Formation of Qualitative Knowledge Obtained from Quantitative Simulation of Mechanisms

Abstract

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This abstract describes an approach to the organization of qualitative design knowledge about mechanism's functioning. This knowledge is being formed on the basis of analytical results obtained in quantitative simulation. Smooth response functions generated by simulation system are approximated by differences of first three orders. Attention is drawn on capabilities of sign combinations of the differences to provide qualitative reasoning when searching for synthesis solutions. The tasks arising are examined from this viewpoint: extraction of qualitative features of function, their classification, setting dependencies between parameters and features, derivation of tendencies of change of the features.

Qualitative simulation [1] is powerful means for the investigation of a physical model with incomplete knowledge and for the generalization of obtained results. Qualitative relations interpreted as ordinal relations (increase, decrease, etc.) between discrete values are employed in qualitative simulation systems (e.g., in Kuipers' QSIM system) and intended for the derivation of possible qualitative behaviors given certain set of qualitative constraints. One of the way to extend the qualitative reasoning techniques over various design applications and thus, to improve decision-making in design, consists in integrating them with existing simulation systems that provide quantitative results. Let us briefly consider this problem by example of mechanisms.

It is known that many computer models for mechanism provide its analysis, i.e., allow the designer to evaluate the functionality when the structure of mechanism is given. Both analysis and synthesis models are usually implemented as computational processes where the regularities arising between structural parameters and behavior of a mechanism remain to be hidden and inaccessible for further use. Since designing is iterative analysis-evaluation-synthesis process, realistic synthesis using a prehistory of design is carried out in a designer's brain and turns to be outside computer supporting tools. In his attempts to find out a reasonable solution the designer applies uncoordinated set of simulation experiments.

Therefore, the problem arises of accumulating the results of simulation in such a way that they could be involved in decision-making process as an integral part of knowledge used at different stages of design activity, including synthesis.

The peculiarity of mechanism as a design object is complicated nature of behavior, for instance, a form of trace of mechanism's motion as well as correspondence between function and structural parameters that ensure required form of the trace. It is important to note that the designer often operates with some set of qualitative features representing function rather than function as a whole, especially in refinement of design. For example, the designer may consider such features as a duration and smoothness of suspension in elevation of output link having tried to slightly change them. These features characterizing behavior need to be structured and explicitly represented to support overall design process.

For this purpose the concept of design prototype [2] is useful as a scheme for generalized heterogeneous knowledge of previous design experience. Organization of design prototype implies uniform and explicit representation of relations among design concepts including function, behavior and structure of design object. These relations are expressed as dependency network that allows a system to facilitate reasoning among the concepts and thus, to support synthesis process.

Qualitative knowledge being formed as a result of repeated simulation, could here play the role of a skeleton to guide decision-making process and accumulate detailed information for the regions of special interest. Qualitative knowledge shall include the regularities of direction of change among the variables describing both structure and qualitative features of function.

In the context of this task it is first required to set the dependencies between design parameters of structure and qualitative features of model's response, represent these dependencies in terms of qualitative relations, and provide means for their analysis and manipulation (derivation of tendencies, boundaries of solution existence, qualitative similarity for the solutions with different parameters, etc.).

Here under consideration are the mechanisms working as generators of function of time. Model of simulation process is considered as:

F(S(p),t) -> {f(t)}

where F is an operator which assigns to the structure S(p) of simulation model a family of generated functions of time {f(t)}. Information about the structure S(p) is restricted by structural real parameters p, independent of time.

The process is investigated on a finite closed time range [t1, 2]. The function f(t) is considered to be reasonable in the sense defined by Kuipers [1] for such subranges in [t1, t2] where f(t) exists with no discontinuity.

The notion of qualitative description (QD) of function is introduced:

QD = (q1, q2, q3),

where q1, q2, q3 are the strings of signs of 1, 2, 3-order descending differences respectively obtained for discrete values of function f(t) on investigated time interval. Each string consists of symbols from the alphabet {+, -, =, N, *}. The symbols "+" and "-" are the signs of a difference, "=" denotes zero value of difference, "N" - no solutions. The symbol "*" means "don't care" similarly to that used in classifier systems [3].

Qualitative features such as extrema and their mutual positions, monotonicity, degree of growth, etc., are extracted from the combination of signs described in QD.

The notion of qualitative state is introduced as an element of dependency network. Qualitative state is coordinate-values of structural parameters along with corresponding QD. For the parameters, in the process of obtaining new simulation results their range of values is being partitioned into subranges with equal QDs. The symbol "*" is also used for classification purposes, which enables selection of and manipulation with such subset of qualitative descriptions that contain a required tuple of qualitative features.

Techniques to handle with mutated qualitative features and their drift on time interval when changing structural parameters, are considered. Besides, the peculiarities of sign combinations in passing through discontinuity point of response function, are investigated for some cases.

The problem was examined using Mechanism Modeling System MMS and experimental system QDES; the latter is intended for the investigation of QD's capabilities.

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