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論　文　内　容　要　旨

報告番号	甲　先　第　**158**　号	氏　名	張　勇
学位論文題目	Study of Adaptive Walking Control for Quadruped Robot Using CPG Network with Motor Dynamics モータの動特性を有するCPGネットワークを用いた4脚ロボットの適応的歩行制御に関する研究		

内容要旨

The proceeding of legged robots has been expanding the application fields from industrial fields to the medical and rescue fields, in comparison with the other proposed robot; the important factor of legged robot is the way of movement on irregular grounds. However, designing an effective walking control system for a legged robot on unknown terrain is complex. It required not only efficient mechanical dynamics arithmetic for simulation, but also an adaptive walking control system.

There are many important contributions about mathematical analysis of the robot dynamics have been developed steadily to simulate the motion of legged robot simulation system. Lagrangian formulation is traditional method to calculate the velocities and acceleration of robotics systems. However, there are superabundance algebraic constraints in the inertia matrix. The dynamics matrix will become difficult to solute the inverse dynamics in real time during the robot moving when external force is influence such as ground friction.

Featherstone's Articulated-Body Algorithm can calculate the mechanical dynamics model of quadruped moving efficiently. The principle of this algorithm can be described by tree-structure mechanisms. Each part of quadruped robot can be constructed of multiple-degree-of-freedom joints in a hierarchy structure. The articulated bodies of the robot are consisted of a rigid body tree system, in which each handle stand for an individual rigid body of the quadruped robot and each branch is connected together with the robot's body. Through recursive analysis of frictionless rigid-body contact between the joints of robot's leg, the dynamics equations system can simulate the motion of quadruped robot in the complex surface.

We also proposed an adaptive gait control system for a quadruped robot traversing over irregular terrain with intermittent crawl pattern used central pattern generator (CPG) networks with motor dynamics. A new CPG model for adaptive walking control from our previous research has been developed. The CPG model includes two DC motors, instead excitatory unit and inhibitory unit, for controlling the robot's joint directly.

In this neural system, the joint DC motor functions, not only as an actuator but also as a component of the CPG model with sensory feedback. Four CPG models

make up of a CPG network to generate an adaptive walking gait as the robot walks.

In order to testify the effectiveness of proposed CPG unit, we have to adjust the parameters of the CPG difference equations for the period signals. Through the limit cycle analyze, the different equation of CPG unit have an ability to generate the stable proudly signals. By arbitrarily changing the parameters, CPG unit has an ability to vary the frequency and the amplitude of internal states.

In the CPG network, CPGs have internal feedback and external input signals which can automatically change the arbitrary values depending on the road surface change. By using gyroscope, the robot has a capability to get the roll angle of robot's body. Through changing the plural parameters of the CPG network, the CPG unit signal can be on-off states for achieving the intermittent crawl pattern walking. For recognizing the angle of the slope, we propose a stable range of the body's roll angle. If the robot is walking on an irregular road and the body's angle is out of this range, the gyroscope sensor will be feedback the body angle to the CPG network. For changing the parameters of the CPG network and using the plural feedback information of the CPG networks, the quadruped robot can move on irregular terrains.

In this paper, the adaptive walking control system using the new CPG model including DC motor dynamics for quadruped robot has been proposed. During the robot walking, CPG units can automatically change the arbitrary rhythmic values depending on the different road condition. The new CPG model has a capability to generate the regular signals for the quadruped robot. Moreover, by changing the parameters of CPG network and using the plural feedback information, the quadruped robot can walk continuously on the irregular terrain. By using the complex feedback value, the robot can avoid stumble on an obstacle.

The superfluous calculation of dynamic is needless when the robot walks on the irregular terrain. In order to confirm that the proposed CPG network can generate a series of adaptive gait in different kinds walking environment, we carried out experiments involving the walking on an up-down slope.

The results of the experiment demonstrated that the proposed CPG network can autonomously generates the suitable periodic motion patterns of each joint in different surface condition.

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論文審査の結果の要旨

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学位論文題目

Study of Adaptive Walking Control for Quadruped Robot Using CPG Network with Motor Dynamics

モータの動特性を有するCPGネットワークを用いた4脚ロボットの適応的歩行制御に関する研究

審査結果の要旨

本研究は，未知不整地における４脚ロボットの適応的歩容生成を生物規範型アプローチに基づいて行っている．生物規範型アプローチは，生物の周期的な運動を司る神経振動子を模擬した工学モデル Central Pattern Generator（CPG）のリズム生成機能を用いたもので，複数の CPG を相互結合した CPG ネットワークの同期引き込み現象を利用して歩容を生成する．歩行環境が既知あるいは整地であれば，CPG ネットワークを４脚ロボットの関節位置指令生成器として用い，指令通りに各関節位置を制御すれば安定歩行は比較的容易に実現できる．しかし，未知不整地あるいは環境変化に加え，ロボットの内部状態等が変化した場合は，安定歩行の実現は困難となる．

そこで本研究では，脚の各関節アクチュエータの動特性を含む新たな CPG モデルを提案し，アクチュエータの動特性変化や外乱に応じて自律的に発振パターンを調整可能であることを確かめている．また，提案する CPG モデルを複数個相互結合した CPG ネットワークにより歩容生成が可能であることも確認している．さらに，環境変化に応じて非周期的な歩容も生成できるように，ロボットの胴体傾斜角を CPG ネットワークにフィードバックする新たな手法も提案している．

提案手法の有効性は，４脚ロボットの動力学モデルを用いたコンピュータシミュレーション解析により，様々な未知不整地環境を想定して詳細に検討している．また，４脚ロボットを設計・試作して実ロボットシステムを構築し，実験でも提案手法の有効性を明らかにしている．特に，比較的大型の実ロボットによる歩行実験に成功している点は高く評価できる．

今後は，様々な歩容の生成と歩行速度の高速化，さらには，より複雑な未知不整地での歩行の実現が課題として挙げられ，本研究の今後の発展は十分期待できる．

以上の結果により，本論文は博士（工学）の学位授与に値するものと判定する．