatigue effects by electrostimulations.

3 Results

Here, we investigated the relationship between the burst duration $T_i$ [s] of the electrostimulation for muscles and the generated torques $\tau_i$ [$\mu$Nm] at the corresponding joints, where $i$ is the index number of stimulations. During one trial, we stimulated one muscle $n$ (> 50) times under the fixed parameters (frequency, duty ratio, and amplitude) and measured the torque generated at the corresponding joint.

Figure 3 shows the torque profile against the burst duration of the PWM signals for the protractor muscle of the middle-right leg in an animal. The parameters were set as 50 Hz, 2.0 V, and 30% duty factor. The results indicate a linear relationship between the burst duration $T_i$ and the generated joint torque $\tau_i$. We found that the linearity holds for a burst duration range of 100–500 ms, corresponding to the typical values of swing and stance durations of walking in stick insects, which property preserves over the parameters and 20 animals.

4 Discussion

The result suggests that we can control joint torques of a single leg so as to “what extent” and “when” we want it to move, which is a necessary prerequisite for hacking the motion of a leg via external muscle stimulation in free walking insects. Next, we will statistically analyze the obtained data by using Hierarchical Bayesian model [9]. This kind of model can predict the relative contribution of several parameters affecting the torque generation, while considering individual differences among animals. Model-based prediction of joint torque generation given a certain muscle stimulation would be an important step for controlling insect walking via the “Motion Hacking” methodology.

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References