INVESTIGATION INTO OPTIMAL FIXTURING COST OF AN ASSEMBLY USING GENETIC ALGORITHM

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Abstract:

Due to the rapid response required in many manufacturing companies, the fixture design principles must be integrated and properly detailed so as to facilitate the fast design development of an optimization methods and various approaches used in fixture design problems are discussed in this paper. Then an Overview of applications of evolutionary algorithms to different domains of fixture design problems is given. The paper presents here the main features of genetic algorithm and its application in defining the cost of an assembly fixture design.

1 Introduction

Fixtures are devices used to locate and hold work pieces in manufacturing operations. Fixture design is also a part of manufacturing process verification, in which fixture performance contributes to the performance of manufacturing processes significantly, in reference to both quality assurance and process stability, also the ease of process operation contributes to the efficiency of production cycle time and operation ergonomics. Fixture Location means the establishment of relationship between the workpiece and fixture. The overall accuracy depends on the accuracy with which the workpiece is located within the fixture. Fixturing cost plays a major role in any production system. The cost and lead time should not be ignored because they take up a greater percentage in a production system. Engineering design is an iterative process that seeks the best possible design at minimum expense. The evolutionary techniques are parallel and globally robust optimization methods. In general, all recursive approaches based on population that use selection and random variation to generate new solutions can be seen as evolutionary techniques. Indeed, the study of nonlinear problems using mathematical programming methods that can effectively handle global optimization problems is of considerable interest. Genetic Algorithms is one such method which has been a subject of discussion by [1-5]. Design optimization is a mathematical technique that seeks to determine the best possible design based on criteria set by the design engineer.

We may define the problem mathematically as

Objective min f(x1,x2, ...,xn)
subject to
Constraints g1(x1,x2,..,xm) > a
g2(x1,x2,...,xk) < b
g3(x1,x3,...,xl) = c

2 Literature review

Various fixture design methods have been suggested in the literature. Some hybrid techniques have also been used by researchers. This review is categorized in three major classes.

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2.1 Fixture design methods

Jeng and Gill [6] formulated a fixture design problem in a hierarchical design structure. Hunter et al. [7] presented a functional design approach in which the functional requirements and constraints are considered as an input to the fixture design process. Hui Wang and Rong [8] presented the case based on a reasoning method to provide a computer aided fixture design solution.

2.2 Fixture setup and planning

Bai, Y. and Rong, Y. [9] developed the geometric analysis technique with a modular fixture assembly to present the fundamental study of automated fixture planning. Kang and peng [10] developed a Web-based fixture assembly planning system. The fixture assembly sequence based on geometry reasoning is automatically generated.

2.3 Fixture verification and analysis

Song and Rong [11] presented a methodology to evaluate the locating scheme and assist the fixture designer to analyze and improve the designed scheme. The analysis with a finite element model is the most comprehensive method for predicting the deformation of the workpiece-fixture system, although the complex modeling and high computational cost are usually criticized by some researchers. Most of the work of deformation analysis is concerned with the effect of deformation under the clamping and cutting forces, which plays an important role in determining the accuracy of the fixture system. The main aim of the synthesis of fixture layout design is to find an optimal scheme for locators, supports and clamps. Currently, numerous approaches regarding fixture synthesis reported. Besides, a number of techniques have been developed to meet the requirement for force closure synthesis in fixture layout design or grasp configuration [4] and [12-14]. Marin and Ferreria [15] presented the necessary and sufficient conditions for the deterministic location of 3-2-1 locator schemes. Many researchers turned the fixture synthesis problems into optimization problems with some different kind of criteria, and used linear or nonlinear programming approaches to solve the optimization problem. To support the fixture design, Demeter [16] presented a fast support layout optimization (FSLO) model with a finite element analysis to dealing with the optimization problem of minimizing the maximum displacement-to-tolerance ratio of a set of workpiece features subjected to a system of machine loads. As an approach to the synthesis of the locator scheme, Menassa et.al [17] used six rules based on machining practices required for selecting the secondary and tertiary locating datum for prismatic workpiece.

2.4 Optimization methods

Optimization of fixture synthesis has been used for a better locating layout and clamp placement. Global optimization techniques help to get better solutions than local optimization ones. Wang et al. [18] presented a mathematical global optimization approach used for the locator layout and clamping placement according to the fixturing accuracy, repeatability, immobility and stability. The locator layout, clamping position, and clamping force were optimized. Over the past decades, much attention has been paid to researches and applications of fixture design .Nee et.al [19] Singapore, employs artificial-intelligence (AI) and computer aided design (CAD) concepts to develop computer-aided fixture design with a human interface. Techniques such as database management, intuitive design rules and computer graphic display are applied to assist fixture-design engineers in creating, retrieving or updating a fixture-component selection, location and assembly. This is not a completely automated fixture-design system, although computer technology could be a great help to manual fixture design. Some other computer-aided or computer-graphics-oriented fixture-design tools have been developed by applying existing CAD/CAM technology. Because the use of CAD/CAM for fixture design and fabrication can be viewed as a special case of computer-aided part design and manufacturing, the details of computer-aided fixture design and fabrication are not further discussed here. Fields et al. and Youcef-Toumi et al. [20] at MIT specifically deal with a fixturing system for "sheet-metal drilling operations”. A set of fixture components are designed for easy robot grasping motions and its assembling. The reconfigurable fixturing system is developed using an integrated CAD/CAM system. Most of the work on fixturing can be divided into two categories: fixture analysis and fixture synthesis, and our work falls into the second one. The problem of fixture analysis is to determine the performance of a given workpiece-fixture system to verify whether the fixture configuration satisfies the design requirements, for example, force closure. On the other hand, fixture synthesis requires determining a fixturing layout to meet a given set of performance requirements. Usually, fixture analysis can be classified into four levels, namely geometric, kinematic, force, and deformation [21], which have been extensively studied in [13], [15] and [22-28]. The four levels refer to checking the interference, deterministic positioning or total restraint (force closure), the equilibrium conditions and the deformation performance respectively. Chou et al. [29] used the classic screw theory to analyze the deterministic localization of the workpiece and the total constraint of the fixture. Asada et.al [22] proposed a different approach for the total constraint based on a geometric perturbation technique. On the force and deformation analysis level, many methodologies have been developed based on different models. The rigid body model with or without friction is the most commonly used model in the previous work [30]. A notable limitation of the rigid body model is its inadequacy of dealing with the indeterminate problem arisen in a fixture system. To overcome this problem as well as to analyze the deformation performance, many researchers consider the workpiece- fixture system as an elastic system. There are several formal models for the deformation analysis such as linear spring model, hertz model and the more accurate finite element model. The linear spring and nonlinear hertz contact model are two typically local elastic models popularly adopted by many researchers [25], [26]. In [4]-[5], with the combination of FEM, the genetic algorithm was used for fixture layout design problem. Kaya [3] used the combined GA and FEM to minimize the maximum deformation of the workpiece and integrated FEA into genetic algorithms (GAs) to optimize fixture layout in which deformations were calculated in a commercial finite element solver, ANSYS software, and sent back to GA. Kulankara [4] presented an algorithm for iterative fixture layout and clamping force optimization of a compliant workpiece using GA. Prabhaharan et al. [5] used GA to minimize the dimensional and form errors caused by deformation. The clamping force optimization was not considered in their work. The genetic algorithm is a powerful technique that mimics some mechanisms of natural evolution but with the drawback of a high computational cost. The main advantage, however, of the proposed method is that we use a continuous strategy to solve the discrete optimization problem, thus it's very efficient in comparison with the aforementioned algorithms.

3 Genetic algorithm (GA)

In principle, GA is a search algorithm based on the mechanics of natural selection and natural genetics. They combine the survival of the fittest among the string structures with randomized yet structured information exchange to form a search algorithm with the innovative flair of natural evolution. A GA starts with a random creation of a population of strings and thereafter generates successive population of strings that improve over time. First, we need to define encoding of each optimization parameter into one string over some finite alphabet consisting of GA's building units called **genes**. Usually, binary coding is used, so we have genes that take values of 0 and 1. The Structure consisting of genes that make up all the parameters is called **genotype**. By merging all these genes, we get the string called **chromo-some.**

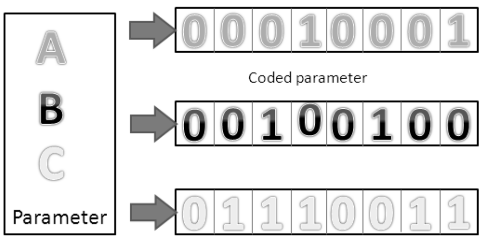

Figure 1. Parameter, genes and chromosomes.

Figure 2. Chromosomes.

Such chromosome represents one point in the search space, that is, an encoded parameter vector.

3.1 Reproduction

It is a process in which individual strings are copied according to their objective function values, 'f' (fitness function), which measures profit, utility or goodness which are to be maximized. Strings with a higher fitness value have a probability of contributing one or more offspring in the next generation. The reproduction operator may be implemented in an algorithmic form in a number of ways such as a roulette wheel selection, rank selection or steady selection and tournament selection. Once a string has been selected for reproduction, an exact replica of the string is made. This string is then entered into the mating pool, a tentative new population for further genetic operator action. The rank selection method is used in the proposed GA.

The objective function for the problem is to obtain an optimum or near-optimal fixture assembly cost based on the minimization of the total fixturing cost of a fixture assembly. The objective function is defined as follows

Minimize

$$T_{FAC} = \Sigma_p \Sigma_{sa} \Sigma_{fa} (a_{p,sa,fa} \text{ x } FAC_{p,sa,fa}) + \Sigma_{fa} \Sigma_{fua} (b_{fa,fua} \text{x} FUC)$$

Where

T_{FAC} - Total fixture assembly cost, P - Parts, sa - Sub assembly, fa - Fixture Assembly, fua - Fixture unit assembly, fsua - Fixture unit sub assembly, FAC - Fixture Assembly cost, FUC - Fixture unit cost, l, m, n – Variables

3.2 Crossover

A simple crossover may proceed in two steps. First, members of newly reproduced strings in the mating pool are mated at random. Second, each part of strings undergoes crossing over as follows: an integer position 'p' along the string is selected uniformly at random between 1 and string length l minus one i.e. (1, l-1). Two new strings are created by swapping all the characters between positions (p+1) and l inclusively.

3.3 Mutation

It is a random alteration of the value of a string position. In binary coding, this means changing a 1 to 0 and vice versa. In GA, its probability of occurrence is generally kept small, as a higher occurrence rate would lead to a loss of important data. GA, with 100% mutation rate becomes random search in the solution space.

Flowchart in Fig. 3 shows the process performed by the proposed GA for finding an optimum solution.

Table 1. The existing cost of fixture assembly from all 3 subassemblies to fixture unit 1

	FA1	FA2	FA3
SA1	10	15	12
SA2	8	7	10
SA3	10	12	13

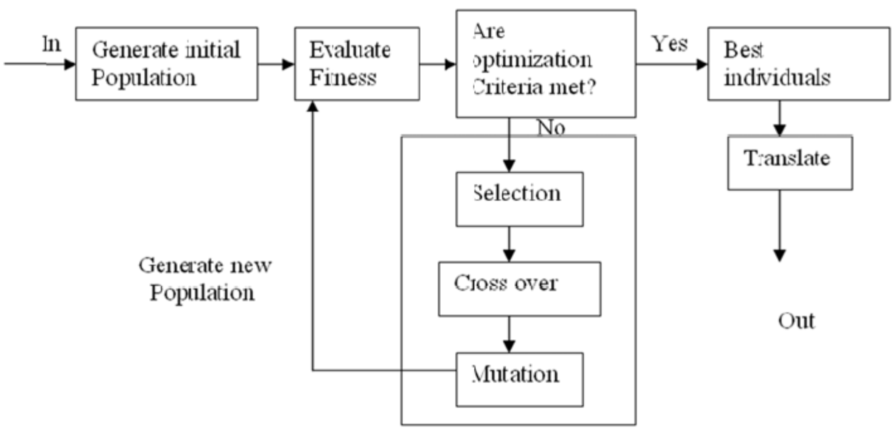

Figure 3. GA procedure.

Table 2. The existing cost of fixture assembly from all 3 subassemblies to fixture unit 2

	FA1	FA2	FA3
SA1	14	18	19
SA2	12	9	6
SA3	15	16	14

Table 3. The 'l' variable Fixture unit1

	FA1	FA2	FA3
SA1	85	70	90
SA2	20	72	20
SA3	22	20	18

Table 4. The 'l' variable Fixture 2

	FA1	FA2	FA3
SA1	30	100	60
SA2	150	130	120
SA3	80	30	72

Table 5. FAC values - The Cost of fixture assembly from all fixture unit assembly to fixture unit subassembly.

	d1	d2	d3
p1	15	14	16
p2	13	14	16

Table 6. m values

	d1	d2	d3
p1	49	55	35
p2	135	60	55

3.4 The optimization procedure using Genetic algorithm

The genetic search process used here is outlined below.

- Step 1: Generate a random initial population of chromosomes of size p.
- Step 2: decode all chromosomes and evaluate the objective function of their corresponding candidate solutions.
- Step 3: if the elitism policy is employed, insert the best chromosomes in to the new generation pool.
- Step 4: choose a pair of parent chromosomes from the current population without replacement, apply the crossover and mutation operators to yield a pair of new chromosomes.
- Step 5: Insert the new chromosomes into the new population. If the new population is smaller than p, return to step4.
- Step 6: If the pre- specified stopping criterion has been met, then stop the search process. Select and decode the overall best chromosome as the final solution. Otherwise, proceed to the next generation and replace the population with the new one, and return to step 2.

MatlabR2008a software is used for genetic algorithm coding and the following expressions are used in main program.

```
Options = gaoptimset;
gaoptimset'CrossoverFraction',1,'MigrationFraction',0.02,
'PopulationSize', 20,...'Generations', 50,
'PlotFcns',{@gaplotbestf,@gaplotbestindiv});
```

3.5 Genetic algorithm parameters

Crossover fraction = 20
Migration fraction = 0.02
Population size = 20
Generation = 50

Based on above GA parameters Fig. 4 shows the best total fixturing cost in the form of convergence graph. Fig. 5 shows the best individual fixture assembly cost.

4 Conclusions

The goal of fast design of machine tool fixtures has been achieved through computer aided design and intelligent optimization techniques. The efficiency and the quality of design have been improved. The Genetic algorithm responds quickly, producing a set of good results. However, the execution time for the GA is longer, because the GA searches for global optimal solutions with more iteration. The proposed methodology can be adapted to fixture design and assembly where computational time is significant.

Table 7. FUC values - The Cost of fixture unit assembly to fixture unit subassembly

	FUSA 1	FUSA 2	FUSA 3	FUSA 4	FUSA 5	FUSA 6
FUA 1	7	9	8	5	6	4
FUA 2	10	8	12	4	11	9
FUA 3	8	6	4	3	2	4

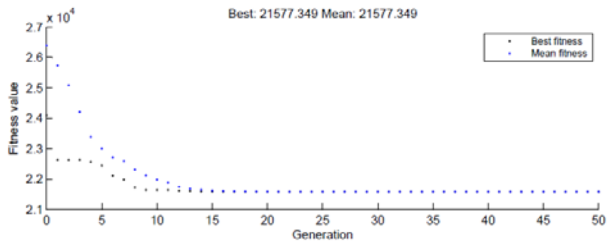

Figure 4. Best fitness.

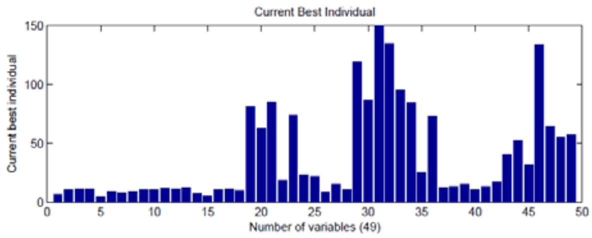

Figure 5. Best individual.

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