On the Control of the Hovercraft System

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Abstract. A simplified model of the hovercraft system, used in the literature to illustrate nonlinear control options in underactuated systems, is shown to be differentially flat. The flat outputs are given by the position coordinates with respect to the fixed earth frame. This fact is here exploited for the design of a dynamic feedback controller for the global asymptotic stabilization of the system’s trajectory tracking error with respect to off-line planned position trajectories.

Keywords: hovercraft, flat systems, trajectory planning

1. Introduction

The control of a ship having two independent thrusters, located at the aft, has received sustained attention in the last few years. The interest in devising feedback control strategies for the underactuated ship model stems from the fact that the system does not satisfy Brockett’s necessary condition for stabilization to the origin by means of time-invariant state feedback (see Brockett, [1]). Reyhanoglu [13] proposes a discontinuous feedback control which locally achieves exponential decay towards a desired equilibrium. A feedback linearization approach was proposed by Godhavn [6] for the regulation of the position variables without orientation control. In an article by Pettersen and Egeland [8], a time-varying feedback control law is proposed which exponentially stabilizes the state towards a given equilibrium point. Time-varying quasi-periodic feedback control, as in Pettersen and Egeland [10], has been proposed exploiting the homogeneity properties of a suitably transformed model achieving simultaneous exponential stabilization of the position and orientation variables. A remarkable experimental set-up has been built which is described in the work of Pettersen and Fossen [11]. In that work, the time-varying feedback control, found in [8], is extended to include integral control actions, with excellent experimental results. High frequency feedback control signals, in combination with averaging theory and

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backstepping, have also been proposed by Pettersen and Nijmeijer [12], to obtain practical stabilization of the ship towards a desired equilibrium and also for trajectory tracking tasks. In [14] the author has examined the ship trajectory tracking control problem from the perspective of Liouvillian systems (a special class of non-flat, i.e., non feedback linearizable systems).

This article is motivated by the recent work of Fantoni et al. [9] where the hovercraft system model is derived on the basis of the underactuated ship model extensively studied by Fossen [5]. In [9], a series of interesting Lyapunov-based feedback controllers are derived for the stabilization and trajectory tracking of the hovercraft system.

In this article, we propose a dynamic feedback control scheme for the hovercraft system based on trajectory planning and trajectory tracking error feedback linearization. For both the trajectory planning and the controller design aspects, use is made of the fact that, contrary to the general surface vessel model [5], the hovercraft system model is indeed differentially flat. The flat outputs are represented by the hovercraft position coordinates with respect to the fixed earth frame (The reader is referred to the work of Fliess and his colleagues [2]–[4] for a definition of flatness and a full discussion of the flatness concept with its many theoretical and practical implications).

Section 2 revisits the hovercraft vessel model derivation performed in [9], taking as the starting point the fully actuated, though simplified, ship model also found in [5] and also in [8]. In that section, it is shown that the obtained hovercraft system model is differentially flat. In Section 3 we pose the trajectory tracking problem and derive a dynamic feedback controller. Section 4 contains the simulation results and Section 5 is devoted to some conclusions and suggestions for further research.

2. The Hovercraft Model

In a book by Fossen [5] the following model is proposed for a rather general surface vessel dynamics

$$M \dot{\nu} + C(\nu) \nu + D \nu = \tau$$
$$\dot{\eta} = J(\eta) \nu$$

where

$$C(\nu) = \begin{bmatrix} 0 & 0 & -m_{22} v \\ 0 & 0 & m_{11} u \\ m_{22} v & -m_{11} u & 0 \end{bmatrix}$$
$$J(\eta) = \begin{bmatrix} \cos \varphi & -\sin \varphi & 0 \\ \sin \varphi & \cos \varphi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

with $M$ being a constant matrix representing the inertia matrix and $D$ is the matrix of constant hydrodynamic damping coefficients. These matrices are, both, diagonal and given by,

$$M = \text{diag} \{m_{11}, m_{22}, m_{33}\}, \quad D = \text{diag} \{d_{11}, d_{22}, d_{33}\}$$

The vector $\nu = [u, v, r]^T$ denotes the linear velocities in surge, sway, and angular velocity in yaw. The vector $\eta = [x, y, \varphi]$ denotes the position and orientation in earth fixed