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Model of an artificial neural network for optimization of payload positioning in sea waves

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ABSTRACT

The optimization problem considered is to define the rotation function of a winch which compensates vibrations of the crane placed on a vessel deck. The aim is to stabilize the payload at a given depth or realize a predefined trajectory despite the sea waves and vessel motion. The model of the flexible rope formulated by means of the rigid finite element method allows us to consider both hydrodynamic forces when a part of the rope is submerged and the complex shape of the rope due to its large displacements. An artificial neural network is proposed to control the position of the payload.

1. Introduction

Increasing demand for exploration and exploitation of hydrocarbons from deep water requires highly accurate, efficient and safe offshore installations. Position control of vessels, risers and payloads is given much attention by many researchers. Modeling dynamics of floating cranes requires consideration of the vessel or platform motion due to the sea environment. Dynamic positioning (DP) has been developed since the early 60-ies and nowadays it is a well-established technology used in many DP vessels for many off-shore activities. However, it is still an area of active research, which can be seen from the large number of papers devoted to dynamic positioning. Many of them describe different control methods used in order to ensure either a fixed position or predefined path of the floating structure.

Leira et al. (2004) are concerned with a control algorithm for adjusting the position of the floater with the riser suspended between the seabed and the floating vessel. To this end object functions are expressed in terms of reliability indices. Numerical and experimental evaluation of a typical dynamic positioning system is presented by Tannuri and Morishita (2006). Nguyen et al. (2007) propose a hybrid controller consisting of several controllers with supervisory control. The authors present stability analysis and experiments to prove that such a solution increases the "weather window", and thus operability can be improved.

Methods using an artificial neural network (ANN) for control are widely reported by many authors, including for control of ship movement. Burns and Richter (1996) present an application of a neural network to control a vessel motion under different environmental conditions. The authors conclude that although the properties of multi-layer neural networks are not yet fully understood, the technology has potential to be used as a ship's guidance system. The situation when the DP system is disabled is studied by Mahfouz (2007) and the solution based on ANN for predicting the capability-polar-plots for offshore platforms is discussed. Ship roll stabilization based on neural networks for a container ship is discussed by Alarçïn (2007). Control of an oil tank for different water depth and wind waves using ANN is the subject of the paper by Pathan et al. (2012).

Another challenging problem is connected with positioning the payload suspended to an off-shore crane when the load sway is affected by the ship's motion. A control algorithm based on energy dissipation by using the winch to vary the length of the hoist cable over time is proposed by Albada et al. (2013). However, the influence of water on the rope is not considered.

Boundary control of a marine flexible installation system is developed by He et al. (2011). In order to compensate the rope's vibrations and move the sub-sea payload to a desired position the authors propose an adaptive boundary control based on Lyapunov's direct method. Compensation of the heave motion of a vessel by means of nonlinear control is discussed by Do and Pan (2008). Heave compensation is especially important when the shipboard crane is moving. The objective of the control strategy presented by Neupert et al. (2008) is to follow a desired path for the payload despite the heave of the vessel. The system considered consists of a hydraulic-driven winch, a crane-like structure and the rope-suspended load. It is assumed that the crane is a rigid body and the rope with the payload is treated as a spring-mass-damper system. Maczyński and Wojciech (2012) present two methods for

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determining the drive function of an auxiliary system and the hoisting winch drum in order to stabilize the payload position.

A similar system is considered in this paper. The aim is to choose the drive function for the winch in order to ensure either the stability of the payload or realization of a desired trajectory. The problem becomes more complicated when part of the rope is submerged and hydrodynamic forces act on the rope. It is also necessary to consider a complex shape of the rope due to its large displacements. Moreover, the length of the rope changes not only due to the winding but also because of the flexibility.

Calculation of the appropriate rotation function of the winch, which compensates vibrations of the crane caused by the sea motion, is treated as a dynamic optimization problem. In order to solve this problem, the dynamic model of the rope with the payload is considered. The equations of motion of the system are integrated at each optimization step for the given set of decisive variables. The modification of the rigid finite element method is proposed in order to consider the vibrations of the rope due to hydrodynamic dynamic forces and its complicated shape.

The dynamic optimization is very time consuming and it cannot be applied for control in real-time systems. Thus, in this paper an artificial neural network is proposed in order to control the position of the payload. The solutions of the optimization problem are used for preparing the learning set for the neural network.

2. Methodology

The system analysed is shown in Fig. 1. It is assumed that a winch drum is placed on a vessel deck.

The motion of the vessel, both in the vertical and horizontal directions, is known. Having assumed that the radius of the winch is relatively small, the motion of the point on the perimeter of the winch drum can be described by functions of time given in the following form:

$$\begin{cases} x_A = x_A(t) \\ y_A = y_A(t) \end{cases} \tag{1}$$

The position of the payload with mass m described by point $E = A_0$ can be adjusted by the variable length of the rope. The rope is treated as a flexible body and its bending flexibility can be considered in the form of either linear or nonlinear physical relations. Longitudinal flexibility is omitted.

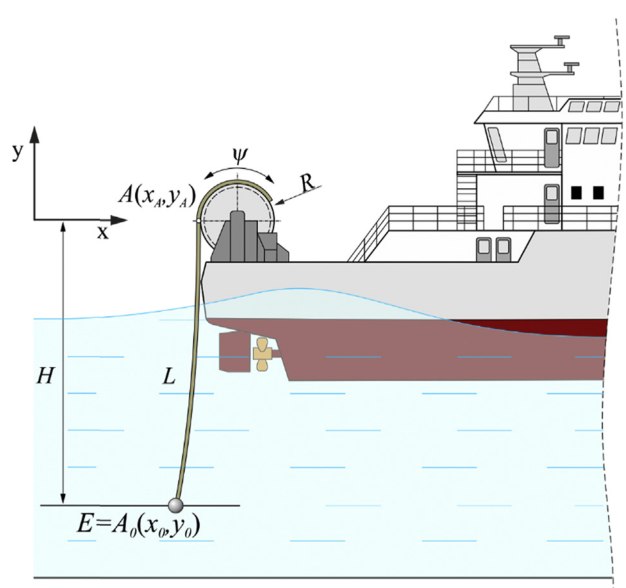

Fig. 1. The vessel with the winch and flexible rope of variable length.

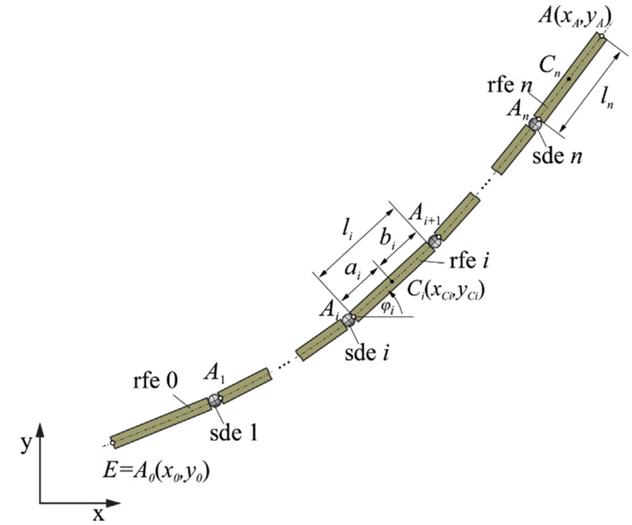

Fig. 2. Discretization of the rope.

2.1. Rope discretization

The rope is discretized by means of a modified formulation of the rigid finite element method RFEM (Adamiec-Wójcik et al., 2015; Adamiec-Wójcik, 2006; Adamiec-Wójcik and Wojciech, 1993; Wittbrodt et al., 2013, 2006). Following the procedure of discretisation, the continuous rope is replaced by an equivalent system of $n+1$ rigid finite elements (rfe) and n massless and non-dimensional spring-damping elements (sde) as in Fig. 2.

Inertial features of the i-th rigid element are described by its mass m_i and inertial moment J_i with respect to the center of the mass C_i. The generalized coordinates of rfe i are the components of the following vector:

$$\mathbf{q}_i = \begin{bmatrix} x_{Ci} & y_{Ci} & \varphi_i \end{bmatrix}^T \quad i = 0, \ldots, n \tag{2}$$

where x_{Ci}, y_{Ci} are coordinates of the center of the mass of rfe i, φ_i is the angle shown in Fig. 2.

2.2. Equations of motions

The equations of motion are derived from the Lagrange equations and to this end the kinetic and potential energies as well as generalized forces have to be calculated. The details are presented in Appendix A.

The length l_n of the last n-th element changes as the rope is wound or unwound from the winch. The situation is shown in Fig. 3. The initial length of rfe n is l_n^0, while l_n is the actual length of the element and a_n, b_n are the initial distances of the mass center C_n from the beginning (point A_n) and the end of the element (point A) respectively.

It is important to note that reeling out the rope not only changes the length of the last rfe n but it also changes the number of elements, especially when the lengths of elements are small.

The Lagrange operators for rigid elements:

$$\epsilon_{\mathbf{q}_i}(T_i) = \frac{d}{dt}\frac{\partial T_i}{\partial \mathbf{q}_i} - \frac{\partial T_i}{\partial \mathbf{q}_i} \quad \text{for } i = 0, \ldots, n \tag{3}$$