Title	状態にジャンプを有する線形化運動方程式に基づくリミットサイクル型動歩行の解析と制御
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Abstract

Limit cycle walking which is proposed to measure and ensure stability by releasing the constraints of walkers, has a high energy efficiency because of zero or low feedback gains required for sustained local stability, and thus has more freedoms to increase versatility in optimizing walking state generation. To increase the ability of handle disturbance, however, limit cycle walking needs to bring high feed gains, which affects the energy efficiency. Considering all closed-loop control systems, the energy consumption by the feed-forward control system which can often significantly justify the extra cost, time and effort required to implement the technology is substantially lower than others. Therefore, if the mathematical model of limit cycle walking which is the requirement of the feed-forward control can be built, the feed-forward control can be proposed as the solution. In addition, the mathematical analysis of limit cycle walking can help to discover and generate the optimal walking states.

First, a general method is proposed to build the mathematical model of limit cycle walker driven by all the settling-time control systems. Through the analysis of discrete control systems, the general formula is proposed for all discrete control systems. Thus when the control input of the continuous control systems is discretized, the mathematical model of the continuous control systems can be built by the general formula of the discrete control systems. Based on the mathematical model, gait properties are analysed, critical and optimal walking states are discovered mathematically and target walking states are generated. All the results are verified by numerical simulations.

Second, feed-forward control is proposed based on the mathematical model of the combined rimless wheel (CRW). Thus, gait properties of state error are analysed and limit cycle walking at target constant walking speed is generated successfully. In addition, the ability of handle disturbance of the feed-forward control is tested by numerical simulations.

Finally, the limit-cycle-walking-based feed-forward control system is extended to the underactuated rimless wheel with torso (URW), a two-DoF limit cycle walker. The optimal walking state, deadbeat mode, is analysed mathematically and generated by numerical simulations. In addition, a constant speed walking is generated on the uneven ground by the feed-forward control system.

keywords: Feed-forward control, Limit cycle walking, Optimal state analysis, Target walking states generation, Mathematical model.