Supplement for: From Adaptive Locomotion to Predictive Action Selection – Cognitive Control for a Six-Legged Walker

Authors

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Results B: Disturbing the physical robot by inducing long steps

As illustrated in Fig. 3, searching movements in the real robot Hector induced long steps far towards the front. This forced movement disturbed coordination and lead to unstable walking situations. Table S1 and Fig. S3 provide results on how the system coped with such cases. We systematically varied prolongation of middle leg and hind leg swing step size by 0.05 – 0.10 m (normal step amplitude is 0.16 m, which is quite large for legged robots of this size) and observed how the system adapts. For each condition, we produced two robot runs (Table S1, see also video S3 showing two example runs).

Table S1: Robot Hector's reaction to disturbances.

Leg being disturbed	Disturbance amplitude [m]	Adaption of the system
ML	0.05	In both runs, stable gait pattern emerged immediately
	0.06	In both runs, stable gait pattern emerged immediately
	0.07	Run 1: After the disturbance, the first swing movement of HL produced an instability. This was resolved by a step backwards of ML. Run 2 led immediately to stable gait.
	0.08	Run 2: After the disturbance, the first swing movement of HL produced an instability. This was resolved by a step backwards of ML. Run 1 immediately led to stable gait.
	0.09	Both cases: After the disturbance, first swing movement of HL produced an instability. This was resolved using a step backwards of ML.
	0.10	In both cases, after the disturbance, the first swing movement of HL produced an instability. This was resolved using a step backwards of either HR (run 1, Fig. S3a) or ML (run 2, Fig. S3b).
MR	0.10	Both runs: stable gait pattern emerged immediately
HL	0.10	Run 1: After the disturbance, the next swing movement of HL produced an instability. This was resolved by a step backwards of ML. Run 2 led immediately to stable gait.
HR	0.10	After the disturbance, in both cases the first swing movement of HL produced an instability and the system applied a step backwards of ML. However, this lead to a further disturbance followed by further internal simulations. In run 1, the robot struggled with this task and, after every second step, started a new internal simulation (observed for three more planning phases, see Fig. S3c). In run 2, the system chose by coincidence the ML step backwards again and this resulted in stable walking pattern afterwards (Fig. S3d).

The results show that for small disturbances the system was not affected and stable walking patterns emerged. For larger disturbances the robot eventually became unstable and the cognitive expansion had to take over (for examples see Fig. S3). As the problem detector induces a search close to where the problem occurred, usually a preferred solution was found and only rarely another solution was selected. The case of disturbing the hind right leg (HR, Table S1) underlines the difficulty of this problem: while a disturbance is resolved through applying an action out of context, this necessarily interrupts the coordination pattern that has emerged up to that point in time. In most other cases, this was not problematic as the system converged very fast again towards a walking pattern that allowed for stable walking. This is due to the adaptivity of the underlying decentralized control architecture.

Figs. S3a) and b) show two different solutions for a long step (disturbance 0.10 m) of the middle left leg. The robot became unstable when trying to lift the hind left leg (HL, briefly before the grey shaded area). Therefore, walking was interrupted and a searching procedure was started (grey area). In a) it tried three unsuccessful actions (red area) before resorting to move the hind right leg backwards (green area) which unloaded the hind left leg and normal walking could continue (blue area). Here, a difference between internal simulation (green area) and testing behavior (blue area) is visible: the swing movement is much shorter on the physical robot, but the emerging pattern afterwards appears the same. In b) the robot runs into the same problem, but instead, in the second trial, moved the middle left leg (ML) backwards. This solved the problem. Therefore this solution could be applied by the real robot (blue area). Figs. S3 c) and d) show a long step induced in the hind right leg (HR). The robot became unstable at the next lift-off of the hind left leg (beginning of first grey area, note the different time scales in c) and d)). The solution found when the first problem (in both figures from 5 to 12 seconds) was detected (step backwards of the middle left leg, in the second trial in c, in the third trial in d)) led a couple of seconds later to another unstable posture. While in c) the robot always selected actions that solved only the immediate problem at hand and did not find a long term solution (at least in the time window observed), in d) the system repeated the middle left leg step backwards, but, in the second internal simulation, selected an early step to the front of the middle left leg (purple bar, initiated by the cognitive expansion). This reestablished a stable gait pattern.

To summarize, walks with the physical robot showed considerable variations, even for the same starting positions. Nonetheless, in nine cases the reactive system overcame the disturbance. For the remaining nine cases the cognitive expansion was able to solve the problem.

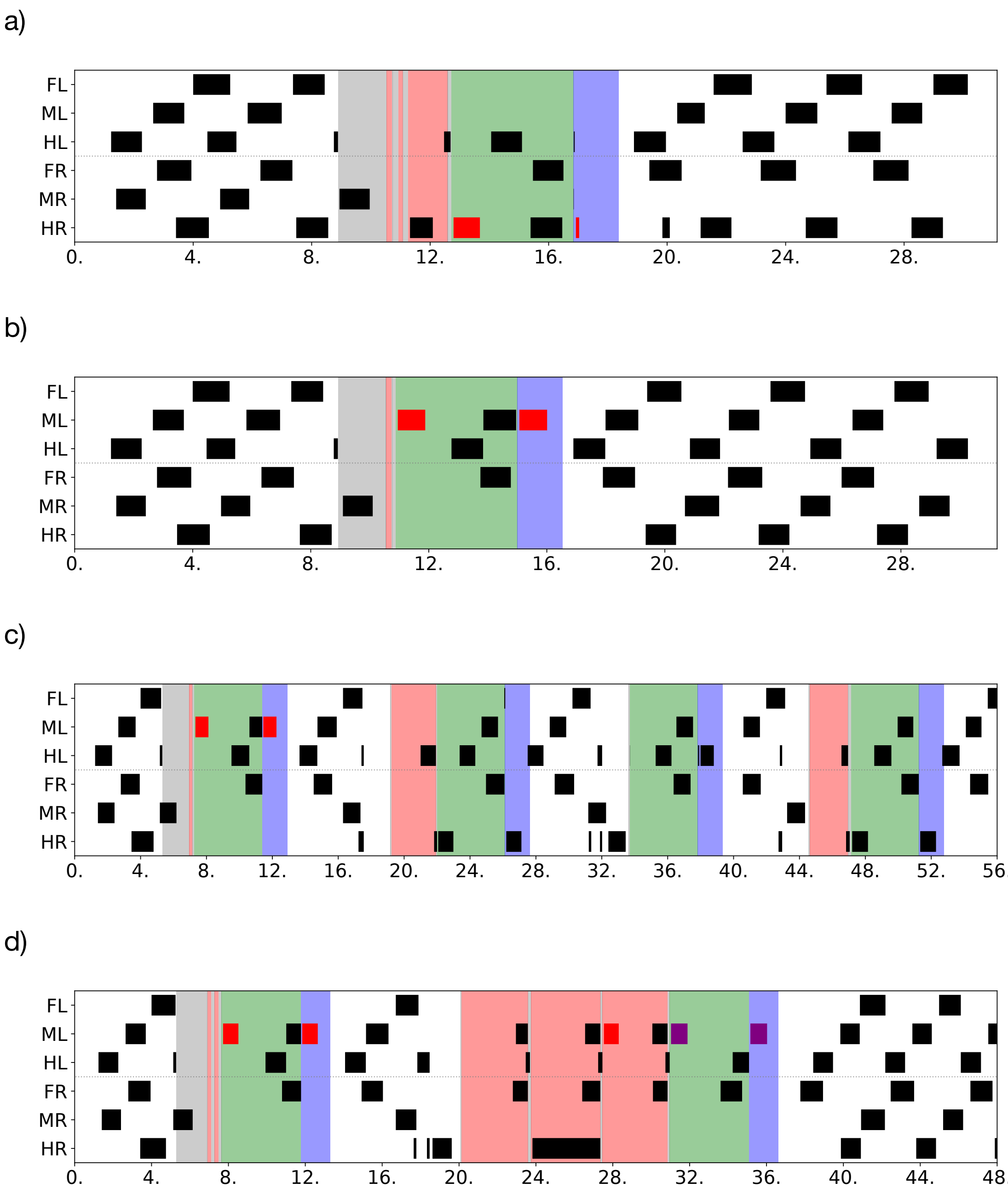

Fig. S3: Footfall pattern for robot Hector walking with a forced long step (velocity 0.016). Black bars indicate swing movements of the different legs over time; dark red bars indicate swing movements backwards during internal simulation (green and red shaded area) or testing of behavior on real robot (blue shaded area). Purple bars indicate selection of forward swing movements. In color shaded areas, the cognitive expansion took over: grey represents initially stopping and selecting an action, red shows unsuccessful testing of that action in internal simulation and green shows a successful internal simulation which finally was applied on the real robot shown in the blue area. Note that during internal simulation, i.e. areas colored grey, red, or green, the real robot is not moved at all. At the end of each internal simulation (either red or green area) the internal model is reset to the real posture of the robot. This means that for each subsequent red, green and blue area (when switching back to the real robot), the initial posture is the same.