**L**_1_ adaptive control used in ship control system when encountering slow varying disturbances

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**ABSTRACT**

To deal with the system uncertainty in the path following problems with slow varying disturbances, a simple but effective **L**_1_ adaptive control strategy is introduced. This control law shows a fast adaptation rate and robust control performance, which can ensure the uniformly bounded transient and asymptotic tracking performances. An adaptive parameter is introduced to capture the uncertainty induced by disturbances. The **L**_1_ adaptive control law is then used to identify the time-varying parameter. An inner-outer loop control structure is used to analyze the system. The simulation result shows the effectiveness of this strategy.

**KEY WORDS:** slow varying disturbances; system uncertainty; **L**_1_ adaptive control

**INTRODUCTION**

Due to various commercial and military needs, steering a surface ship along any admissible predefined path is an important task in ship control community (Fossen et al., 2003; Breivik and Fossen, 2004; Do and Pan, 2006b; Moreira et al., 2007; Li et al., 2009; Kaminer et al., 2010). Typically, this goal can be divided into two categories, namely the path following (PF) problem and the trajectory tracking (TT) problem (Breivik and Fossen, 2005a). The PF control problem regards the geometric demands as the primary task, and takes the dynamics aspect as a secondary objective, negligible if necessary (Breivik and Fossen, 2005b).

Since a seagoing ship is always sailing in the seaway, the severe and complex wave disturbances will affect the ship motions, especially in PF problems. The disturbances often cause a large uncertainty of the whole control system, and make the control law less effective. Such challenges related to the parameter uncertainty and robustness issues have drawn much attention in the control community (Skjetne et al., 2005; Aguiar and Hespanha, 2007). Strategies such as high gain, robust and adaptive control are often used to reject the effects of the uncertainties (Zhang et al., 2000; Do and Pan, 2006a,b; Ashrafuion et al., 2008).

Typically, the disturbances can be divided into high frequency and low frequency components. The controller should not react to the high-frequency components of the disturbances, because this will increase wear on actuators (Fossen, 1994). However, a good controller should compensate for the constant or slow varying bias of the disturbances (Do and Pan, 2005). It is not easy for traditional control methods, such as PID control, to deal with such slow varying disturbances. Some adaptive control strategies are introduced in ship control community to deal with such problems (Skjetne et al., 2004; Do and Pan, 2005).

In this paper, a single adaptive parameter is introduced into the control system to capture the uncertainty caused by the slow varying disturbance, and a so-called **L**_1_ adaptive control strategy is used to control the PF system and to identify the adaptive parameter. A high positive correlation relation between the adaptive parameter and the slow varying disturbance is shown in the simulation part. This method was first introduced in aircraft control community (Cao and Hovakimyan, 2006a,b), it is called **L**_1_ adaptive control because it belongs to the family of adaptive strategies, and at the same time, the stability analysis of this control law needs the concept of **L**_1_-norm. Compared to the conventional adaptive controller, **L**_1_ adaptive control strategy guarantees the low-frequency control signal and ensures asymptotic convergence of the tracking error to zero. Moreover, the new control architecture tolerates high adaptation gains, leading to improved transient performance (Cao and Hovakimyan, 2006a).

This control strategy has fast adaptive and converge properties in the presence of unknown high-frequency gain, time varying unknown parameters and time-varying bounded disturbances without restricting the rate of their variation (Cao and Hovakimyan, 2007a). It has been widely used, especially in aircraft control area. Several experiment results show the effectiveness of this control strategy (Cao et al., 2007; Gregory et al., 2009). **L**_1_ adaptive control law has relatively simple form, which makes it quite suitable for the ship motion control. However, the application of **L**_1_ theory to ship control is relatively rare, to our knowledge, only Breu and Fossen used this strategy to deal with the parameter resonance problem of ships (Breu and Fossen, 2011). In this paper, we explore the possibility of introducing this control method into path following problems for surface ships.

Inspired by the papers (Breivik and Fossen, 2005a; Kaminer et al., 2007), a cascaded control structure is used in this paper. The PF problem is decoupled into an inner-outer control loop structure. The outer-loop guidance subsystem only considers the kinematic and guidance information about the system, the inner-loop control subsystem considers the dynamics of the system. This structure actually decouples the space requirement and the time requirement. As to the PF problem in this paper, more attention is paid to the space requirement, the primary objective is to steer the ship to move along the given curve...