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Re-optimization strategy for truck crane lift-path planning

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ABSTRACT

When a truck crane lifts a load, the most important considerations are the safety and efficiency of the lift path; therefore, the objectives in planning a lift path should be the minimization of both the path length and number of operations. Most proposed methods for lift-path planning simply focused on the optimization of the path length. As a result, a planned path may include a large number of operations that makes the path complicated and degrades the safety and efficiency of the lift process. This paper presents a method to optimize the number of operations for a lift path with an optimized length for a truck crane by making the most efficient use of the crane characteristics. First, a conventional search algorithm is used to optimize the length of a lift path. Thereafter, a new operating-path optimization method is presented to reduce the number of points on the planned path based on construction of simple spaces and fundamental operating paths. Simulations produced satisfactory results, demonstrating that this method reduces the number of operations on a short lift path, thereby improving the safety and efficiency.

1. Introduction

The widespread use of cranes in fields such as construction and the power industry has led to closer scrutiny of the safety and efficiency of crane operations [1, 2, 3]. Finding a lift path (either a load path based on load positions or an operating path based on crane operations) that enables satisfactory performance is very important for a truck crane [4]. A number of path-planning methods have been devised in various areas, such as an A-star algorithm for a wireless network [5], integrated local trajectory planning for autonomous ground vehicles [6], a potential field algorithm for remote sensing [7], an ant colony algorithm for a robot [8], and a particle swarm algorithm for a vehicle [9]. However, two problems that make these methods unsuitable for the path planning of a truck crane are that they do not take the characteristics of lifting operations into account, and they are computationally expensive.

Many lift-path planning methods for cranes have been reported. For example, a genetic algorithm (GA) optimization model was used to solve a location problem for a tower crane and find the path with the shortest transport time [10, 11]. Converting the information of three-dimensional space into that of two-dimensional space in order to simplify calculations enabled the trajectory of a load path to be found to maximize the simplicity of operations [13]. An improved rapidly exploring random tree (RRT) generated a lift path for a crawler crane that yielded a shortest path [12]. An improved potential field algorithm yielded a shortest path for a truck crane [14]. And algorithms based on a probabilistic roadmap (PRM) [15] were designed to minimize the lifting costs of a crawler crane and truck crane. However, these methods optimized only a single objective function, and the planned lift-paths always include numerous switches among different operations, which means that they cannot take both safety and efficiency into account simultaneously. Thus, they cannot provide solutions that meet lifting requirements in actual practice.

On the other hand, a direct-swing constraint-based path planning method for overhead cranes found the shortest transport time and maximum rotational angle [16]. A multi-objective lift-path planning method for a truck crane, based on an expansion of an algorithm by Y. Srinivas, determined both the shortest lift path and longest safe distance [17], with the performance index constructed from the weighted sum of the lift-path length and safe distance. The same performance index was used in a grid-based artificial-potential-field method that found an optimal global path for a truck crane [18]. Weights in the performance index were determined by the importance of the objectives for path planning [19, 20]. However, due to the lack of an explicit mathematical relationship among goals, weight selection is rather subjective.

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A further issue in path planning is that the number of points on the resulting path is usually very large. As one solution, a mask-effect-based optimization method revised a planned path by reducing its complexity [21]. This method reduced the number of points based on a straight-line strategy; that is, if a straight line between two points does not cross any obstacles, all intermediate points on the path are removed. However, this straight-line strategy does not take the characteristics of lifting operations into account to avoid obstacles.

In short, three problems exist in lift-path planning. First, a single objective leads to an unsatisfactory evaluation of a lift path. Second, most multi-objective lift-path planning methods transformed the multiple objectives into a single objective using the weighted sum of the multiple objectives. Due to the lack of an explicit mathematical relationship among those objectives, the weight selection is somewhat subjective. Third, optimization involving the removal of unnecessary points on the lift-path is inefficient, because it did not consider the characteristics of lifting operations.

This paper presents a re-optimization strategy for truck crane lift-path planning. The proposed method makes use of the characteristics of lifting operations, and takes both the path length and number of operations into account. The number of crane operations is reduced by decreasing the number of points on a planned path with an optimized length. This new method is known as operating-path optimization (OPO). Optimization is performed based on construction of simple spaces (CSS) and fundamental operating paths (FOPs). Simulation results demonstrate the validity of the method.

2. Problem formulation

Unlike a crawler crane, a truck crane remains in a fixed position during the lifting process. The positions of the load, boom, and crane, among others, are defined according to an orthogonal coordinate system that has its origin on the center of the crane turntable.

The load position and center of the load mass can be described by using the absolute position of the load in the orthogonal coordinate system, with the form of $[x_j,y_j,z_j]^T$ for the point, p_j, or by using the absolute posture of the crane (Fig. 1). The crane posture consists of three elements: (1) the vertical angle, α, that the boom makes with the xy plane; (2) the horizontal angle, β, that the boom makes with the positive x-axis; and (3) the length of the sling, γ, that the hook makes with the top of the boom. Thus, the description of the load position

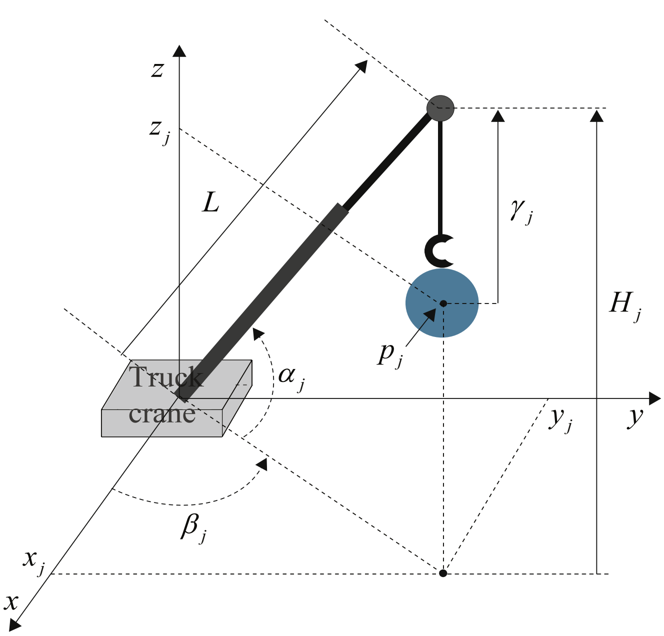

Fig. 1. Parameters of load position at the point p_j.

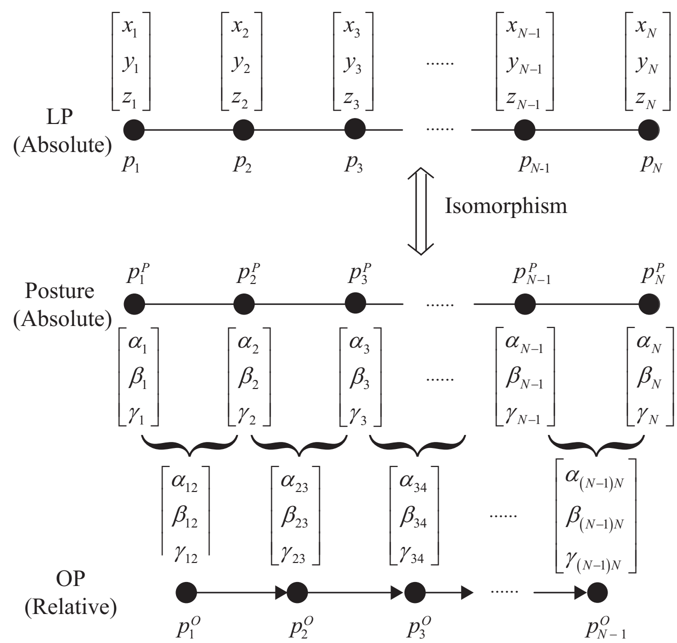

Fig. 2. Definitions of LP and OP.

using the crane posture has the form of $[\alpha_j,\beta_j,\gamma_j]^T$ for the point, p_j^P (Fig. 2), which is identical to p_j. The two descriptions of the load position can be converted into one another as follows:

$$\alpha_j = \arccos\left(\frac{R_j}{L}\right), \tag{1}$$

$$\beta_j = \arctan\left(\frac{y_j}{x_j}\right), \tag{2}$$

$$\gamma_j = H_j - z_j, \tag{3}$$

where

$$\begin{cases} R_j = \sqrt{x_j^2 + y_j^2} \\ H_j = \sqrt{L^2 - R_j^2}. \end{cases}$$

Note that the position of a load refers to its center of mass, which is a point. If the size of a load needs to be considered, the point is simply enlarged into a sphere.

According to the different descriptions of the load position, there are two ways to represent the process of moving a load from one point to another. One is known as a load path (LP), which is a set of absolute load positions. Thus, an LP with N points has the form of $p_j = [x_j,y_j,z_j]^T$ $(j = 1,2,\cdots,N)$ (Fig. 2). Its advantage is that it makes it easy to calculate the distance between the load and an obstacle directly; while its drawback is that it does not directly contain the crane operations, and therefore cannot provide a crane operator with precise guidance on lifting.

The other method is known as an operating path (OP), which is a set of crane operations between two load positions. A truck crane performs three operations: luffing the boom, slewing the turntable, and hoisting the hook (Fig. 3). Let $p_j = [x_j,y_j,z_j]^T$ and $p_{j+1} = [x_{j+1},y_{j+1},z_{j+1}]^T$ be two adjacent points on a lift path. Assume that for any of the three operations, the load moves from p_j to p_{j+1}. A luffing operation is characterized by the luffing angle,

$$\alpha_{j(j+1)} = \alpha_{j+1} - \alpha_j, \tag{4}$$

which is the angle in a vertical plane between the boom for p_j and that for p_{j+1} [Fig. 3 (a)]. A slewing operation is characterized by the slewing angle,