論文の内容の要旨

Configuration Design of Manipulator System for Multiple-Goal Tasks Considering Multiple Criteria
（複数基準を考慮した多点到達作業を遂行するマニピュレータシステムのコンフィグレーション設計）

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Multiple-goal tasks exist widely in manufacturing, such as inspection, spot welding, and pick-and-place task. In such task, the end-effector of manipulator has to reach several goals, which are defined by the position and orientation in some workspace coordinate system. The manipulator stops at each goal, while its end-effector performs some operation on the operation point. For some tasks, the position and orientation of goal are uncertain since the operation points are given following some probability distribution. Configuration design of manipulator system that includes selection of manipulator system, layout design, and motion planning is commonly used to improve the efficiency of manipulator system for a multiple-goal task realization. Selection of manipulator system is to choose the appropriate manipulator system from a set of existing manipulator systems or combinations of pre-defined manipulator system components (e.g., joint module and link module). Layout design is to optimize the robot base placement and motion planning is to search for the motion path among goals and minimize the path length with collision-free. Task completion efficiency and cost are two important performance indices in configuration design of manipulator system for a multiple-goal task, since they represent the productivity and profitability, respectively. By evaluating these two criteria, Pareto solutions of manipulator systems can be obtained. The user can select the appropriate manipulator system with appropriate layout and motion path easier from such Pareto solutions. Previously, various techniques and algorithms have been proposed for the selection of manipulator system, layout design, and motion planning. However, the configuration design of manipulator system for a multiple-goal task by evaluating task completion efficiency and cost simultaneously has not been thoroughly studied. The objective of this study is to realize the configuration design of manipulator system for a multiple-goal task by evaluating the task completion efficiency and cost.

In order to achieve the purpose of this study, two key themes must be solved: (1) configuration design of manipulator system, and (2) robust optimization against uncertainty of goal. It is difficult to solve these two themes due to complex problem hierarchy and uncertainty of goal. In this study, we aim to propose methods to solve these two themes.

In the configuration design of manipulator system, an inspection task is taken as the sample task (Chapter 3). The manipulator systems consist of a 6-DOFs manipulator and 1-DOF positioning table are selected to complete the task, as shown in Figure 1. Two performance indices are considered, i.e., the task completion time and cost. The specifications of a given task and candidate manipulator system, such as the number of goals and the D-H parameters of manipulator, are set as input parameters. The manipulator system type with structural configuration, location of positioning table, and the kinestate of manipulator system are set as the design variables. An approach that integrates 3 loops: system selection, layout design, and motion planning is proposed to solve this problem based on the analysis of problem hierarchy. To obtain the Pareto solutions of manipulator systems within a reasonable amount of computational time, the system selection is set as the outer loop, and involves the structural configuration design (connective relationship among manipulator system components). Multiple objective particle swarm optimization (MOPSO) is used to search for the appropriate manipulator system with structural configuration without evaluating all systems. Layout design is set as the intermediate loop, which uses the particle swarm optimization (PSO) to search for the location of positioning table. MOPSO and PSO are used in system selection and layout design because they can converge to good solutions faster by comparing to the similar population-based algorithms: multi-objective genetic algorithm and genetic algorithm. Motion planning is set as the inner loop, which uses nearest neighborhood algorithm (NNA) to coordinate the motion of manipulator and positioning table since NNA can converge to a good solution with low computational time. The relative cost is used to calculate the cost of manipulator system based on the specifications of manipulator system. An evaluation method based on the retrieval performance evaluation (F value) is utilized to evaluate the obtained Pareto solutions. The proposed method is proved to be effective by comparing to three methods that involves a random search algorithm for 5 tasks through a simulation. The tasks are different from the size of object and the number of inspection points. The simulation is conducted 5 times for each task. The F value derived by using the proposed method is improved on average by 72.4% relative to the worst results that derived by the other methods in this simulation. The configuration design of manipulator system can be realized for the inspection task by the proposed method. The Pareto solutions of manipulator systems with appropriate layout and motion path are obtained.

In the robust optimization against uncertainty of goal, a pick-and-place task is taken as the sample task (Chapter 4). The manipulator systems consist of multiple manipulators and a moving conveyor are selected to complete the task, as shown in Figure 2. The part flow is considered as the performance index. The combination of part dispatching rule is set as the design variables to coordinate the actions of multiple manipulators. In the pick-and-place task, the position and orientation of goal is uncertain since the parts on the conveyor are fed following some probability distribution. The fed parts can be considered to distribute on a hypothetic conveyor following some probability distribution and the hypothetic conveyor can be divided into many small areas with the same number of parts. The parts distribute in each small area follow the same probability distribution with various random seeds. To obtain the reliable solution, the robust part flow and combination of part dispatching rules against the uncertainty of goal should be taken into account. The robust solution means that, against any random seed for the probability distribution in the small area of hypothetic conveyor, the picking rate derived by the combination of part dispatching rules with the part flow can satisfy the picking rate constraint. In other words, the maximum minimum-maximal part flow with optimal combination of part dispatching rules should be obtained against the uncertainty of goal. To obtain a robust solution efficiently, an approach that integrates the greedy randomized adaptive search procedure (GRASP) with the Monte Carlo Strategy (MCS) is proposed to solve the problem considering part dispatching rules. The GRASP is utilized to search for the optimal or near-optimal combination of part dispatching rules from a set of rules since it has high converge speed and is ease implementation. The MCS is used to estimate the minimum-maximal part flow for one combination of part dispatching rules. When using MCS to estimate the minimum-maximal part flow, the question arises how to estimate minimum-maximal part flow based on the samples (the small area of hypothetic conveyor that is used to estimate minimum-maximal part flow) and what kind of raw data (i.e., how many samples and how many parts should be in one sample) should be used. The part flow derived by each sample is assumed to follow the Normal Distribution. The confidence interval estimator is used to estimate the mean and deviation of part flow for one combination of part dispatching rules. The minimum-maximal part flow is calculated by using minimal estimated mean subtract 3 maximal standard deviation. The sample size and number of parts are determined based on the width of confidence interval for mean and standard deviation of part flow. The proposed method is verified to be effective by comparing to two methods through simulations. The part dispatching rule of first-in first-out (FIFO) is used to control the last robot in the multi-robot system to pick up parts left by other robots, while the part dispatching rule of shortest processing time (SPT) is used to make the other robots pick up as many parts as possible. Such coordination can make the multi-robot system in a pick-and-place task perform efficiently. The task completion success ratio derived by the proposed method can reach almost 99.5% for a task which consists of 10,000 small areas of hypothetical conveyor with various random seeds. The task completion ratio is improved by 73.3% and 19.6% relative to that derived by GRASP (only use GRASP to search for the combination of part dispatching rules) and GRASP+GA (use GRASP to search for the combination of part dispatching rules and use genetic algorithm to calculate minimum-maximal part flow), respectively. Simulation results show that the proposed method is effective and the solution obtained by the proposed method is robust against uncertainty of goal.

The proposed methods for configuration design of manipulator system and robust optimization against uncertainty of goal are discussed. The applicability of the proposed method is analyzed and discussed.

In this research, the configuration design of manipulator system was realized for an inspection task. Pareto solutions of manipulator systems were obtained by evaluating task completion efficiency and cost.

The optimal combination of part dispatching rules and maximum minimum-maximal part flow were obtained against the uncertainty of goal in a pick-and-place task. The proposed methods are effective in configuration design of manipulator system for a multiple-goal task and robust optimization against uncertainty of goal.

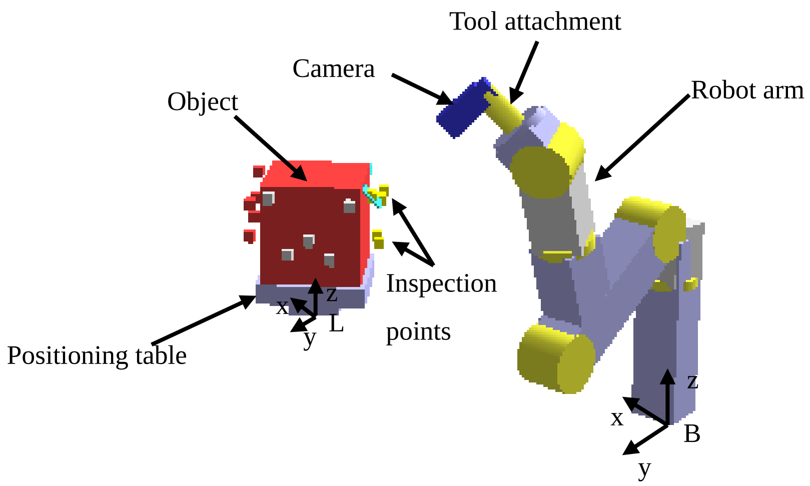

Figure 1 A manipulator system consists of a robot arm, a positioning table, an object, a camera, and a tool attachment. B is the base of the robot arm; L is the base of the positioning table.

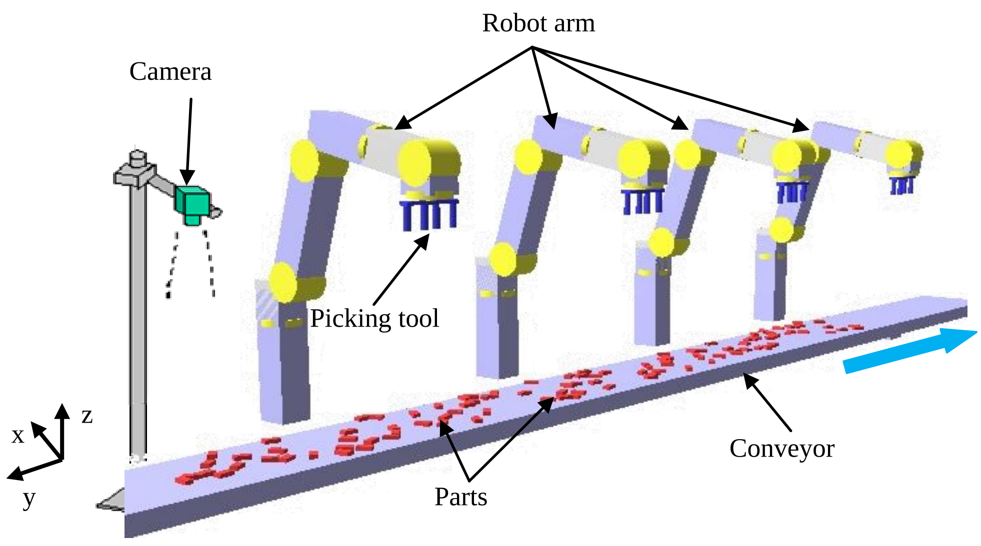

Figure 2 A multi-robot conveyor system that consists of multiple robot arms and a moving conveyor.