HIPAIR: Interactive Mechanism Analysis and Design Using Configuration Spaces

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We present an interactive problem solving environment for reasoning about shape and motion in mechanism design. Reasoning about shape and motion plays a central role in mechanism design because mechanisms perform functions by transforming motions via part interactions. The input motion, the part shapes, and the part contacts determine the output motion. Designers must reason about the interplay between shape and motion at every step of the design cycle.

Reasoning about shape and motion is difficult and time consuming even for experienced designers. The designer must determine which features of which parts interact at each stage of the mechanism work cycle, must compute the effects of the interactions, must identify contact transitions, and must infer the overall behavior from this information. The designer must then infer shape modifications that eliminate design flaws, such as part interference and jamming, and that optimize performance. The difficulty in these tasks lies in the large number of potential contacts, in the complexity of the contact relations, and in the discontinuities induced by contact transitions.

Current computer-aided design programs support only a few aspects of reasoning about shape and motion. Drafting programs provide interactive environments for the design of part shapes, but do not support reasoning about motion. Simulation programs, which compute and animate the motions of the parts of mechanisms, reveal only one of many possible behaviors. Commercial simulators only handle linkages: mechanisms whose parts interact through permanent surface contacts, such as hinges and screws. Other packages handle specialized mechanisms, such as cams and gears. They cannot handle mechanisms whose parts interact intermittently or via point or curve contacts. Yet these *higher pairs* play a central role in mechanism design. Our survey of 2500 mechanisms in an engineering encyclopedia shows that 66% contain higher pairs and that 18% involve intermittent contacts.

We have developed a problem solving environment, called HIPAIR, for reasoning about shape and motion in mechanisms. The core of the environment is a module that automates the kinematic analysis of mechanisms composed of linkages and higher pairs. This module provides the computational engine for a range of tasks, including simulation, behavior description, and parametric design. It is comprehensive, robust, and fast. HIPAIR handles higher pairs with two degrees of freedom, including ones with intermittent and simultaneous contacts. This class contains 90% of 2.5D pairs and 80% of all higher pairs according to our survey.

HIPAIR computes and manipulates configuration spaces. The configuration space of a mechanism is a geometric representation of the configurations (positions and orientations) of its parts. Configuration spaces encode the relations among part shapes, part motions, and overall behavior in a concise, complete and explicit format. They simplify and systematize reasoning about shape and motion by mapping it into a uniform geometrical framework.

The videotape explains configuration spaces and illustrates how HIPAIR supports mechanism design and analysis. HIPAIR has been tested on over 100 parametric variations of 25 kinematic pairs and on dozen multipart mechanisms, including a Fuji disposable camera with ten moving parts.

References

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