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Adaptation of walking pattern generated by reinitializing strategy

By

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In this short paper, we theoretically view our walking model [1].

Our model has shown that the initial state coordination directed by *a global variable* (the walking velocity $\dot{x}_1$) establishes flexibility to various changes in condition. The reasons that the flexibility emerges can be summarized as follows: (1) Most perturbations are reflected in the global variable. (2) The initial state, *i.e.*, the system state near the neutral state, is a constraint which determines the behavior of the system after a bifurcation point. (3) Because the initial state is coordinated by the global variable at every step, the subsequent behavior of a system fit for a given perturbation is generated in real time. That is, the connection between the global variable and the initial state is such that any perturbed motion of the system is consistently re-coordinated at the bifurcation point of the system. This mechanism yields flexible control when implemented under various condition changes.

From a theoretical viewpoint, the connection between the initial state and the global variable brings about an interesting phenomenon in which the constraint is metabolized. The constraint generates the subsequent walking motion, which involves generating the motion of the global variable $\dot{x}_1$. One constraint therefore generates the next. According to the general theory of physics, since the constraint determines the trajectory of the system, the dynamics of the system appears to be virtually independent to the other variables representing components of the system. This finding implies that walking likewise determines subsequent walking motion since $\dot{x}_1$ is equivalent to walking in this case. We consider such a constraint metabolism induced by the system itself to be one of the mechanisms important for autonomy.

Our model, with this characteristic, can be expressed mathematically as follows. We define the time at the i-th BSP as T_i and $\dot{x}_i(T_i)$ as Z_i, and put $\mathbf{w}_i = (x_1, \ldots, x_6, \dot{x}_2, \ldots, \dot{x}_6, \mathbf{u})|_{t=T_i}$. Since the equations of our model are deterministic, Z_{i+1} is determined by Z_i and $\mathbf{w}_i$. That is, Z_{i+1} can be expressed by the following formula:

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$$Z_{i+1} = V(Z_i, \mathbf{w}_i).$$

In order to reproduce subsequent walking, we need to find a finite interval $S = [Z_{\min}, Z_{\max}]$ which is an attractive basin such that $Z_i \in S$ is satisfied for $i \geq 1$. In this paper, we assume the following: the variable, which is effective for determining $\dot{x}_1$ at next BSP near the neutral state ($Z_i \approx Z_{\min}, Z_{\max}$), is the global variable $\dot{x}_1$ itself, and a small variance in $\mathbf{w}_i$ hardly affects the outcome of the walking motion. According to these assumptions we varied the angle of the knee and hip joint as a function of $\dot{x}_1$, and found that there exists an attractor basin S_a such that $S_s \subset S_a$ where S_s is the attractor basis for the simple walking model without the posture controller.

Moreover, under the assumptions, we can say that the variable $\dot{x}_1$ is representative of the variables in the system (or $\dot{x}_1$ is at a different hierarchical level from the other variables) since only $\dot{x}_1$ or Z_i determines whether walking can continue or not. In that sense, our model is a prototype for models that can adapt to various perturbations. In order to clarify that the assumption used here is valid, further numerical analysis focused on the neutral state is required. This will be reported in the a forthcoming paper.

References

[1] Ohgane, K. and Ueda, K, Instability-induced hierarchy in bipedal locomotion *Phys. Rev. E*, **77** (2008), 051915.