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Development of an adaptive disturbance rejection system for the rapidly deployable stable platform—Part 2 Controller design and closed loop response

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ABSTRACT

Currently, both military and civilian operations that require at-sea cargo transfers are severely limited by environmental conditions and loading forces that induce vessel motions. To increase the robustness of at-sea cargo transfer to these environmental conditions and loading forces, efforts have recently been made toward an actively controlled, rapidly deployable stable platform (RDSP). The purpose of the research presented here is to implement an output feedback adaptive controller and adaptive disturbance rejection scheme that will mitigate the effect of environmental conditions and reject disturbances caused by various loading situations. Because of the controller's distinct ability to adapt to various operating conditions, anticipate and reject load disturbances of unknown magnitude, and adjust to stay within input saturation constraints, the framework is a good fit for the RDSP. Three missions are considered using a previously developed 3 degree of freedom simulation of a 1/10th scale RDSP prototype. Results show successful mitigation of load disturbances and a significant reduction in pitch motions using a control command that remains within the given amplitude and rate constraints. In the case of cargo transfer operations, the adaptive control system is able to significantly increase the cargo throughput by rejecting the disturbances before they are able to cause large pitching dynamics.

1. Introduction

Military and civilian applications abound for stable, floating ocean platforms. These include oceanographic research stations, rocket launching platforms, in-flight helicopter refueling stations, deep water stable craneships, and others. While there are many uses for a stable floating platform, the need for a stable craneship is what drove research toward the deep water stable craneship concept vessel (Selfridge, 2005). This concept is a predecessor to the rapidly deployable stable platform analyzed in this paper. Current technology restricts the use of conventional craneships to relatively low sea states and limits the rate at which loads may be transferred. For example, skin-to-skin operations used for transferring large loads (>2600 kg) between vessels are typically halted in Beaufort Sea State 3 (wave heights of approximately 1 m (World Meteorological Organization, 1970). Average wave heights in the open ocean of approximately 4 m (Driscoll et al., 2006) force conventional craneships to be on standby for more than half of the time. Unfortunately, when responding to a crisis situation or sustaining a military endeavor, delaying the entire operation while waiting for the seas to calm could have serious consequences.

A rapidly deployable stable platform (RDSP), currently under development, shows promise for meeting the operational requirements for higher sea states. The RDSP consists of two elements: (1) a catamaran, shown in Fig. 1(a), and (2) a detachable spar buoy, shown in Fig. 1(b). The RDSP has two modes of operation: horizontal transit mode (HTM) and vertical operations mode (VOM), shown in Fig. 2. When performing cargo transfers the RDSP is configured in VOM, where the spar extends vertically below the catamaran and hoists it completely out of the water. In this operating mode, the catamaran and spar form a stable platform that presents a small cross-sectional area to passing waves, thereby improving seakeeping properties.

A 1/10th scale prototype (Fig. 1) of a RDSP (11.4 m spar) has been developed at Florida Atlantic University (FAU) (Marikle, 2009). The prototype's open loop response provided in Part 1 of this paper shows only low amplitude oscillations for many

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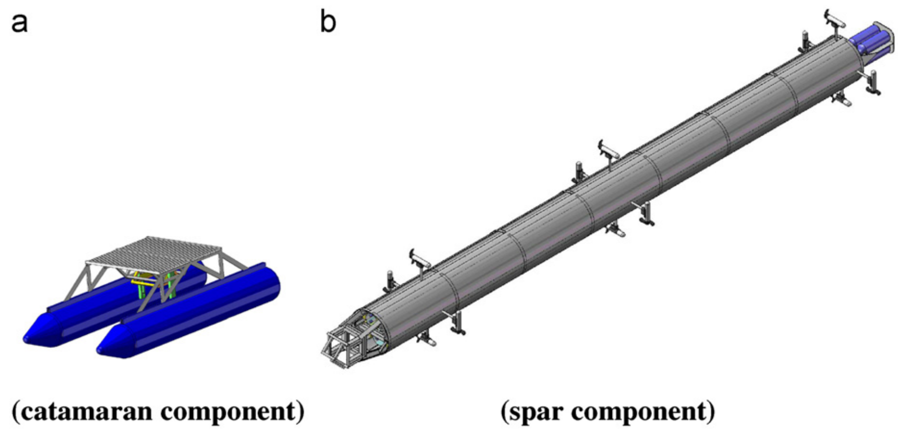

Fig. 1. Components of FAU's 1/10th scale RDSP prototype.

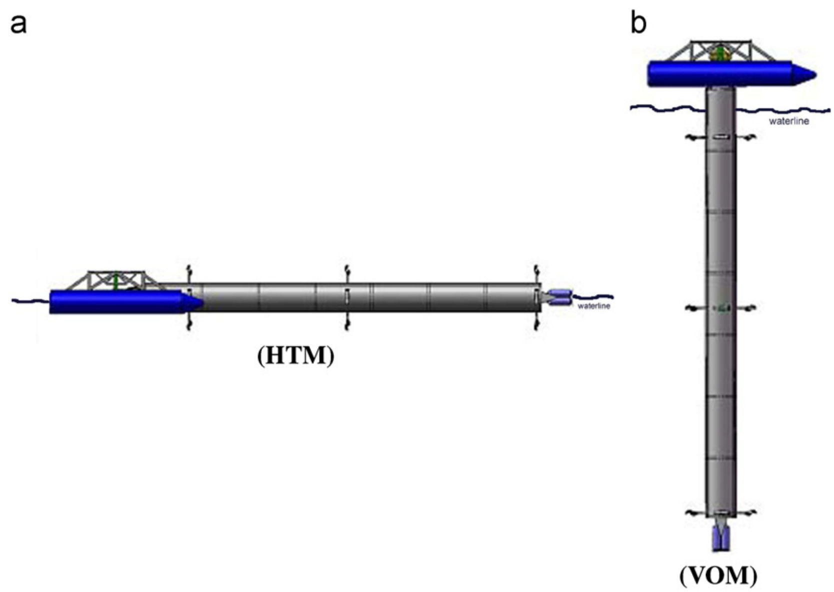

Fig. 2. The RDSP's two operational modes.

situations (VanZwieten et al., 2010a). However, even small pitch oscillations can cause serious difficulties for the types of operations envisioned. For example, pitching amplitudes of only 3° correspond to vertical motions with an amplitude of 2.63 m at the end effector of a crane with a 50 m reach from the RDSP's center of gravity. Thus, to further increase seakeeping capabilities, the RDSP was designed with active control in mind. Its current sensor system consists of accelerometers, tilt sensors, pressure sensors, a compass, and a GPS that provide enough information to determine the states of the RDSP (VanZwieten et al., 2008a; Marikle, 2009). Actuation is induced via three sets of four electric thrusters in a configuration that allows a pure moment of up to 940 N m to be produced when each thruster produces a maximum thrust of 47 N.

Due to the complexity of the RDSP dynamics as well as the variance in environmental and load conditions that can be expected, an adaptive control approach is taken in this paper. Adaptive control exhibits a robustness to unmodeled dynamics, nonlinearities, and parameter variations that makes it an attractive option for many applications. Based widely on the foundational work of Lyapunov (1992), LaSalle (1976), and LaSalle and Lefschets (1961), adaptive control has received considerable attention in the literature (see Mareels and Jan Willem Polderman, 1996; Narendra and Annaswamy, 1989; Aström and Wittenmark, 1995; Ioannou, 1996, for example). Many different variations of adaptive control presently exist, but a central theme is the online parameter tuning capabilities that adapt according to the dynamical (and sometimes even environmental) features of a given plant. The sub-type of adaptive control that is used here is direct model reference adaptive control (DMRAC) (see Parks, 1966; Hang and Parks, 1973; Monopoli, 1979, for some early references). The term "direct" alludes to the adaptation of the parameters appearing directly in the control law, rather than employing plant parameter identification. Narrowing even more to the algorithm that will be applied to the RDSP, we draw our attention to an output feedback version of MRAC that is augmented with direct adaptive disturbance rejection (DADR). With this controller, the gains for both the model reference and disturbance rejection components are tuned adaptively. The original theory was developed by Balas and Fuentes for linear systems in Balas (1995) and Fuentes and Balas (2000, 2002). It has produced good results when applied to large space structures, ocean platforms, wind turbines, and evolving systems (Balas et al., 2000; Fuentes et al., 2001; Mehiel et al., 2002; VanZwieten and Balas, 2007; VanZwieten, 2008; VanZwieten et al., 2008c, 2009, 2010b). The theoretical result provides a guarantee that adaptive