低重心型平行二輪ビークルにおける質量移動機構を用いた車体傾斜制御設計に関する研究

和文要旨

近年，二本の駆動輪を車体中央に平行に配置した平行二輪型移動ロボットが，パーソナルビークルや搬送ロボットなど，さまざまな応用を持つ移動ロボットとして盛んに研究・開発されている．さらに，実用化に向けた実証実験も進められており，平行二輪型移動ロボットは今後のさらなる発展と活躍が期待されている．しかし，従来の研究で進められている平行二輪型移動ロボットの多くは重心が車軸より上部に位置する不安定な倒立振子構造であるため，駆動系や制御系が停止した場合に倒立状態を維持できない点が安全面の問題として挙げられる．

そこで，本研究において，電源系や駆動系，制御系を車軸よりも下に配置して，搭乗者を含めた車体の重心位置を車軸よりも低位置にすることで，構造的な安定性を得る低重心型平行二輪ビークルを提案する．低重心型平行二輪ビークルは安定な振子構造により無電源時においても安定して自立できる．しかしながら，このビークルは，搭乗者の姿勢によって静的に車体が傾くことがある．そこで，本論文では，着座した搭乗者をシート位置とともに移動させ，車体の傾斜を水平に補正するように車両全体の質量の配置の偏りを調整するシートポジショニングシステムを導入する．さらに，車両が走行する場合において，搭乗者の挙動やビークルの加減速によって生じる車体揺動を，車体内部にあるウェイトを移動させることで抑制するアクティブマスシステムを導入する．また，ビークル操作はジョイスティックなどの操作端末によって行われる．したがって，健常者のみならず高齢者や障がい者にも平行二輪ビークルが持つ高い機動力を生かしつつ，安全な移動を提供することを考慮した．

さて，パーソナルビークルとしての利用を考えた場合，多様な搭乗者の利用が考えられ，搭乗者毎に車体の重心位置や総質量が異なり挙動も変化する．また，車両のフレーム構造および外装などにより寸法や質量などの仕様が異なる場合においても挙動が変化する．さらに，搭乗者の質量が大きい場合などにおいて車体全体の重心位置が車軸よりも上部に移動し不安定な倒立振子構造となり，無電源時に自立することが不可能となる．そのため，ビークル全体が安定な振子構造を常に有するための搭乗者の質量等の条件を明確にし，搭乗者の体格の変化に対応可能な制御システムを構築する必要がある．まず，車体揺動抑制制御の構築のために，車両の仕様や搭乗者の体格が異なる場合の挙動を再現可能なシミュレーションモデルを構築する．次に，車両の仕様や体格の異なる搭乗者に対して，できるだけ少ない数のパラメータ数を同定することを考え，簡便にモデルパラメータを同定する実験手順を提案する．また，構築したシミュレーションモデルおよび同定パラメータを用いて，車体姿勢が安定な振子構造を常に保持するための搭乗者条件を示す．そして，モデル解析および制御パラメータの理論解析結果を用いて車体揺動抑制制御系をバックステッピング非線形制御を用いて構築し，低重心型平行二輪ビークルを用いたシミュレーションおよび実験により制御系設計手法の有効性を示す．最後に，車輪の駆動力のみを用いた車体揺動抑制制御と制御性能を比較し，本論文にて構築したアクティブマスシステムによる車体揺動抑制制御が有用であることを示す．

Study on design of vehicle body attitude control using mass transfer mechanism in parallel two-wheel vehicle with underslung vehicle body

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ABSTRACT

In recent years, two-wheeled inverted pendulum vehicles realizing high mobility have been developed. In such vehicles, an inverted pendulum control system maintains the vehicle's stability by only using the two driving parallel wheels. Therefore, the gravity center of the vehicle body with a passenger is higher than the wheel axis, and the vehicle is moved by leaning the vehicle body forward or backward by moving the gravity center. However, in the case that the vehicle is in the power-off or control-off status caused by a breakdown in the vehicle, the stability of the vehicle cannot be maintained. The inherent mechanical instability of the inverted pendulum vehicle is inimical to safety. Consequently, the vehicle should be modified to provide stable support when the power supply stops or when the passenger gets on and off the vehicle. Moreover, we are now considering such the vehicle that the passengers focused on not only young people but else elderly and handicapped people can drive with sitting attitude. Then, in this case, since the gravity center is lower than the standing posture, the larger action of the passenger's upper body is required for operating the vehicle. However, the elderly or handicapped passenger is difficult to behave the large action in the vehicle.

This paper presents an advanced parallel two-wheel vehicle that has an underslung vehicle body. In the proposed parallel two-wheel vehicle, since large wheels which its diameter is 1.05[m] are applied, and the battery, the actuators and the controller are placed at the lower position in the vehicle body, the gravity center of vehicle body with a passenger can be assigned at the lower position than the wheel axis. Therefore, the vehicle has a pendular structure that enables the vehicle body with the passenger to always maintain the stable posture, even if the vehicle is in the power-off or control-off condition. A 2-DOF joystick that has operation in pitching and yawing is applied to the proposed vehicle. The elderly or handicapped passenger can operate easily and intuitively the vehicle by this joystick. Then, when the passenger sits on the seat of the vehicle, the vehicle body is leaned by moving the gravity center of the vehicle body with the passenger. For compensating the vehicle body leaning, the seat positioning control system is proposed in this paper. The vehicle body's static posture lean control can be compensated by the proposed control system. Furthermore, the proposed control system is able to change the angle of the vehicle body in a state of stopping the vehicle. In the control system, the control input to the servomotor system is generated by PID control, consisting of

Proportional control to compensate the error between the reference angle and the pitch angle of the vehicle body, Integral control to the integrated error, and Differential control to the angular velocity of the vehicle body. By moving the seat with the passenger, the posture of the vehicle body is compensated. And, while the vehicle is driven, the vehicle body is swayed due to the pitching oscillation by the acceleration of the vehicle driving. In order to suppress the vehicle body's swaying, the pitch sway suppression control system with an active mass is proposed in this paper. The proposed control system that does not use the driving force of the wheel is possible to stabilize the sway of the vehicle body even if the wheel is fixed by the braking device. Therefore, proposed attitude control system is advantageous for the safety of the parallel two-wheel vehicle. For designing the control system, the dynamics of the pitch angle in relation to the vehicle's body swaying is modelled by using the Lagrange equation of motion. Then, the control system is designed by the backstepping method.

The vehicle will be used by diverse passengers in the future. In this study, the mathematical model of the swaying of vehicle body with passenger and its model parameters identification are proposed. In the model parameters identification, it is clarified that the model parameters of each passenger are similar except for the passenger's mass. Furthermore, the control parameters are independent to interference from the model parameters. Therefore, in design of the sway suppression control to the diverse passengers, the only passenger's mass is given to the control system. Finally, effectiveness of the proposed control system is verified by experiments using the parallel two-wheel vehicle.

Keywords: Parallel two-wheel vehicle, Lower gravity center, Sway suppression control of vehicle body, Active mass system, Backstepping method, Model parameters identification