Applied Soft Computing 9 (2009) 159–172

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Evolutionary multi criteria design optimization of robot grippers

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ARTICLE INFO

Article history:
Received 29 September 2006
Received in revised form 28 March 2008
Accepted 1 April 2008
Available online 8 April 2008

Keywords:
Robotics
Optimal gripper design
Evolutionary computing
Multicriterion optimization
MOGA
NSGA-II
MODE

ABSTRACT

This paper explores the use of intelligent techniques to obtain optimum geometrical dimensions of a robot gripper. The optimization problem considered is a non-linear, complex, multi-constraint and multicriterion one. Three robot gripper configurations are optimized. The aim is to find Pareto optimal front for a problem that has five objective functions, nine constraints and seven variables. The problem is divided into three cases. Case 1 has first two objective functions, the case 2 considers last three objective functions and case 3 deals all the five objective functions. Intelligent optimization algorithms namely Multi-objective Genetic Algorithm (MOGA), Elitist Non-dominated Sorting Genetic Algorithm (NSGA-II) and Multi-objective Differential Evolution (MODE) are proposed to solve the problem. Normalized weighting objective functions method is used to select the best optimal solution from Pareto optimal front. Two multi-objective performance measures (solution spread measure (SSM) and ratio of non-dominated individuals (RNIs)) are used to evaluate the strength of the Pareto optimal fronts. Two more multi-objective performance measures namely optimizer overhead (OO) and algorithm effort are used to find the computational effort of MOGA, NSGA-II and MODE algorithms. The Pareto optimal fronts and results obtained from various techniques are compared and analyzed.

1. Introduction

Many real-world problems involve two types of difficulties namely (i) multiple, conflicting objectives and (ii) a highly complex search space. Instead of a single optimal solution, competing goals of real-world problems give rise to a set of compromise solutions generally called as Pareto optimal. In the absence of preference information, none of the corresponding trade-offs could be said to be better than those of others. Also the search space can be too large and too complex to be solved by exact methods. Thus, efficient optimization strategies that are able to deal with both the difficulties are required. Evolutionary algorithms (EAs) that possess several characteristics are desirable for this kind of problem and are preferable to classical optimization methods. Moreover, evolutionary multi-objective optimization has established itself as a separate sub-discipline combining the fields of evolutionary computation and classical multiple criteria decision-making. Solution to any multi-objective optimization problem is a family of points known as non-dominated solutions or Pareto optimal set, where each objective component of any point along the Pareto optimal front can only be improved by degrading at least one of its other objective functions. Pareto optimal front is a curve that joins all Pareto optimal set points. If all objective functions of a solution cannot be improved simultaneously, then that solution is said to have non-domination character.

Evolutionary techniques for multi-objective optimization are currently gaining significant attention of researchers in various fields due to their effectiveness and robustness in searching for a set of trade-off solutions. Unlike conventional methods that aggregate multiple attributes to form a composite scalar objective function, EAs with modified reproduction schemes for multi-objective optimization are capable of treating each objective component separately and lead the search in discovering the global Pareto optimal front. The advantages of using population-based search techniques for multi-objective optimization problems are as follows: (1) Population-based search techniques (e.g., EAs) give multi-directional search. They deal simultaneously with a set of possible solutions (the so-called population). This allows us to find several possible solutions in a single run of the algorithm, instead of performing a series of separate runs as in the case of the traditional mathematical programming techniques. (2) They optimize all the objectives simultaneously and generate a set of alternative solutions that offer more flexibility to decision makers.

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doi:10.1016/j.asoc.2008.04.001

The simultaneous optimization can fit nicely with population-based approaches such as EAs, because they generate multiple solutions in a single run. (3) They converge quickly and give more number of Pareto optimal solutions. (4) They improve computational efficiency. (5) They could achieve significant computational speed-ups, because their running time is very short.

Grippers play an important role in automation systems. They are the interface between the workpiece and the whole automation system which realizes a certain production process. Mostly a gripper design is a special and unique solution for handling task of a given workpiece. Therefore the component "gripper" has a high impact on economical aspects, when flexible automation systems are needed. The two-finger grasp is extensively used both for human and industrial grip, since it may be considered the simplest efficient grasping configuration. Most of the gripping systems that are installed in industrial automations and robots are mechanical two-finger grippers. They are used both for manipulation and assembling purposes since most of these tasks can be performed with a two-finger grasp configuration. A gripper can be considered as a critical component of automated manipulations since it interacts with the environment and particularly with the piece to be machined or manipulated so that the gripper greatly contributes to a practical success of using an automated or robotized solution. Therefore, a good design of a gripper may be of fundamental importance. The design of a gripper must take into account several aspects of the components and the system together with the peculiarities of given application or multi-task purpose. Strong constraints for the gripping system can be lightness, small dimensions, rigidity, multi-task capability, simplicity and lack of maintenance. These design characteristics can be achieved by considering specific end-effectors or grippers.

Several research projects exist in these industrial-gripping systems. Researchers are working on the imitation of the flexibility of the human hand. Karlsruher Hand developed by Osswald [1], the IFASHand developed at RWTH Aachen and the DLR-Hand developed by Butterfass et al. [2] are the best examples of them.

Zhu et al. [3] discussed about a novel special robot gripper for Chinese on-orbit satellite serving. Cesare Stefanini et al. [4] developed a new miniature gripper design suitable for endoscopic surgery and similar applications. Manley et al. [5] designed a custom gripper with stainless steal two-fingers parallel actuator for a fully automated robotic system. It was developed and deployed in-house in a modular way to meet the needs of a high throughput chemistry laboratory. Zhong et al. [6,7] designed and fabricated a gripper actuated by shape-memory-alloy (SMA) wire.

Pham and Gourashi [8] developed knowledge-based systems (KBSs) to conceptual design of robot gripper design. The problem of estimating the minimum forces extracted by robot fingers on the surface of a grasped rigid object is very crucial to guarantee the stability of grip without causing defect or damage to the grasped object. Solving this problem is investigated using Ants Colony Optimization algorithm by Abu Zitar [9]. Abu Zitar et al. [10] presented an evolutionary programming (EP)-based solution for the nonlinear frictional gripper problem. Ramesh Kolluru et al. [11] discussed about the design and modeling fundamentals of a multi-degree-of-freedom reconfigurable robotic gripper system (RGS) designed to automate the process of limp material handling reliably and without distortion, deformation and/or folding. To solve the problem of designing a gripper for a huge variety of workpieces, the use of CAD software is helpful [12]. This software should detect possible gripping points on different CAD workpieces. The goal is to find similar gripping areas on different workpieces, so that a gripper can be designed with the least amount of adjusting mechanisms or, if possible no moving parts. Zhang and Goldberg [13] described an Internet-based CAD tool that automatically designs gripper jaws that rotate a given rigid convex polygonal part from a selected stable orientation to a desired final orientation to facilitate insertion or assembly. Yan et al. [14] proposed a method to estimate wrist force/torque for robots. The method adopts the data fusion technique according to the output variations of the finger force sensors installed in the gripper. The finger force sensors are used to measure the clamping force of the gripper in the design. Al-Gallaf [15] presented a novel neural network for dexterous hand-grasping inverse kinematics mapping used in force optimization. The optimal grasping force is found out by the neural network.

According to aimed optimum objective functions (depend on applications and workpiece dimensions), optimum gripper dimensions have been found out using genetic algorithm (Andrzej Osyczka et al. [16]). The same work has been carried out using genetic algorithm with fuzzy rules by Rajan Filomeno Coelho [17].

The limitations of the works of Andrzej Osyczka et al. [16] and Rajan Filomeno Coelho [17] are as follows: (1) their algorithms do not treat all objective functions simultaneously, (2) the method used by them cannot be directly used for treating multi-objectives. As they are simple techniques, they need some modifications in their mechanism to treat multi-objectives simultaneously and (3) they give only one optimal solution. But for a real-world problem, a Pareto optimal front that offers more number of optimal solutions for user's choice is most desirable.

The new things in our paper are as follows:

1. To overcome limitations of the works of Andrzej Osyczka et al. [16] and Rajan Filomeno Coelho [17], this paper presents the optimization procedures based on three evolutionary techniques (Multi-objective Genetic Algorithm (MOGA), Elitist Non-dominated Sorting Genetic Algorithm (NSGA-II) and Multi-objective Differential Evolution (MODE)) to optimize three gripper configurations. The evolutionary algorithms MOGA, NSGA-II and MODE are proposed in multi-objective approach. They handle all objective functions simultaneously. Also the proposed evolutionary algorithms MOGA and MODE are having modified reproduction schemes to handle all objective functions simultaneously.
2. For the first robot configuration, an improved optimization model (one new objective function and two new constraints (fuzzy rules) are added with existing optimization model) is used. For the other two robot configurations, new optimization models are formed and used. Also the second and third robot configurations are specially discussed in this paper.
3. Finding a minimum combined objective function, which has five objective functions, nine constraints and seven variables is taken as the problem. The difference between maximum and minimum griping forces, force transmission ratio between the gripper actuator and gripper ends, the shift transmission ratio between the gripper actuator and the gripper ends, the length of all the elements of the gripper and the effect of the gripper mechanism are the objective functions considered.
4. The problem is divided into three cases. The combined objective function in case 1 has the first two objective functions. The combined objective function in the case 2 comprises the last three objective functions. All the five objective functions are considered in the case 3.
5. A comprehensive user-friendly general-purpose software package to obtain the optimal parameters using the proposed MODE algorithm is developed using VC++. Using this software we can solve any type of design optimization problem in any field.
6. The proposed optimization methods have following advantages: (1) they may give global optimal solution, (2) they consider all the important decision criteria for the optimum design of robot grippers, (3) they are easier to program and implement