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Inverse Kinematics of 2-DOF Rotary Crane Fixed on Two Barges for Collaborative Tasks During Offshore Installation

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Inverse kinematics was studied to compute the joint parameters of rotary crane systems with two Degrees of Freedom (2-DOF) and the lengths of the wire ropes that would enable a target structure to reach the desired position and orientation during the performance of collaborative tasks in offshore installation operation using two floating cranes. First, the connecting positions between the wire ropes and the target structure in a local coordinate system of the structure were described in a global coordinate system. The forward kinematic equations of two rotary crane systems were modeled with the joint parameters of the crane systems and the lengths of the wire ropes. Inverse kinematics reverses these equations to determine the joint parameters of the crane systems, making the wire ropes perpendicular to the base or water plane. The connecting positions between the wire ropes and the boom of each crane system were computed using these joint parameters, and the lengths of the wire ropes considering their tensions were also computed using the balance equations of the forces and moments acting on the structure and the wire ropes, including the gravitational forces and tensions. Convergence problems such as singularities and out-of-reach targets were considered. Multiple solutions were also considered to achieve the desired posture and to determine how to choose an optimal one. Finally, the inverse kinematics was validated by applying it to monopile installation simulation using two floating cranes.

INTRODUCTION

Background

A floating crane is almost essential for installing an offshore structure. Depending on the shape of the offshore structure and the environment of the installation area, some cases may require more than one floating crane. As carrying out collaborative tasks with two floating barges at an offshore site is quite dangerous, however, it is necessary to verify the safety of the collaboration by conducting a simulation before the real operation. To perform the simulation, the length of the wire rope and the joint angle of the crane according to the installation position and posture of the object structure are required. Currently, iteration work is necessary to confirm correctness by calculating the joint angle of the crane and the wire length manually. Therefore, in this study, inverse kinematic analysis was performed to automatically calculate the rotation angle and wire length of the two-axis rotary crane according to the position and attitude of the installation structure.

Related Works

Inverse kinematic analysis is performed to calculate the angle of the crane joint and the length of the wire according to the position and attitude of the installation structure. Forward kinematics is a method of calculating the position and posture of the endpoint when the joint and wire length of the crane are provided. Inverse kinematics, on the other hand, is a method of calculating the joint and wire length of the crane when the position and posture of the endpoint are provided.

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KEY WORDS: Inverse kinematics, rotary crane system, offshore installation, floating crane, joint parameter.

Park et al. (2014) conducted a study on the development of an automatic welding robot. They calculated the joint angles by performing an inverse kinematic analysis of the weld position. Jeong et al. (1997) conducted a study to measure the robot's attitude through the wire parallel mechanism. It involved measuring the attitude of an object through inverse kinematic analysis using the wire length for an object connected with six wires. Kim et al. (2010) conducted a study to determine how to suppress the shaking of heavy objects using mobile harbor cranes. They tried to minimize the motion of the container by moving a sub-trolley through inverse kinematic analysis of the container movement. Rushworth et al. (2016) conducted a study on the development of a mobile walking machine tool. They used the revolute, gimbal, spherical, and prismatic joints to devise a mechanical leg, and they provided the walking machine tool with the joint values of each leg through inverse kinematic analysis. Yamamoto and Mohri (2000) studied the inverse kinematics problem for imperfectly constrained parallel wire mechanisms. In addition, a study was developed to calculate the position and the cutting force at which the machine operates using the kinematics (Xu et al., 2017). Table 1 shows the results of the comparative analysis of inverse kinematics.

For an incompletely restrained object, an analytical solution of the inverse kinematics problem was carried out when the geometric constraint of the wire force vector was linear. The inverse kinematic analysis algorithm was derived using the force vector of the wire, without inducing the inverse kinematics through the joint. Inverse kinematic analysis was performed to calculate the lengths of the joints and wire ropes of the crane according to the position and attitude of the installation object, which was supported by dual two-axis cranes during collaborative operation. The length of the rope was calculated, and based on this assumption, installation simulation analysis was performed by substituting the rope length value into the dynamic kinetic equation of motion.

In addition, various model tests or simulations were performed in offshore projects. Roveri et al. (1996) conducted a study to