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Multi-objective hybrid algorithms for layout optimization in multi-robot cellular manufacturing systems

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ABSTRACT

Hybrid evolutionary algorithms to optimize layouts for multi-robot cellular manufacturing systems, which includes cooperative tasks among the robots is proposed in this paper. Layout area, operation time and manipulability of robot are the three design criteria useful to evaluate the robotic assembly systems are presented. Layout design candidates are represented using a sequence-pair scheme to prevent interferences between assembly system components, and the introduction of dummy components is proposed to represent layout areas where components are sparse. The main objective of this paper is to propose and evaluate hybrid algorithms by hybridizing them with genetic algorithm, which has been in use for decades. Differential evolution (DE), artificial bee colony (ABC), charged system search (CSS) and particle swarm optimization (PSO) are hybridized with genetic algorithm to have four hybrid (GA+DE, GA+ABC, GA+CSS and GA+PSO) algorithms. The performances of these algorithms are tested with genetic algorithm reported in the literature. The concept of non-dominated sorting genetic algorithm (NSGA-II) is borrowed to handle multiple objectives and to obtain Pareto solutions for the problems considered. These hybrid algorithms are evaluated using an example design problem of multi-robotic assembly system, and the effectiveness of these algorithms are presented in this paper. It is found that GA+PSO performs better over other hybrid algorithms considered. The application of the proposed algorithms are tested using Mitsubishi RV-6SQ robot configuration.

1. Introduction

In recent years, several researchers began investigating issues in multiple mobile robot systems. The field of cooperative autonomous mobile robotics is still new and this domain is not matured enough. Researchers working in this field are beginning to understand how to develop and control certain aspects of multi-robot systems [1]. The capabilities of Multi-robot systems are high when compared to single robot systems. But, there will be an increase in complexity of the control system to manage. A centralized control system which coordinates multiple robots may be very complex. When the robots do not share information, there is no need for any mechanism to update the global information; robots can be easily added to the system. The independent operation of individual robots can lead to increased flexibility and robustness since the addition of robots can be easily achieved without any need for changing software or hardware as more robots are added. However, optimal control cannot be achieved due to the lack of information [2].

Arai, et al. [1] identified the following seven principal topic areas of research in multi-robot systems:

- Biological Inspirations;
- Communication;
- Architectures, task allocation, and control;
- Localization, mapping, and exploration;
- Object transport and manipulation;
- Motion coordination; and
- Reconfigurable robots.

Object transport and manipulation are the key tasks occur in robotic assembly systems. These systems are also called as robotic cellular manufacturing system [18]. Enabling multiple robots to cooperatively carry, push, or manipulate common objects has been a long-standing, yet difficult, goal of multi-robot systems. Many research projects have dealt with this topic area; fewer of these projects have been demonstrated on physical robot systems. This research area has a number of practical applications that make it of particular interest for study [1].

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Robots are widely applied in automated cellular manufacturing systems to transfer parts between stations, which are called as robotic cellular manufacturing systems (RCMS). RCMS are a type of manufacturing system in which one or more flexible robots carry out a large number of assembly operations that would be performed by human workers in conventional cellular manufacturing systems. When compared with conventional human cellular manufacturing systems, RCMS are seen to offer advantages, such as reduction of material flow distances and local inventory. However, although reduced operation costs due to automation of the manufacturing systems can be achieved by introducing RCMS, the design of assembly operations and robot teaching can become quite complex and time-consuming when launching new manufacturing systems. The layout design stage is one of the most important stages when seeking to build efficient RCMS. The layout design stage is an upstream stage of the manufacturing system design process, and decisions made then exert considerable influence on the detailed design of robot motion planning and the teaching process. Therefore, skillful decision-making during the layout design stage is essential to minimize design changes during the detailed design stage and teaching process, and to enhance the efficiency and reliability of the manufacturing systems when deployed [18].

The motivation of this paper is to propose multi-objective hybrid evolutionary algorithms to generate layouts for a multi-robot environment where assembly tasks are performed. In present day context robots are very much used in assembly systems for part transfer from storage to assembly stations and also between assembly stations.

This paper is organized as follows: Section 2 presents the literature review, the performance measures used to evaluate the layouts are discussed in Section 3, the implementation of sequence-pair representation scheme to generate layouts is explained in Section 4, the hybrid evolutionary algorithms proposed are presented in Section 5, Section 6 presents the conclusion and future research directions.

2. Literature review

Numerous research has been reported on object transport and manipulation in a multi-robot environment. Layout design is one of the most important decision-making problem in the object orientation and transportation domain. This section is focusing on the literature related to layout optimization in RCMS.

Layout design is the process in which industrial robots and other manufacturing system components are allocated at specific positions so that the assembly tasks can be handled appropriately. Barral et al. [3] developed a tool for optimizing assembly workcell layout using simulated annealing algorithm. This method yields several possible and optimal positions for a machine, and several layouts are thus obtained at the end of execution. Tay and Ngoi [44] proposed a heuristic algorithm to optimize the layout of a robot workcell. These methods require explicit constraint handling regarding component overlapping, since component coordinates are handled as design variables, and this implementation obstructs global searching of the solution space.

Layout problems have raised important issues in many research fields, such as printed circuit board problems [39] and facility layout problems [10,13], and effective optimization methods which can avoid the handling of overlapping constraints have been reported [5,6,23].

These methods have limitations, such as the degradation of solutions when resolving overlapping stations, while mixed-integer formulation approaches [15,33,37] can be used for small-scale problems. Sequence-pair representation can avoid overlaps among stations and allow the manipulation of various sizes of rectangles representing the stations [31]. Several researchers reported that this representation enables very effective layout optimization in packing-type problems [9] and facility layout problems [26,28].

Izui et al. [18] proposed a genetic algorithm based layout optimization method with sequence-pair representation for RCMS. Lim et al. [25] used five nature inspired algorithms to optimize robot workcell layouts. Multiple objectives are to be optimized in layout design problems [12,38].

Part transfer operations in RCMS have been widely used in many automated assembly systems. An efficient manufacturing system requires layout design and task allocation should be done concurrently [35]. Suemitsu et al. [42] proposed a multiobjective layout design optimization technique using genetic algorithm for robotic cellular manufacturing system layouts that can simultaneously determine the positions of manufacturing components and also task scheduling.

Metaheuristic approaches in solving facility layout problems, such as genetic algorithms [26,40], simulated annealing [36] and swarm intelligence algorithms [46,47], is getting more popular. To date, very few researches reported on the design of layouts with simultaneous optimization of layout and task schedule in RCMS with multiple robots. Moreover, so far no literature reported on the use of hybrid metaheuristic algorithms to solve this problem. This research deals with the development of four hybrid metaheuristic algorithms to generate layouts for a part transfer function in a RCMS with multiple robots.

Differential evolution (DE), modified artificial bee colony (MABC), charged system search (CSS) and particle swarm optimization (PSO) are hybridized with genetic algorithm to have four hybrid (GA+DE, GA+MABC, GA+CSS and GA+PSO) algorithms to optimize the layout design. The efficiency of these methods is evaluated by comparing with an existing method which is based on genetic algorithm. The main difference between RCMS layout problems and conventional packing-type or general facility layout problems is that optimal spacing among distributed components is extremely important in RCMS problems. This paper uses sequence-pair representation and a dummy component approach to provide appropriate spacing among the robots and other components.

3. Layout optimization in multi-robot cellular manufacturing systems

This paper focused on the RCMS where multiple robots are employed to perform parts transferring and assembly operations and the aim is to achieve a minimize layout area without compromising the performance of assembly robot based on operation time and manipulability. There are four main components in the RCMS. The components are assembly robot, assembly table, part boxes and dummy blocks. The assembly robot used to illustrate the problem is Mitsubishi RV-6SQ [18]. The parameters of this robot is used to conduct the experiments.

3.1. Problem environment

In an assembly line, a robot needs to pick a part from a location where many parts are piled up and laid randomly. In order to complete an assembly task the robot will need to change the orientation of the part first. However, it is a difficult task for a single robot to change the part orientation because a robot can only do gripping motion. Therefore, multiple robots are needed. For example, the first robot picks up a part and passes it to the second robot, during the first transferring point; the part orientation is adjusted accordingly. Once it is done, the second robot transfers it to the final robot to complete the assembly task. The overall idea is illustrated in Fig. 1. The transferring point is assumed to be the midpoint between two assembly robots. The details of assembly robot used in this paper are explained in Fig. 2.