Robust robot bouncing: Passive compliance and flexible phase locking

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Bouncing is one of the early locomotor milestones in the development of motor skills in human infants. As such, its study should yield insights on the mechanisms underlying the acquisition of motor skills. Goldfield et al. realized a longitudinal study of young infants learning to bounce in a Jolly Jumper. They observed developmental stages (assembly phase, turning phase, phase) that may be typical to infant's acquisition of motor. To gain a mechanistic view of those stages, we replicated the study using a small humanoid robot (Figure 1, left) suspended to a fixed frame by rubber springs. In human infants, the combination of the Jolly Jumper and the natural compliance of the infant's musculoskeletal system significantly reduce the dynamic loads of bouncing. In robots, however, mechanical compliance is often neglected because of its negative influence on positional accuracy, stability and control bandwidth. Yet, for a bouncing robot, it provides critical improvements such as, lower inertial forces, efficient energy storage and restitution, and shock tolerance. Compliant extensions for RC servomotors were constructed in the form of viscoelastic material placed in brass bushes and mounted in series with the actuators (Figure 1, top right). In addition, a compliant foot system was implemented using two springy toes and a rigid heel (Figure 1, bottom right).

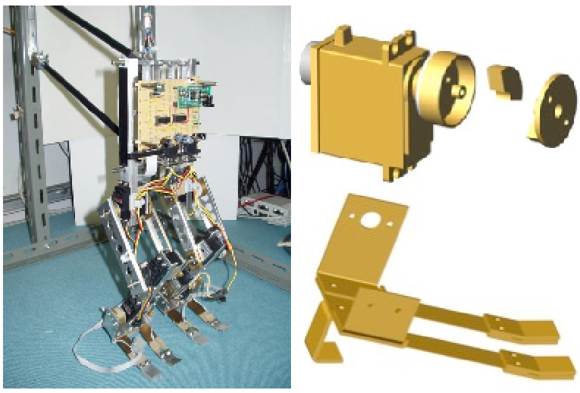

Figure 1: Robot (left) and detailed mechanism (right).

Systematic experiments with the real system, and Lagrangian analysis of the torques in the simulated setup, showed the compliant joints to provide enough damping to cut off oscillations after only one phase (Meyer et al., 2004). As expected, mechanical compliance induced joint backlash, which, from a control point of view, expressed in the form of delays in the feedback loop. In most robotic locomotion studies in which oscillators are used as central pattern generators, harmonic oscillators are used such as, e.g., Matsuoka oscillators. Unfortunately, those oscillators tend not to be very robust to delays in the feedback loop, which prove critical to sustain a stable bouncing pattern. Since more physiologically plausible neuronal formalisms showed more flexibility in phase locking, we implemented a control architecture based on the Bonhoeffer-Van der Pol (BVP) formalism (Fitzhugh 1961). We confirmed that the architecture could successfully entrain to sensory feedback from touch sensors placed under the robot feet. In addition, we systematically investigated the capability of the control architecture to adapt to sudden changes in environmental conditions. Shown in Figure 2, our experimental results confirm the greater flexibility of the BVP formalism.

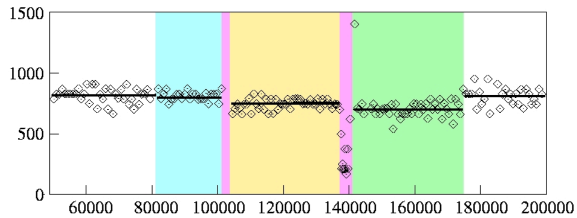

Figure 2: Time series of inter-bounce intervals when obstacles are placed under the robot (4.5, 10.2 and 14.7cm). All axes are given in milliseconds.

References:

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