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Application Possibilities Of Artificial Intelligence Methods In Design For Assembly

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The recent research activity in design for assembly (DFA) has been directed towards the development of architectures and ontologies to apply artificial intelligence, in order to assist the design activity and to apply automation to the more complex, conceptual and decision-making tasks. The present paper surveys the application of artificial inteligence (AI) techniques in engineering design. Within this context, fuzzy logic (FL), genetic algorithms (GA) and artificial neural networks (ANN), as well as their fusion are reviewed in order to examine the capability of this methods and techniques to efectively address various assembly design tasks and issues. Representative approaches with high relation to the assembly planning are presented.

Keywords: fuzzy logic, genetic algorithms, artificial neural networks, engineering design, design for assembly, assembly planning

1. ENGINEERING DESIGN

The scientific community has extensively studied design during the last decades for the establishment of general purpose and domain-independent scientific rules and methodologies. Besides summarizing and reviewing the developed design models and methodologies, the researchers investigated the nature and the characteristics of the design process, classified the design models into categories and located possible research opportunities.

Three general design models are identified: the descriptive, the prescriptive and the computerbased model. The descriptive models for design tend to capture the processes, strategies and methods that designers use in order to address certain design problems. The prescriptive models are well addressed in preliminary design stages and are extensively used by the designers since they provide an intuitive sense to the design process. The computer-based models enhance features from the both aforementioned categories and are capable of performing many different design activities. On the basis of these three general design models, several design methods have been proposed with the characterization ‘design-for-X’, each of them viewing a different aspect of design. The applicability of a design model or a design methodology highly depends on the type of the problem under consideration. Through the review of the existing literature, the following issues regarding the design process become distinguishable: (a) the design knowledge representation (modeling), (b) the search for optimal solutions, (c) the retrieval of pre-existing design knowledge and the learning of new knowledge [1].

2. INTELLIGENCE (AI) METHODOLOGIES IN ENGINEERING

Soft Computing (SC) is an evolving collection of artificial intelligence methodologies aiming to exploit the tolerance for imprecision and uncertainty that is inherent in human thinking and in real life problems, to deliver robust, efficient and optimal solutions and to further explore and capture the available design knowledge [1]. Some authors suggest term SCAD (Soft Computing-Aided Design) for describing the research domain where engineering design meets fuzzy logic (FL), artificial neural networks (ANN) and genetic algorithms (GAs), which are the core methodologies of soft computing.

Artificial Neural Networks mimic biological information processing mechanisms. They are typically designed to perform a nonlinear mapping from a set of inputs to a set of outputs. They are non-programmed adaptive information processing systems that can autonomously develop operational capabilities in response to an information environment. ANNs learn from experience and generalize from

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previous examples. They modify their behavior in response to the environment, and are ideal in cases where the required mapping algorithm is not known and tolerance to faulty input information is required [2]. Artificial neural networks are being applied to a wide variety of automation problems including adaptive control, optimization, decision making, as well as information and signal processing.

The transition from the Aristotelian logic (between two competing states one and only one is true) to the fuzzy logic (multiple competing states may be true at the same time, each one at a different degree of truth) was accepted by the scientific community with hesitation. The ability, however, of modeling the uncertainty through fuzzy logic attracted many researchers that contributed to the foundation of various fuzzy logic concepts relative to engineering design. During the last decades, researchers have been using fuzzy logic as a representation framework in design problems characterized by inherent uncertainty during decision-making [1]. Fuzzy logic has also been applied to design activities where there are needs other than knowledge representation, e.g. for cognitive support in reverse engineering and for decision making in demanding domains, such as conceptual design.

The genetic algorithms are members of a collection of methodologies known as evolutionary computation (EC). These techniques are based on the selection and evolution processes that are met in nature and imitate these principles in many scientific domains. Like biological individuals whose characteristics are encoded in their genetic material, GAs encode the contents of each candidate solution for a mathematical optimization problem into the genome of a hypothetical individual. Individuals compete for survival by gaining a higher probability of reproduction which depends upon their fitness score (the objective score of the candidate solution they represent). Mating mechanisms based on crossover and mutation manipulate the genomes of the parents to produce offspring that then form a new generation of solutions. Over several generations the genetic characteristics of the population improve until optimal solutions arise. GAs are not influenced by the search start point, or by the continuity of the search space, or assumptions about convexity. Since they are highly parallel, they are well suited to combinatorial problems. [1].

Saridakis and Dentsoras [1] identified strong and weak points of SCAD techniques using a simple arithmetic methodology in order to determine potential areas of improvement and possibilities for further application of these techniques. The authors determined dependency strengths (arithmetic values from zero to three) between the three design tasks and the eight design issues (see table 1, legend). For each area of soft computing technique they identified how efficiently each approach of the specific area addresses the design tasks (table 1, first colmun). Then, an average evaluation metric for all approaches in the specific field is extracted ranging from one to three. This evaluation metric is then multiplied by the strength of their dependency with the design issues, thus providing an evaluation denoted with a percentage about how well the design issues are addressed by the referenced (table 1, second colmun). The results of this arithmetic evaluation process are depicted in the diagrams shown in Table 1.

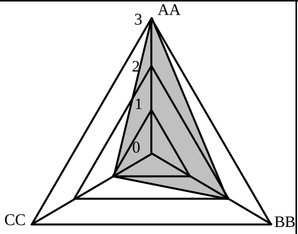
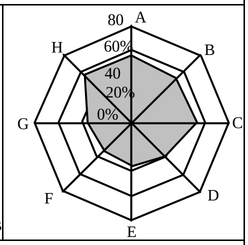
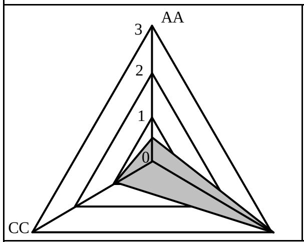
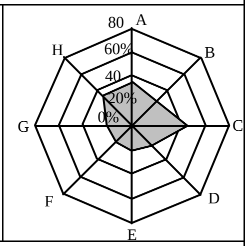
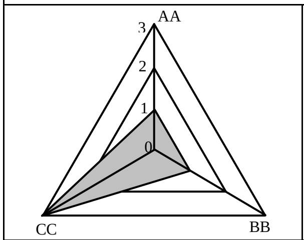
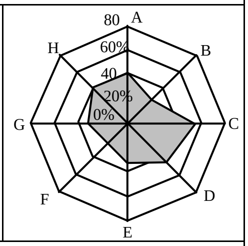
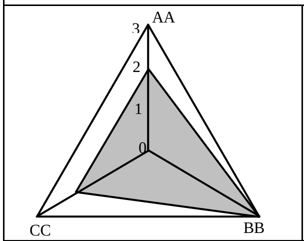
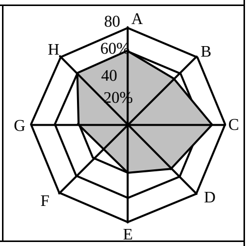
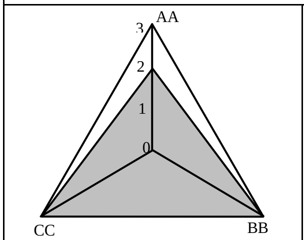
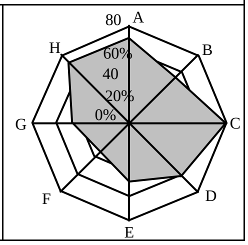
Very low percentages reveal a large efficiency gap and significant opportunity for further research. It is evident that the fusion of SC techniques provides more robust design frameworks, which address the set of the identified design issues more efficiently. Finally, the combination of SC techniques with case-based design approaches provides even more efficient results.

This research shows that soft computing techniques are mainly utilized to perform specific design tasks (e.g. representation, optimization, etc.) and the approaches that deploy soft computing methods in an integrated manner are rare. The expansion of SCAD systems in industrial activities render the deployment of supportive technologies such as agent-based, web-based and AI systems imperative in order to address the identified design issues [1] .

3. ASSEMBLY DESIGN

Assembly has traditionally been one of the most important stages for product development which generally accounts for 50% or more of manufacturing costs, and also affects the product quality. To reduce manufacturing costs, it would be prudent to carry out assembly oriented and related research and development. Design for assembly is now an accepted technique and used widely throughout many large industries [5].

Table 1. Evaluation diagrams per research area [1]

Design Tasks	**Design Issues**
Fuzzy logic in Engineering design	
	
Genetic Algorithms in Engineering design	
	
Neural Networks in Engineering design	
	
Fusion of SC techniques in Engineering design	
	
Case-Based Design and SC	
	

Legend:	
AA: Design knowledge representation, BB: Search for optimal solutions, CC: Retrieval and learning of design knowledge. Dependency strengths: 3 = strong, 2 = medium, 1 = light, 0 = none.	A: Uncertainty management and conceptual design, B: Collaboration, communication and coordination, C: Solution extraction under lacking knowledge/ uncertainty, D: Management and reuse of existing design knowledge, E: Generality and domain-independence, F: Extensibility and connectivity to other tools, G: Balance between automation and human activities, H: Simplicity.

DFA was first systematized in the 1960s by Geoffrey Boothroyd and his colleagues Alan Redford and Ken Swift at the University of Salford, England. Research first focused on methods of feeding parts by means of vibratory and other mechanical. Attention turned in the 1970s to classifying parts and assembly tasks in an effort to provide a simple way for engineers to judge the assembleability of their designs. Hitachi developed a set of assembleability evaluation methods at this time as well. [6].

Assembly involves the integration of components and parts to create a product or system. Assembly planning is a crucial design step for generating a feasible assembly sequence. Good assembly sequence planning has been recognized as a practical way to reduce operation difficulty, the number of tools and working time. The implementation of design for assembly (DFA) and design for manufacturing (DFM) resulted in enormous benefits, including the simplification of products, reduction of assembly product costs, improvement of quality, and shrinkage of time to market. Generally, assembly sequence planning (or assembly planning) can be classified into two major aspects: assembly modeling dedicated to CAD models and its capability, and assembly sequence generation. The common approach for assembly modeling is graph-based shown as parts mating graph and topological relation between components of a design [3].

Assembly planning includes generation, representation and selection of assembly part sequences. It is a very important issue in the design of assembly as different part sequences can drastically affect the eficiency of the assembly process [5]. The main purposes of assembly analysis and evaluation are concerned with minimizing the cost of assembly within the constraints imposed by the requirements to meet the functionalities of the product being assembled. Assemblability and assembly sequence evaluation play a crucial role in assembly oriented design. In the conceptual design of an assembly, it is important to consider the assemblability, disassemblability and control flexibility. An assembly sequence is the most important part of an assembly plan and it affects other aspects of the assembly process: resources, assembly line layout, efficiency and cost as well as various details in the product design. Automating the generation of assembly sequences and their optimisation can ensure the competitivity of manufactured goods and increase profit margins.

4. AI METHODOLOGIES IN ASSEMBLY DESIGN

Due to complexity of assembly and product design, there is an increasing need to integrate artificial intelligence with the designer intelligence for maximum benefits and expediting advanced design process. As such, it is necessary to apply knowledge-based systems techniques to the assembly oriented product design processes [6]. Automatic identification of assembly attributes from a CAD description of a component have been investigated and resulted with developed intelligent CAD system by encoding the Boothroyd design for assembly knowledge with feature-based representation. Such a system provides users with suggestions in order to improve a design and also to help obtain better design ideas. Another famous knowledge-based design for assembly system was developed by LUCAS Engineering. This system runs through a length phase of questioning the designer for product data needed for the analysis. The output gives specific advice on which product or component would benefit from a change to its design.

Numerous researchers employed artificial intelligence tree search, or graph search methodology to generate an assembly sequence. Unfortunately, the search space increases explosively when the number of components in a design grows. For relieving this combinational complexity, heuristic rules and genetic algorithms (GAs) have been used in the searching process. Other studies used the Hopfield and back propagation neural network (BPNN) as the means to generate optimum or sub-optimum assembly sequences [3].

Chen [3] proposes a three-stage integrated approach with some heuristic working rules to assist the planner to obtain an optimal assembly plan. In the first stage, Above Graph and transforming rules are used to create a correct explosion graph of the assembly model. In the second stage, a threelevel relational model is developed to generate a complete relational model graph and the incidence matrix. The relational model graph can be advanced transformed into an assembly precedence diagram (APD), which is used to describe the assembly precedent relations of the parts. Based on these graphs, the designer can easily find the feasible sequences and evaluate the difficulty of assembly. In the third stage, a case study is utilized to evaluate the feasibility of the proposed model in terms of the differences of underlying assembly characteristics and to generate a near-optimal assembly sequence according to the defined performance criteria.

The experimental results for the case study verify the feasibility of the proposed approach which facilitates the DFA in potential applications of 3D component models to assist manual or automatic assembly in a virtual environment, and allows the designer to recognize the relative position, geometry constraints and relationships of the 3D components using graph-oriented methods: Above Graph, APD and relational model graph.

An approach proposed by Zha [6], [7], [8], [10], can be used to generate all feasible assembly sequences of the product by reasoning and decomposing the leveled feasible sub-assemblies, and representing them through Petri-net graph and assembly tree. A new unified class of object-oriented knowledge based Petri nets, incorporating knowledge based expert systems and fuzzy logic into ordinary place–transition

Petri nets, is defined and used for the representation and modeling of the distributed design processes. In this work, a fuzzy comprehensive approach to assemblability and assembly sequence evaluation is used. Model for assemblability evaluation is based on the additive aggregation of the degree of dificulty of assembly operations. The proposed intelligent approach and framework focus on the knowledge-based integration of product design, assemblability analysis and evaluation, and design for assembly with economical analysis.

Senin in his work [12] investigates the application of GA-based search techniques to concurrent assembly planning, where product design and assembly process planning are performed in parallel, and the evaluation of a design configuration is influenced by the performance of its related assembly process. Feasible decompositions of product are recombinated into assembly plans and encoded into genomes. Each individual represents a plan, with its fitness score representing the plan performance evaluation score, which is defined as a simplified evaluation of plan execution time.

Marian et al. used GA with a classical structure for the optimisation of assembly sequences [13], but modified genetic operators, to avoid the combinatorial explosion. Proposed GA works only with feasible assembly sequences and has the ability to search the entire solution space.

Dini et al. [14] also deploy genetic algorithms to generate optimal assembly plans. The genetic algorithm produces near-optimal assembly plans starting from a randomly initialised population of assembly sequences in the context of minimizing both the orientation changes of the product and the gripper replacements, while grouping technologically similar assembly operations. The quality of the generated assembly sequences is assessed by a space-state search algorithm that adopts a best-first search algorithm and seeks the path that corresponds to a feasible sequence with the lowest total cost.

Another approach for the assembly line planning problem is proposed by Chen et al. [15]. In this study, a hybrid genetic algorithm addresses assembly planning with various objectives, including minimizing cycle time, maximizing workload smoothness, minimizing the frequency of tool change, minimizing the number of tools and machines used and minimizing the complexity of assembly sequences. Moreover, a self-tuning method was developed to enhance the effective schema of chromosomes during the deployment of the proposed genetic operators.

Although genetic assembly planners find improved assembly plans with some success, they also tend to converge prematurely at local-optimal solutions. Smith [16], [17] presents an assembly planner, based upon an enhanced genetic algorithm, that demonstrates improved searching characteristics over an assembly planner based upon a traditional genetic algorithm. The author introduces two new genetic operators to help reduce premature convergence in genetic assembly planners.

Zha [9] studies the assemblability and the assembly sequence evaluation in the engineering design through a neuro-fuzzy approach. According to this approach, the fuzziness is a property of the degree of difficulty assigned to the operation which can be represented by a fuzzy number between 0 and 1. The assembly operations have been evaluated based on various criteria, such as time and equipment required, although the analysis focuses on the difficulty of operation. Moreover, a neural network automatically tunes the membership functions of assemblability factors, so as to adjust the assembly difficulty score. Using the neuro-fuzzy approach, the relationships between product definition data, assembly factor, and assemblability can be formulated followed by sensitivity analysis that could predict how a design parameter change will affect the assemblability.

Zha [11] also presented a neuro-fuzzy approach to intelligent design and planning of manual assembly workstation. Simulated assembly tasks were carried out on a multi-adjustable workstation, and the posture and motion data of operators were recorded and analyzed. The trained neural network is capable of memorizing and predicting the angles of human joint motions associated with a range of workstation configurations. The developed algorithms can generate the design/layout results more quickly and accurately than other existing heuristic or analytic algorithms.

5. CONCLUSION

Numerous researchers employed successfully artificial intelligence methodologies to generate an optimal or near optimal assembly sequence. Complete AI-based integrated assembly oriented design process is still complicated by the complex interactions and domain knowledge between the technical and economical aspects of design process of assembly. Therefore, the development of a truly intelligent methodology and system for the concurrent integration of design for assembly process is stil in progress.

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