Adaptive oscillation estimation and adaptive motion control of an oscillatory base manipulator subject to frequency variation

Summary of Doctoral Dissertation

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In offshore works using mechanical systems like such as a crane on a ship or an offshore structure, disturbances due to ocean wave-induced base oscillation often cause serious problems such as increased danger at work and decreased task performance. Furthermore, decreased accuracy of measurement obtained from a sensor is also a problem. Hence, reduction of the danger, recovery of the task performance and improvement of the measurement accuracy are expected in such cases. As an approach to solve these problems, motion control of mechanical systems taking into account such base oscillation is important.

Previous works have dealt with motion control for an oscillatory-base manipulator which can be regarded as a model system of mechanical systems installed on ships or offshore structures. The previous works have been based on H∞ control and sliding mode control and made the following two assumptions:

A1: an inclination angle of the base can be accurately measured;

A2: variation of the oscillation-frequency is small.

In order to achieve A1 and relax A2, this dissertation proposes an estimation method of inclination angles of the oscillatory base and a motion control method of an oscillatory-base manipulator subject to variation of oscillation frequency. Accordingly, the dissertation presents mainly two topics; one is about an “adaptive oscillation estimation method” which is an estimation method with gain tuning and filter switching algorithms, and the other is about an “adaptive motion control method” which is a control method with selectively switching controllers.

The dissertation is organized into four chapters. Chapter 1 introduces the background, related works, and the objectives of the study. Chapter 2 presents the adaptive oscillation estimation method subject to variation of oscillation frequency. Chapter 3 presents the adaptive motion control method of an oscillatory-base manipulator subject to variation of oscillation frequency. Finally, Chapter 4 makes concluding remarks. Then, summaries of Chapter 2 and 3 are given as in the following.

Chapter 2 presents the adaptive oscillation estimation method, which incorporates a proposed adaptive gain Kalman filter and a switching algorithm of the adaptive Kalman and the conventional H∞ filters. Chapter 2 is organized as follows:

- the adaptive gain tuned Kalman filter;
- the switching algorithm of the adaptive Kalman and conventional H∞ filters;
- simulations of the proposed estimation algorithm using a single sine wave model;
- simulations of the proposed estimation algorithm using ship oscillation models with ocean waves.

The objective of this estimation method is to overcome unknown variation of oscillation frequency in estimating base oscillation with the nominal frequency information. The adaptive gain tuned Kalman filter is based on the way such that a covariance matrix of estimation error by the Kalman filter is periodically adapted by using innovations, which are statistic data of gaps between measurements and their estimates. For adaptive gain tuning, the ratio of the theoretical trace of covariance of the innovation and the computed trace of covariance of the actual innovation as feedback information is periodically multiplied to the covariance matrix of estimation error by the Kalman filter, which leads to the adaptive gain.

In addition, stability analyses on Kalman filtering is presented to obtain a sufficient condition ensuring asymptotic stability of the time-varying closed-loop Kalman filter at any time, which is one of important

original theoretical contributions.

The switching algorithm of the adaptive gain tuned Kalman and conventional H∞ filters, which is the central part of this estimation algorithm, has been developed to exploit the advantages of each filter. The conventional Kalman filter is capable of effectively reducing influence of Gaussian noises such as sensor noises. On the other hand, the H∞ filter works effectively in the presence of deterministic noises such as model errors induced by frequency variation. In order to switch the filters, the square means of the innovations output by the adaptive Kalman and H∞ filters are utilized and their ratio is the criterion of switching filters.

The proposed estimation method is evaluated by simulations using a single sine wave and ship oscillations where frequency variation is considered.

The simulation of the single sine wave demonstrates three cases which are ones without an initial estimation error, with a small initial estimation error, and a large initial estimation error. As a result, the performance of the adaptive Kalman filter shows the effectiveness of the gain-tuning. Furthermore, the proposed switching estimation method is robust against the frequency variation.

The simulation of the ship oscillation demonstrates three ship dynamical model with a linear model and with two nonlinear models, i.e., hard-spring and soft-spring types with respect to the restoring moment. Furthermore, the simulation demonstrates three cases, which are ones without an initial estimation error, with an initial estimation error, and with an initial estimation error and larger amplitude of ship oscillations than the other cases. As a result, the performance of the adaptive Kalman filter shows the effectiveness of the gain-tuning. Furthermore, the proposed switching estimation method is robust against the frequency variation.

Chapter 3 presents the adaptive motion control method. This method is based on the way such that one of several H∞ controllers is selectively deployed. Chapter 3 is organized as follows:

- problem settings;
- dynamical model of an oscillatory-base manipulator;
- adaptive control algorithm for variation of base oscillation frequency;
- simulations of the proposed adaptive control algorithm using a single sine wave model;
- simulations of the proposed adaptive control algorithm using ship oscillation models with ocean waves.

This dissertation considers a simple case of a two-degree-of-freedom (DOF) manipulator with one-DOF base motion. The motion control problem is to achieve motion control of the manipulator in the presence of disturbance due to the base oscillation.

As a criterion to select the H∞ controller, the square means of the innovation calculated by several adaptive gain tuned Kalman filters are used. The advantage of H∞ control is to be useful and effective when the system can be considered to be linear and time invariant and when the frequency range of the base oscillation is known in advance.

The validation of the proposed adaptive control method is demonstrated by simulations using estimates of a single sine wave and estimates of ship oscillations subject to a large amplitude respectively, which are further compared with the conventional type of an adaptive control method, so called the gain-scheduling method. As a result, the proposed adaptive control method is robust against the frequency variation. Furthermore, the performances of the proposed method at steady states are much better than those of the gain-scheduling one, however the proposed method exhibits undesirable chattering when being switched.

Finally in this dissertation, a modified adaptive control method which is the method of combining outputs of H∞ controllers is presented, to cope with the chattering of the adaptive control method. The modified method is evaluated by simulations and reveals much better performances with no chattering.