

論文 / 著書情報
Article / Book Information

題目(和文)	最適化に基づくロバスト制御器の構築とヒト型ロボットの歩行制御への応用
Title(English)	Optimization Based Robust Controller Design and Application to Bipedal Robot Control
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Category(English)	Doctoral Thesis
種別(和文)	論文要旨
Type(English)	Summary

論文要旨

THESIS SUMMARY

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Department of Graduate major in システム制御 コース
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申請学位 (専攻分野)： 博士 (工学)
Academic Degree Requested Doctor of
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要旨 (英文 800 語程度)

Thesis Summary (approx.800 English Words)

As control theory and machine learning theory are developed, robots play an important role in a society nowadays. The number of robots introduced to industrial field increases year by year, and robots start doing tasks that are burdensome for human. Furthermore, robots which can work in cooperate with human are also being developed and paid attention now. It is expected that robots will work in many fields and they work together with human in future.

There are too many constraints which must be satisfied for safety when robots work in real environments, for example, constraints to avoid collision with human and obstacles, constraints not to violate hardware and actuator restriction, etc. Hence it is necessary to construct control systems which can handle such kinds of constraints in practical uses. Several methods to realize such control have been proposed so far, and a new method called Control Lyapunov Function and Control Barrier Function based Quadratic Programming (CLF-CBF-QP) controller has recently been proposed. It calculates control input by solving a convex quadratic optimization problem under two kinds of constraints, a control Lyapunov function (CLF) constraint for output zeroing control and a control barrier function (CBF) constraint for satisfying given state constraints. Even if a system is nonlinear, the optimization problem to be solved becomes a simple convex quadratic programming problem. Therefore, this controller can calculate control input considering given constraints in real time. It appears to have a great potential for applications in robotics, e.g., UAV, bipedal robots, multi-robot systems.

Although the CLF-CBF-QP controller has a good property of the fast calculation, its control performance cannot be guaranteed in the presence of disturbances and model uncertainties. Some researchers have proposed a robust CLF constraint and a robust CBF constraint considering disturbance effects. However, there are still many issues left unsolved for practical uses because they assume some ideal conditions that all system's states can be observed without any noises and systems are affected by only matching disturbances. Moreover, it is also important to consider how we should design output functions to control systems affected by disturbances. If an entire system cannot be linearized and it has zero dynamics under given output functions, it is not enough to achieve the robust output zeroing control in order to stabilize the entire system. We also need to design output functions so that the zero dynamics have desired characteristics under effects of disturbances. This issue must be considered when we control underactuated robot systems.

From this background, we propose new robust optimization-based controllers which can compensate effects of disturbances and model uncertainties, and we also apply them to construct a walking control framework of underactuated bipedal robots affected by disturbances as a practical application.

In the first half of this paper, we first propose new robust CLF and CBF constraints based on disturbance estimation methods which estimate disturbances as stochastic variables, especially Gaussian process regression (GPR) and unscented Kalman filter (UKF). Then we propose the following four robust optimization-based controllers considering unsolved issues mentioned above.

1. Continuous time robust CLF-CBF-QP controller considering effects of matching disturbances
2. Continuous time robust CLF-CBF-QP controller with a stochastic observer to estimate states and matching disturbances
3. Continuous time robust CLF-CBF-QP controller considering mismatching disturbances
4. Discrete time robust CBF-QP controller considering matching disturbances

Compared with previous studies, contributions of these controllers are achieving calculation of cost-effective control input based on the stochastic information of estimated disturbances, handling wider class of disturbances and estimation errors of states and disturbances. The effectiveness of these

controllers has been confirmed through several numerical simulations.

In the latter half of this paper, we propose a walking control framework of underactuated bipedal robots affected by disturbances. It consists of two parts, designing output functions to make stable periodic locomotion, robust output zeroing control of designed output functions. We first introduce a hybrid zero dynamics (HZD) based control method which is a promising method to realize a periodic locomotion for underactuated bipedal robot systems. Based on this HZD based control, we propose a design method of output functions realizing stable periodic locomotion of disturbed underactuated robots. This method consists of direct collocation method which is one of numerical methods to solve optimal control problems and disturbance model identification based on GPR. One of good features of this method is that it can be used for robot systems having several underactuated states. Then we propose a robust optimization-based controller to realize robust output zeroing control of designed output functions. This controller also handles some constraints which should be guaranteed during locomotion, input constraints, friction constraints. The effectiveness of this control framework is verified through walking simulations of a planar 5 link robot affected by an external push force.

備考：論文要旨は、和文 2000 字と英文 300 語を 1 部ずつ提出するか、もしくは英文 800 語を 1 部提出してください。

Note : Thesis Summary should be submitted in either a copy of 2000 Japanese Characters and 300 Words (English) or 1copy of 800 Words (English).

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