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TurboQuad: A Leg-Wheel Transformable Robot Using Bio-Inspired Control

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The ability of the robot to negotiate the terrain strongly depends on its morphology and control strategy. Wheeled morphology is extremely good on the flat terrain, and the legged morphology has great mobility on the rough terrain, as proved by the legged animals. Thus, as the terrain nowadays is highly mixed with natural rough terrain, artificial rough terrain (ex: stair, bumps, etc), and artificial flat terrain (ex: road), designing a good robotic platform which can operated on all three categories may be a good solution. In the last few decades researchers have come up with two different approaches to elevate robots' adaption to the environment: one is to design special mechanisms to overcome uneven terrain, and the other is to focus on behavioral development of a given robot to adapt different situations. Both approaches exist, but only a few works tried to solve the problem from both aspects simultaneously.

Previously, we had developed a leg-wheel transformable robot *Quattroped*, equipped with a special transformation mechanism which can transform wheeled morphology to legged morphology and vice versa [1]. We have demonstrated the functionality of both wheeled mode on flat terrain and legged mode on rough terrain, which adequately utilizes the right morphology to the given environment setting. However, executing the leg-wheel transformation requires the robot in its rest mode, so the original motion status has to be interrupted. This disadvantage may not be significant if the classification of the terrain is obvious (i.e., fewer operation numbers of leg-wheel transformation), but this may be a problem when the terrain is highly-mixed. Here, we report on a new version of the leg-wheel transformable robot *TurboQuad* as shown in Fig. 1, which is capable of in-situ leg-wheel transformation without interruption the original motion status. This feature is achieved by two novel setups on the robot: one is new leg-wheel mechanism and the other is new control architecture, which will be briefly described in the following paragraphs.

Like *Quattroped*, each leg-wheel of *TurboQuad* has two degree-of-freedom, providing radial and rotational motions. Unlike the *Quattroped* where several extra motors are utilized for leg-wheel transformation, *TurboQuad* uses the same set of driving motors for leg-wheel transformation, by shifting the centers of the half-circle rims out of the same point. The new method significantly reduce the complexity of mechanism and associated mechatronic setup. More importantly, the driving motion and leg-wheel transforming motion can take place simultaneously.

Fig. 1. Photos of the robot *TurboQuad*

Besides the new mechanism, the control strategy is also crucial for successful leg-wheel transformation on the robot, where a bio-inspired control structure based on the Central Pattern Generator (CPG) is adopted. Each unit CPG is construct based on a Hopf oscillator, and all of them are worked as a modified coupled oscillator network. The structure is composed by three layers. The bottom layer is behavior layer, in this layer the motors (muscles) take their actions by receiving trajectories signal (neuron signal) from the above layer. The middle layer is pattern generation layer (neuron system), and rhythmic trajectory signal is generated through coupled oscillator networks. The top layer is the commanding layer (brain), it provide high-level concepts like speed, steering, and gaits into parameter space for the middle layer. This control structure can instantly generate smooth and continuous trajectory, allowing the robot to have smooth transition between different gaits and modes. This bio-inspired control structure is therefore a frame for all kinds of behavior transformation. When the remote operate gives the command like speed adjustment or steering to the robot, it is transformed into the parameters such as duty factor, swing frequency, relative phase, leg-wheel weight, and steering angle for the middle layer. Then through unit CPGs in the middle layer with assist of Hopf bifurcation, smooth leg-wheel trajectory can then be generated. The coupled oscillator network allows four CPGs to generate different gaits by relative-phase control. Finally, the leg-wheel trajectories are sent to the motors for joint trajectory generation.

As an initial demonstration, three modes are developed on the robot, including wheeled mode, legged trot mode, and legged walk mode. Two different legged modes are designed based on the observation of animals, which uses different gaits to achieve high efficiency, smooth motion on different environment settings. The video contains three main sections. The first section reports control system and mechanisms, and the second and third sections shows how *TurboQuad* uses different gaits to negotiate artificial and natural environment settings, respectively.

REFERENCES

[1] S. C. Chen, K. J. Huang, W. H. Chen, S. Y. Shen, C. H. Li, and P. C. Lin, *"Quattroped: A Leg-Wheel Transformable Robot,"* IEEE/ASME Transactions on Mechatronics (T-MECH), May 2013, DOI 10.1109/TMECH.2013.2253615

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