Clarence Rodgers
Advisor: Prof. Joran Booth (MEMS), Prof. James Aspnes (CPSC)
CPSC 490
2/25/2021

Combined Mechanism Classification and Continuous Optimization for Generative Design

Background:

Computational tools for mechanical design are increasingly universal in nearly all engineering industries. Modern CAD/CAE software provides sophisticated tools to drastically decrease the cost and time required for product prototyping and design realization. While the largest adoption is undoubtedly in modeling and manufacturing, this tooling has expanded into earlier phases of design as well. “Generative” or “computational design” is an umbrella term describing a process through which the computer is made to iterate and optimize without direct user input, altering fundamental aspects of the system such as mechanism geometry or actuator selection.

The most readily available generative design tools are intended for optimization of static systems. Autodesk’s *Generative Design* leverages finite-element simulation and additive manufacturing capabilities to optimize for weight without sacrificing structural load paths. [1] Dynamo’s *Refinery Toolkit* allows architects to automatically iterate over floorplans or building styles given a set of site constraints. [2] This style of design, referred to as “optioneering”, permits depth in design consideration, but still relies largely on user input, experience, and intuition. [3]

There is a great deal of work looking to expand generative design beyond just generation of “options” and into fully automated workflows. This research, too, is often based focused on optimization of static structures, such as improving the balance of an arbitrary 3D print. [4] Work which deals with dynamic systems is generally intended for a creative field, such as toys, graphical movies, or character automata. Within these projects, the generative work is limited in scope to a particular type of mechanism. Wampler and Popovic focus only the development of gaits. [5] Coros et al. implement a full workflow of automated mechanism generation for characters, but it only samples from a limited collection of parametrized sliding joints and four-bar linkages. [6]

Research in generative robotics typically shows a similar limitation. Megaro el al. and Ha et al. both intentionally limit the solution space by generating robots with a limited set of “modules,” or actuators and linkages. [7,8] Leger’s work is similarly modularized but is notable for its use of genetic generators for optimization. [9]

Thus, there is a sense that generative mechanical design techniques are necessarily limited in scope, failing to consider huge regions of the solution space for any given desired motion output. The work of Coros et al., which is perhaps the most sophisticated and complete in its usability and interactivity of those listed here, still only scratches the surface of capability with four-bar linkages and cyclic motions. [6]

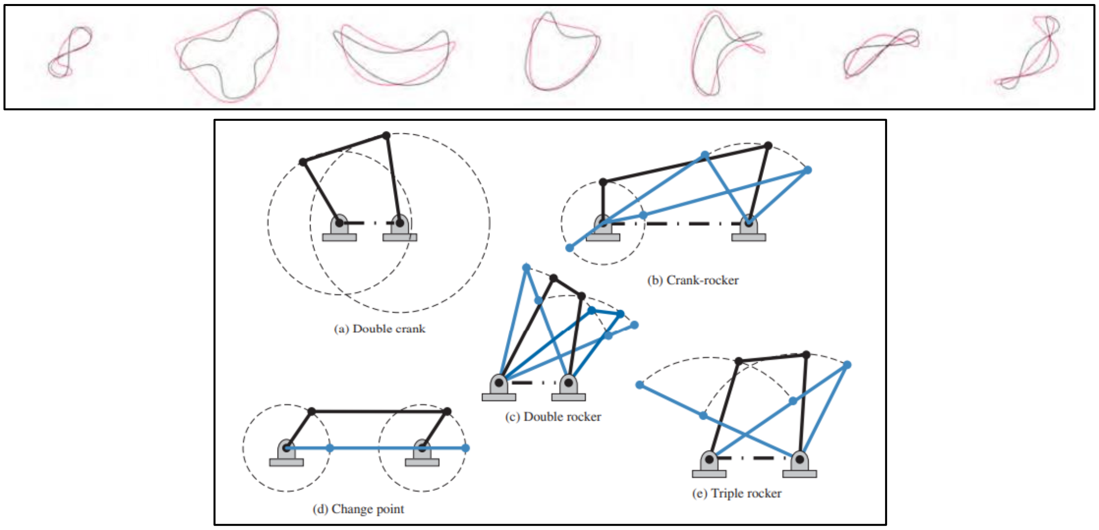

Figure 1: (Top) Example outputs, in red, of the design system proposed by Coros et al., compared to desired motion profiles, in black. [6] (Bottom) Categories of fixed-length, four-bar linkages with illustrated motion capability. [9]

A more complete design system would take advantage of all types and classes of mechanisms, leveraging simple concepts as building blocks for complexity. There is precedent for this computational classification and mechanism decomposition. The most common representations are matrix-based and graph-based, both relating input to output motion characteristics through fundamental blocks which are easily chained together. [10,11] The concept of leveraging these basic representations for mechanism definition is known as "type synthesis." [11]

Project:

This project will thus seek to combine the concepts of type synthesis and mechanism classification with more focused, continuous parameter optimization techniques, such as those proposed by Coros et al. This will serve as a step towards a more complete generative design system. Deliverables include:

1. A concrete application of the mechanical representations described in literature on type synthesis, specifically implemented for use with a multi-label classification system.
2. An implementation of a continuous parameter optimization for at least one mechanism type, with an emphasis on generic building blocks to interface with the above classification outputs.
3. A visualization system for the mechanisms described.

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