Identification of System Transfer Function of a Ship Mounted Two-DoF Manipulator under Ocean Random Waves

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ABSTRACT
Identification of system transfer function of a ship mounted two-DoF manipulator is challenging due to the existence of randomness in the ocean waves. This paper is presented to address such a task by proposing a time-varying autoregressive moving average with exogenous input (TVARMAX) model with Kalman smoother (KS) as an estimator. System input is torque and speed of the motor while system output is angular position of manipulator joint. Given the measured system input and output obtained from experiment with disturbances at the base of manipulator in terms of ship motions (surge, heave, sway, roll, pitch and yaw motions), an off-line system transfer function identification is performed. Finding result reveals that the identified system transfer functions are successfully identified with acceptable accuracy where it is significantly affected by the ocean random waves induced ship motions. If the sea state increases (from calm to rough) the location of zeros and poles shift to the right-half plane on the complex s-plane, indicating the instability of manipulator motion on the ship. The identified results are able to describe the system dynamics, and can be recommended for developing the adaptive control for manipulator stabilization.

KEY WORDS: Identification system; transfer function; TVARMAX; Kalman smoother; ship; manipulator; sea state.

INTRODUCTION
In robotic system, a two-DoF manipulator system (two revolute joints, $\theta_1$ and $\theta_2$) is widely used for different engineering applications either in rigid or flexible modes. State of the art may be found in numerous literatures such as (Gaidhane, 2019; Bingul, 2011; Kumar, 2017; Lerma, 2017; Li, 2016; Gao, 2019; Dunnigan, 2011; Guller, 2012; Sato, 2015; Nguyen, 2015; Wang, 2016; Sun, 2017; Wang, 2018). When such a system is mounted on a ship, then its dynamics and control system are significantly affected by the ocean random waves induced ship motions. Consequently, they become a coupled system as illustrated by Fig. 1. The application might be relatively rare to be found, and is mostly assigned for coastal surveillance.

In practice, time series of environmental conditions such as wind, wave and current, responses of the ship and manipulator system are available in the form of field measurement, experiment and numerical simulation. Such measured data can be utilized to generate dimensionless form namely transfer function (TF) either in time domain (impulse response function, IRF) or frequency domain (frequency response function, FRF). Generation of the TF involves system identification process. Through the estimated TF, dynamic behavior of a ship mounted two-DoF manipulator under ocean random waves can be investigated. It can be further used for developing the suitable and optimal control system so that the serious damage to the mechanical, structural and electrical components of the manipulator system can be minimized.

This paper is addressed to generate the TF from available measured data. There are three TFs that can be identified sequentially from a ship mounted two-DoF manipulator. First is the speed of electrical motor to the joint angle of manipulator, second is the torque of electrical motor to the joint angle of manipulator, and the last is a combination of both