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Review

Parallel genetic algorithm based automatic path planning for crane lifting in complex environments

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ABSTRACT

Heavy lifting is a common and important task in industrial plants. It is conducted frequently during the time of plant construction, maintenance shutdown and new equipment installation. To find a safe and cost effective way of lifting, a team works for weeks or even months doing site investigation, planning and evaluations. This paper considers the lifting path planning problem for terrain cranes in complex environments. The lifting path planning problem takes inputs such as the plant environment, crane mechanical data, crane position, start and end lifting configurations to generate the optimal lifting path by evaluating costs and safety risks. We formulate the crane lifting path planning as a multi-objective nonlinear integer optimization problem with implicit constraints. It aims to optimize the energy cost, time cost and human operation conformity of the lifting path under constraints of collision avoidance and operational limitations. To solve the optimization problem, we design a Master–Slave Parallel Genetic Algorithm and implement the algorithm on Graphics Processing Units using CUDA programming. In order to handle complex plants, we propose a collision detection strategy using hybrid configuration spaces based on an image-based collision detection algorithm. The results show that the method can efficiently generate high quality lifting paths in complex environments.

Contents

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1. Introduction

Heavy lift planning is an important job in industrial plants. To lift large and heavy targets, capacities of cranes can reach up to thousand tons. Lifting operations, however, work with potential accidents. The OSHA database [1] till year 2013 reported a total 3135 crane related accidents in USA. Many of them caused human death. Lifting safety is thus of utmost importance. Cost reduction is another major concern in the lifting industry. According to a rental rate survey conducted by Cranes & Access in 2011 [2], the average daily rental of a terrain crane with a capacity of 350 tons can cost almost US$ 8400. Electric power and fuel consumptions also take up a significant portion of the cost in lifting operations. For instance, the power consumption of the terrain crane LTM 1200 from Liebherr is 370 kW per hour [3]. Therefore, optimizing the time and energy cost in crane usage is highly desired. Besides, manpower cost is increasingly becoming a critical factor in lifting. The lifting path planning involves a complicated and sophisticated decision making process conducted by a lifting team. The team consists typically of one lifting supervisor or manager, one engineer, one crane operator, one or more signalmen and riggers. Currently, lifting path planning is mostly done by manual exercise which can be error-prone and very time-consuming. Even with an experienced lifting team, it easily takes a few weeks to complete the entire planning procedure.

Heavy lift planning involves multiple phases typically including crane selection, crane location determination, and lifting path planning. For lifting projects with multiple lifts, the planning may involve scheduling taking into consideration the interference among multiple cranes. If the plant contains dynamic objects, the planning also requires replanning mechanisms to alter the lifting path according to the changed environment. There are different types of commonly used cranes: tower cranes, terrain cranes, crawler cranes and so on. Among them, tower cranes have the least number of Degrees of Freedom (DOFs) and crawler cranes have most DOFs (up to 7). This paper focuses on the lifting path planning problem for terrain cranes with the assumption that scheduling, crane selection, crane locating and feasibility checking are readily available. Our objective is to develop an automatic lifting path planning system being able to output optimized lifting paths in near real-time and thus improve the safety and efficiency of heavy lifting in complex environments such as petrochemical and pharmaceutical plants, and construction sites.

1.1. Computer-aided lift planning

The complexity and hazards of lifting operations inspire the development of computer-aided lift planning methods making use of computer simulations and computations to assist the lift planning process. Early efforts focused on the use of simulation based systems to assist interactive lift planning. These systems helped in automated mechanical checking, safety monitoring and evaluations for interactive lifting paths. Hornaday et al. [4] proposed their conceptual design of the HeLPS simulation system. Lin and Haas [5] continued the work and designed a system being able to perform initial setup planning for cranes and performance measurements for user defined paths. Varghese et al. [6] extended the HeLPS system by monitoring safety factors during interactions. Chadalavada and Varghese [7] developed a plug-in approach for the Autodesk Inventor with their CLPS simulation system. Their solution approach was made up of plant modeling, interactive manipulation and comprehensive safety monitoring.

Sub-problems of lift planning such as crane selection, feasibility checking and crane layout have also been addressed by other researches. Olearczyk et al. [8] discussed the crane selection and locating problem concerning lifting capacities and clearances. The crane location determination problem was solved by optimizing weighted distances from crane locations to pick and place locations of the lifting targets constrained by clearances of tail swing, boom and outriggers. Safouhi et al. [9] and Lei et al. [10,11] dealt with the crane location determination problem using geometric analysis on 2D CAD drawings. In particular, Lei et al. [10] also proposed a method for feasibility checking of multiple lifting cases. The method mapped the pick and place areas into the configuration space (C-space) of the crane and checks the mapped areas with the obstacle regions (C-obstacle). Lei et al. [11] discussed the scenarios where pick and place locations are overly separated and thus a crawler crane is required to walk (or crawl) towards the place location. Similar to Safouhi's idea [9], The method dilated the obstacle regions by the size of the lifting target and the tail-swing radius of the crane. Lei's method was able to provide walking paths of crawler cranes as 2D lines without interference with the dilated obstacles. Sometimes, multiple cranes are required to work together. The algorithm by [12] addressed the multiple tower crane layout problem in construction sites. A hybrid particle bee algorithm was applied to solve the layout problem and better results were reported compared with other types of algorithms.

So far, in all previous studies and existing systems, automatic lifting path planning is attempted mostly at theoretical level with rare implementation reported for practical uses. This is partially because the problem itself is very challenging due to the complexity of plant environments and cranes. The three major concerns of lifting path planning are efficiency, solution quality and success rate. The existing methods used combinations of different search algorithms and collision detection strategies to fulfill the above mentioned criteria. The first class of methods utilized global optimum search algorithms together with C-spaces with precomputed collision information to achieve high solution quality. Sivakumar et al. [13] considered the simplified representation of cranes as planar kinematic chains with two rotational DOFs. Simple Genetic Algorithm (SGA) was performed on the 2D C-space where precomputed collision results were factored in the fitness function as violation penalties. Ali et al. [14] designed a two-stage fitness function and used parameter-based reproduction operators for the Genetic Algorithm (GA) search in a 3D C-space. Both of the GA-based methods were able to achieve highly optimized solutions. However, these methods were computationally forbidding due to the computational intensive nature of GA. Ali's method also suffered from the high computational cost for generating the 3D C-space. As a result, the methods only managed to deal with simple CAD plants. The second class of methods also relied on precomputed collision information. Instead of using the global optimization algorithms, this class of methods use fast search algorithms for finding good but not necessarily optimized collision-free lifting paths. The method by Reddy and Varghese [15] represented cranes as linked rigid bodies with three DOFs (swinging, luffing and hoisting). Heuristic depth first search was performed in the free space. Given a simple CAD plant environment, their planner was able to achieve good solutions as arrays of independent configurations. The algorithm, however, still required the substantial time and memory to generate the 3D free space.