Evolving Planar Mechanisms for the Conceptual Stage of Mechanical Design

Paul Lapok
Edinburgh Napier University
EH10 5DT
United Kingdom
p.lapok@napier.ac.uk

Alistair Lawson
Edinburgh Napier University
EH10 5DT
United Kingdom
a.lawson@napier.ac.uk

Ben Paechter
Edinburgh Napier University
EH10 5DT
United Kingdom
b.paechter@napier.ac.uk

ABSTRACT

This study presents a method to evolve planar mechanism prototypes using an evolutionary computing approach. Ultimately, the idea is to provide drafts for designers at the conceptual design stage of mechanism design which meet their design brief. The designers can review, analyze and incorporate the drafts into the development of a mechanical system. This work proposes a stepping stone towards a generative design system which is capable of evolving such planar mechanisms with a focus on the configuration and shape of their components. In this paper, we present a use-case of evolving four-bar linkages with attached shaped component to study the evolutionary approach. In addition to kinematics, we consider properties such as the shape of levers, placement of rotation joints, torque, friction, restitution, and mass. The design aim was to move a mechanism as fast as possible in the forward direction whilst overcoming obstacles in a virtual environment involving gravity. Our method was evaluated using complex environments with different obstacles. The results verify that it was able to evolve a variety of high performing mechanism drafts. The study provides a promising outlook of using this method to support the conceptual stage of mechanical design.

KEYWORDS

Generative Design, Planar Mechanisms, Four-Bar Linkage, Evolutionary Algorithm, Conceptual Design

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1 INTRODUCTION

This work presents an evolutionary computing approach for evolving design prototypes of planar mechanisms, involving specific design tasks. Mechanism design has a large number of different application areas. They range from industrial applications, such as production systems to design conveyor systems, or sorting machines, to automotive design, e.g. for wiper mechanisms, or mechanical redundant devices such as closure systems. The results of this study promote the development of a design support tool for human designers. The goal is to implement a method which enables to study evolutionary algorithms applied to the area of planar mechanisms and to produce design drafts which solve a set of design problems. We pursue it by addressing the following steps:

- Define a general design objective and a set of different design problems
- Describe the design problems and the design solutions in a computer readable format
- Define a method to evaluate the performance of potential solutions
- Define a method to describe complex shapes with a compact set of descriptive parameters

2 EXPERIMENTAL DETAILS

2.1 Evolutionary Simulator for Planar Lever Systems

A simulator was implemented allowing to evolve and visualize design solutions. It provides features for testing different problems, representations, and evolutionary algorithm configurations. The integrated evolutionary algorithm uses binary tournament selection which takes the fitter individual of two random chosen individuals from the population. With an equal chance, a simple mutation operator or a two-point crossover operation and simple mutation is applied in every iteration. The simple mutation operator changes the values of between one and up to 25% of the genes. The values are changed using a gaussian distribution. Children replace individuals of the population. These individuals were selected by taking two random individuals of the population and replacing the weaker one with the child. The population size was set to 40 and 4 children were produced in each generation. These parameters were identified through repeated experimentation. The algorithm was stopped after 20,000 evaluations.

2.2 Genetic Representation of Mechanism

An evolutionary representation for a four-bar mechanism was developed to define the mapping procedure between genotype and phenotype. The mechanism is shown in Figure 1.

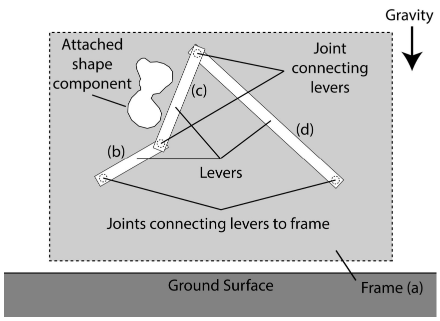

Figure 1: Four-bar mechanism with attached shape component

The chromosome is an array of floating-point values which describes the speed and torque of the driving component *b*; the joint positions within the frame *a*; and the shape and position of the attached lever component. The shape is based eight rectangles places around the origin; calculating the outline of all partly overlapping rectangles; and using the resulting vertices as control point for a B-spline function such as shown in Figure 2.

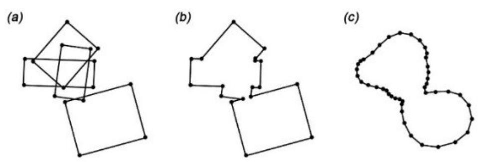

Figure 2: Generating a candidate shape

2.3 Experiments

The assembly was put into an environment with a ground surface including gravity. Seven different environments were defined to investigate the generative system's abilities to produce solutions for these environments shown in Figure 3.

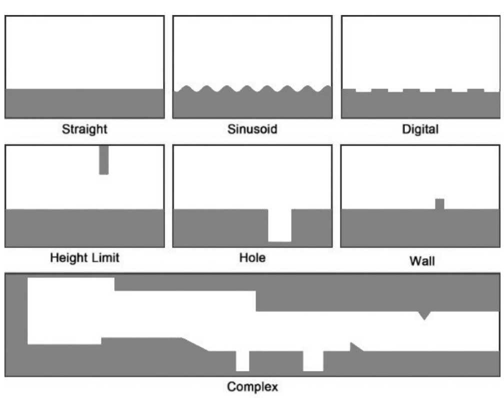

Figure 3: Environments

The evolutionary algorithm and its' operators were evaluated by comparison to random search. The contribution of the attached shape was validated by comparison to evolved mechanisms without attached shape.

3 Results and Evaluation

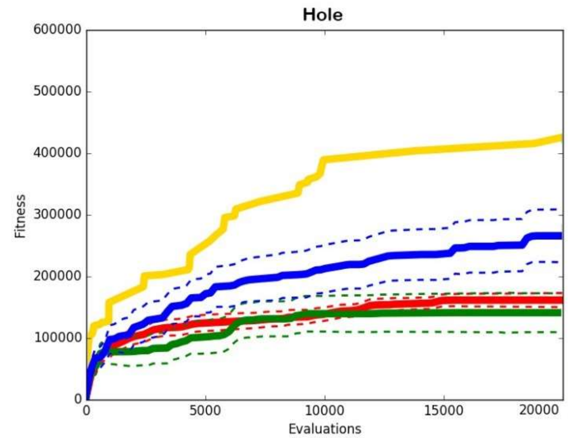

Figure 8: The median fitness of 24 runs with ±95% bootstrapped confidence intervals for the Hole problem: EA with shape (blue) vs EA without shape (green) vs random search with shape (red). Also, the best solutions of all runs (gold) is shown.

Results show that the additional shape attached to the mechanism leads to a better solution quality. The evolutionary algorithm is performing significantly better than random search. The genetic operators contribute to finding better performing solutions. The recombination operator is able to escape from local optima's and navigate to different regions of the search space. Furthermore, it was found that the algorithm performs well when increasing the problem complexity of an environment with multiple obstacles.

4 Conclusion

This work presents a method which enables to study evolutionary algorithms for evolving planar mechanisms. It contributes towards understanding of generative design systems, focused on industrial applications by providing the following:

- A design task, allowing to specify multiple comparable design problem instances and evaluate the performance of evolutionary algorithms.
- An approach to computationally describe design problems and solutions for planar mechanism design.
- A method to evaluate a planar mechanisms performance using a two-dimensional physics environment.
- An encoding to reduce the number of descriptive parameters for shapes was developed.
- The evaluation of an evolutionary algorithm, discussing benefits and drawbacks.

As a use case, we focused on the ability to traverse different environments by evolving a freely movable four-bar linkages with an additional attached shape component. Overall, the results show that the system is capable of increasing the fitness of candidate solutions and of producing interesting mechanisms which perform the desired behaviour. The shape and configuration adapt to the environment and its obstacles.