Use Your Spine! Effect of Active Spine Movements on Horizontal Impulse and Cost of Transport in a Bounding, Quadruped Robot

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Introduction Within the field of quadruped robot research, much focus has been put on design of leg compliance and leg configuration [1, 2, 3, 4], and controller design [5]. Typically, design goals include robot speed, cost of transport, robustness against perturbations, and range of available speeds. Recently, research has started mimicking the spine of quadruped animals, both in the frontal and the sagittal plane. A widely accepted hypothesis predicts higher speed, resulting from active spine motion.
Here we present results from hardware experiments with an active-spine equipped quadruped bounding robot, showing that through reduction of horizontal impulse the robot's mechanical cost of transport was reduced.

Robot Hardware Bobcat-robot (Fig.1) was designed as an RC-servo controlled quadruped robot with nine motors: two per two-segment leg, proximal hip/shoulder joint and leg length controlling actuator. One RC-servo was mounted at the robot's spine, allowing active rotation in the sagittal plane. The robot weights around 1 kg, including mechanics, actuation, and computation on-board. Power was provided by a tether. The two-segment legs (touch down length 0.125 m) of the robot include an extension spring, producing leg-internal extension forces against external leg-compression forces. Active leg flexion was implemented using a cable mechanism.

Experiments Experiments were conducted applying a) a *fixed spine strategy*, i.e. a bounding gait with the spine RC servo motor blocked, and b) an *active spine strategy*, where the spine control signal was phase-coupled with the robot's hip joints. For both spine strategies, leg length and leg angle control were based on an open-loop, CPG-based controller with active leg compression [6]. For the maximum speed of both strategies, the robot was guided over a force plate, while equipped with motion capture markers. Synchronized ground reaction forces were recorded along with kinematic motion data, high-speed video footage[1], and the robot's electrical net power consumption. Average speed, collision angle (CA, [7]), collision fraction (CF [7]), mechanical cost of transport (COT_{mech}, [7]), electrical cost of transport (COT_{elec}, [8]), and Froude number (FR) were calculated from the data.

Results The most prominent difference (Tab. 1) between active and passive spine bounding strategies was found in the horizontal average impulse per stride (sum of absolute intermediate impulse values, J_h). Although the active spine gait was faster, it showed an almost three times lower J_h. We conclude that a well-timed spine movement allowed to redirect the impulse into forward motion instead of a breaking force, leading also to a ≈ 30 % lower average mechanical cost of transport. Due to the very high-geared RC servo motors, and the relatively high locomotion frequencies, COT_{elec} remained very high.

[1] http://tinyurl.com/c8wfuga

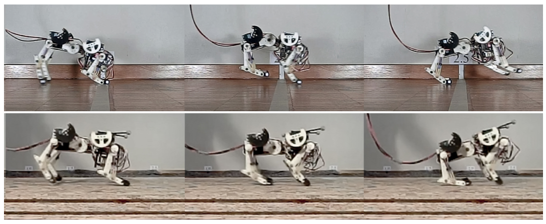

Figure 1: Active (top) and fixed (bottom) spine locomotion.

Table 1: Active spine and fixed spine experiments. Shown are horizontal impulse J_h, collision angle CA, collision fraction CF, mechanical and electrical cost of transport, speed v, locomotion frequency f, Froude number FR.

	J_h [Ns]	CA	CF	COT_{mech}
Active	0.26	0.38	0.54	0.52
Fixed	0.71	0.46	0.71	0.79
	COT_{elec}	v [m/s]	f [Hz]	FR [J/Nm]
Active	8	0.72	3.5	0.50
Fixed	6.5	0.62	4	0.31

Future Work We will focus on the effects of closed-loop control, towards more complex spine control signals.

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