A Review on Design Optimisation and Exploration with Interactive Evolutionary Computation

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Abstract. Interactive Evolutionary Computation (IEC) utilises human-computer interaction as part of system optimisation and therefore constitutes an ideal platform for developing and improving systems that are subjectively influenced. Recently, interest in the usage of IEC for subjectively influenced design practice has shown an increase. In this paper the current state of the utilisation of IEC based optimisation platforms for varying design applications are reviewed. The design fields are categorized by conceptual design, industrial design, and finally, artistic design. We also present problems facing IEC and current research practice to resolve them.

1. Introduction

Subjectivity is an important aspect of many optimisation practices where, it is needed to take advantage of human experience and judgment, to complete a problem definition, to allow flexible problem reformulation, or to represent different views and criteria on design evolution. However, due to its variable and fuzzy nature, it is difficult to model and optimise.

Interactive Evolutionary Computation promotes cooperation between human and computer and optimises target systems based entirely or partially on subjective input from a human user. Qualitative modelling is thereby eliminated and their handling is outsourced to where it comes from: the human system user.

The term IEC includes the computational methods of Interactive Genetic Algorithms (IGA), Interactive Genetic Algorithms (IGP), Interactive Evolutionary Strategies (IES), and Interactive Evolutionary Programming (IEP) under its domain. In this paper, we refer to IEC as the general framework containing either one of these sub categories.

The approach has proved very versatile and has been used in various applications where subjectivity is an inherent part of the target system to be optimised. Some example applications include music [3], graphic art [4], hearing aid fitting [5] game development [6], and more recently, mental health diagnosis [7] and industrial design optimisation processes that typically involve subjectivity [8].

This paper reviews key papers including the usage of IEC in design applications, identifies its advantages and shortcomings when based in a design context. Section 1 looks into conceptual design applications where a single design optimisation objective is pursued, Section 2 reviews systems where IEC has been applied to multi-objective industrial design optimisation. Section 3 briefly looks into artistic design domains where IEC has been utilized, and Section 4 outlines current trends and issues in IEC research.

2. Single Objective IEC for Conceptual Design

The conceptual stage holds the key to successful problem formulation, which influences the following stages of design development and therefore needs to be handled successfully. Successful knowledge accumulation on possible solution space at this stage can result in the softening of strict constraints, shifting of search space into areas previously thought inappropriate with discovery of new solution properties, and inclusion of new design success criteria. As a result problem definition often is observed to shape up during the conceptual design development stage where qualitative features of possible solutions are observed. This nature of cognitive design development brings on the need for (1) easy exploration of the solution space and experimentation with possible changes, (2) the flexible accommodation of qualitative design exploration. Additionally, the conceptual design stage is the stage where innovation is intense. Innovation is a human attribute, where subjectivity and creativity plays an important role and experimentation with different solution scenarios helps the triggering of innovation as different design solution possibilities are explored and problem space is better understood.

In this context IEC can be used to help provide the computer with a means of "understanding" of the humans' subjective opinion on how the solution search is to be lead, while the user is provided a means of how qualitative opinions and solutions space are interrelated. In this sense, the visual interface is used as a communication tool between the user and the computer, and IEC based interfaces enhance this design exploration stage as the impact of user opinion is almost immediately felt upon the next generation of designs. As a result, IEC based platforms are observed to provide ideal tools for conceptual design. This section outlines some key research where IEC has been used solely or partly used for aiding conceptual design.

2.1 Machine Design

Ochi and Hagiwara [9] applied IEC to machine design support. In their system the previous applications of Kotani [10] was improved upon. An initial library of designs was used as a start-off point to accelerate the evolution. Three basic design stages were modelled into the system: the generation of the fundamental machine module, the generation of a functional module, and final stage where these generated parts were combined. It was reported that the proposed systems achieved user satisfactory results in less than half the time previously proposed systems did and that unexpected and innovative results were obtained from the human-computer fusion.

2.2 Image Evolution

Graf and Banzhaf [11] demonstrated how interactive evolution can be applied to 2-D bitmap images. Their system was an early indicator of the usage of artificial evolution for achieving flexibility and complexity in image design with user-input and detailed knowledge. The image structure is made of tie points which could be directly manipulated and reinserted into the design population by the users. Evolution of the images is achieved by the modification of the tie points. The user interaction is a simple one, asking the favourite image(s) to be selected as survivors to the next generation. As the system is built on image manipulation, it was found to be applicable across a wide range of conceptual design fields such as visualizations of automotive and aerial vehicles, and engineering products. The system is useful for conceptual design for the generation of innovative novel design ideas since design experimentation is easy and interesting results can be achieved even with low population sizes and few generations.

2.3 Virtual Modelling System

In Nishino *et al.*'s virtual modelling system [12], a freehand sketch was taken as an input to the system which automatically converted the 2D sketched image into a 3D deformable model. This 3D model then was used by IEC based 3D shape explorer which triggered the evolutionary phase that generated various different shapes by varying the parent shape's geometric parameters. After the completion of the evolutionary phase the finalization of the shape took place using a parametric 3D modeller which provided a user interface to sophisticate the model. It was reported by the experimental subjects that the system was capable of generating shapes that are difficult to create by traditional Computer Aided Design (CAD) tools that normally require the user to master many esoteric commands before starting to work. In this system no special knowledge except simple sketching was necessary. On the other hand, the system's efficiency depended highly on the user's performance to intuitively sketch and consistent evaluation of the evolved shapes as is mostly the case in general IEC based systems. The system was an ideal tool for conceptual design in which approximate shape exploration is what is needed rather than a precise modelling tool that is used to control model parameters tightly for the manufacturing stage.

2.4 Aesthetic Design

As part of the conceptualization stage IEC can be an ideal tool to be used by marketing to gather customer requirements or to aid market segmentation. As most IEC interfaces do not require extensive training for usage, it can be used as the basis for a simple methodology to understand the customer's likes and dislikes and help make the communication with the market more efficient. Yanagisawa and Fukuda [13] have used an enhanced IEC to help a customer set design parameters by simple evaluation of displayed samples. Design attributes to which a user pays more attention were estimated with *reduct* in rough sets theory. New design candidates were then generated by the user's evaluation of design samples. While values of attributes estimated as favoured features are fixed in the refined samples, the others were generated at random. It was reported that the enhanced IEC was better in the generation of user-satisfactory designs than regular IEC.

3. Combining Multi-objective Optimisation with IEC for Industrial Design

Moving from the conceptual design stage to lateral stages, improvement or optimisation on the design takes place. It is here that various qualitative or quantitative design criteria and trade-offs are discussed. Evolutionary Multi-Objective Optimisation (EMOO) platforms play an important role to observe the search space available across the various criteria and negotiate compromise solutions. As EMOO platforms are built on genetic principles, the introduction of IEC into the platform is a simple and efficient way to handle subjectivity. This section reviews some of these combination approaches that were used in industrial design.

3.1 Micro-electrical Mechanical System Design

In Kamalian *et al.*'s [14] Micro-electrical Mechanical System design platform, IEC was used as a single objective optimisation method, after the generation of trade-off solutions with a multi-objective genetic algorithm that optimised designs according to various quantitative objectives. Their system showed that the preferences of subjects were significantly towards designs that were optimised by the IEC enhanced system, as opposed to the designs optimised without IEC. Human evaluation resulted in the embodiment of design expertise to identify potential design or manufacturing flaws which otherwise would be invisible to the evolutionary algorithm.

3.2 Interactive Evolutionary Design System

Cvetkovic and Parmee [15] have developed the Interactive Evolutionary Design System (IEDS), where a rule based preference component allowed the designer to interactively express his/her preferences in terms of natural language. These preferences were used to direct the EMOO search. The IEDS has been developed as a design tool to allow the initial dominance of a cognitive design model that evolves to adopt subjective information, which in following design stages is strictly dominated by a quantitative problem statement. The IEDS made extensive use of IEC to accommodate the inclusion and removal of objectives, changes to their relative importance, changes in upper and lower parameter bounds that define the problem.

The IEDS have been applied to Preliminary gas turbine design and military airframe design, and produced promising results, suggesting that the integration of evolutionary search, problem exploration and optimisation using human-computer interaction could improve the handling of complex conceptual design environments.

3.3 Interactive Multi-objective Optimisation Design Strategy

Tappeta and Renaud [16] developed the interactive Multi-Objective Optimisation Design Strategy (iMOODS), which makes use of preference exexpressions that are user-defined by an interactive process. In the iMOODS method, the decision maker (DM) starts the solution search by specifying an initial "aspiration point". Together with the DM's initial preferences, the Pareto set in the preferred region are generated using projection. The preferred Pareto points and Pareto sensitivity information are then used to create an approximate Pareto surface generation for the current design. The DM can alter his/her preference settings real time. Although the iMOODS accommodates the DM's subjective views in terms of preference handling, it does not take into account objectives that are qualitative in their nature. The strategy was applied to the design of an autonomous hovercraft system and an aircraft concept sizing problem. The authors reported that the strategy is effective and efficient in capturing the DM's preferences and arriving at an optimum design that reflects these preferences.

3.4 Interactive Multi-objective Design Optimisation

Brintrup *et al.* [17] proposed the integrated optimisation of qualitative and quantitative criteria in an interactive multi-objective framework. This method treated qualitative criteria as one of the objectives of EMOO, and gathered its fitness from the user through the IEC module of the framework. The platform was tested by a floor-plan design where two conflicting objectives were negotiated. The experimental subjects reported satisfaction with the framework and the framework proved to be an ideal method to combine criteria that are different in nature.

3.5 Multi-criteria Decision Making Strategy

Hsu and Chen [18] have applied a Learning Classifier System (LCS) to cooperate with an interactive GA approach to aid multi-criteria decision making (MCDM), based on the concept that IGA has unique characteristics to facilitate good MCDM. IGA is particularly suitable for supporting this decision making approach while the design of the GA does not require a fixed fitness function, and makes the search among attributes easier as this is dealt by the computer. The LCS mimicked user ratings and was used to aid user fatigue in the model. The model was tested on the design of a cartoon facial mask. Preliminary results indicated a promising direction in multi-criteria decision making research.

3.6 Interactive Multi-objective Animation Design

Designing human like motions in animation by computer graphics is a difficult task. From a dynamics point of view the problem can be modelled by many quantitative objectives such as the minimization of the joint torques, change of joint torques, acceleration of the handled object and completion time of the motion. On the other hand, as humans have the capacity to evaluate the naturality of the motion, a subjective viewpoint is also needed. Shibuya *et al.* [19] proposed to use a multiple objective genetic algorithm based platform to optimise the quantitative objectives. Later the individuals generated by the algorithm were presented to the user, who picks and ranks preferred individuals. This preference ranking was then used to create the new generation of individuals. The experimentation showed that the approach generated high quality solutions with less stress on users than conventional methods.

4. IEC as the Generator of Artistic Design

As the IEC does not need an explicitly defined fitness function, it is reported that its potential applicability in artistic domains is high. This section briefly looks into the key reports that use IEC in artistic design.

Ventrella [20] has applied IEC to the design of animated characters. Here, the users were asked to identify "amusing behaviour" in the evolved individuals. The usage of interactive techniques in this case has proved not only to be efficient in generating innovative figures but also a task that was observed to include an entertaining element in human-computer interaction.

Lee *et al.* [21] applied IEC to the fashion design domain. The system uses IGA to get a preferable design by user. The IGA used is a simple one that evolves designs based on user scores.

In 3D lighting design system by [22], a designer is given a design motive and is asked to evaluate the lighting of the design from an artistic point of view. The location and intensity of lights sources are the variables which affect the appearance of the design. The study compared the IEC with manual lighting of designers. Designers whose manual lighting was evaluated poor have been able to significantly improve their lighting design capability using the IEC system.

5. IEC as a Design Tool: Trends and Issues

IEC based design systems come in many forms that range from as qualitative enhancers of quantitative multi-objective design optimisation, to conceptual 3D model exploration tools. It has been applied to diverse design domains ranging from machine parts to artistic design domains such as fashion design. This shows the flexibility of evolution with human-computer cooperation. Human subjectivity is a necessary part of design as its accommodation can help mandatory parts of the design process such as innovation, problem definition, alternative solution exploration, incorporation of human experience and intuition. EC provides the necessary design solution exploration and optimisation while the interactive component provides an ideal way to incorporate human subjective opinion into evolutionary synthesis.

One of the remaining problems in IEC that hinder its application as a stand-alone design exploration tool is human fatigue. Human fatigue is the inability of the human designer to assess a large number of designs over a large number of generations due to psychological or physical exhaustion. It is also observed that evaluation of solutions with very minor differences as the convergence reaches to an optimum is another contributor to human fatigue. Other difficulties may arise from the type of application. For example motion or music must be evaluated as a whole and memory limitations of the human makes this task difficult.

Rating scales can be problematic too. Due to the subjectivity involved, we cannot guarantee a mathematically consistent rating that will impact in proportion or accordance with the changes in the qualitative space. The reasons for this might be simply due to user inconsistency or human fatigue such as user not remembering older designs for an accurate comparison or provide a rating that can represent this comparison.

The evaluation might differ when the user compares designs with the whole range of designs seen until current generation, or designs within one population only. In the former case, convergence is more likely to occur but as the number of generations increase, it gets more difficult for the user to compare.

Current non-applicational IEC research focuses on these problems and various proposals to combat human fatigue, and problems due to inconsistency or rating perspectives. Te usage of neural networks [1] or other prediction mechanisms to mimic user evaluation after a number of generations of user evaluation, combining regular EC and IEC to get user guidance only in some generations [14], outsourcing quantitative design objectives to a regular EC and subjective design objectives to IEC thereby reducing the evaluation numbers, active user intervention [24] for human fatigue; scaling user ratings to absolute [1] for scaling problems; providing better user interfaces [23] for inconsistency problems are discussed in the IEC research community to combat the problems of IEC and enable it to be used as an efficient tool for design applications.

In its pure alone form, IEC is an excellent tool for innovative conceptual design generation. As part of other optimisation systems or soft computing packages IEC can also be applied as a knowledge input tool for lateral stages of design improvement. Combination of IEC with EMOO [2], and other soft computing techniques such as Fuzzy Systems and Agent Based Systems [4] show promising research directions.

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