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An Interim Report of Research on  
DISCRETE CONTROL OF CONTINUOUS PROCESSES  
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by

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## 1. Synopsis

The purpose of this research has been to develop a fundamental theory for the control of continuous-state (physical) systems by discrete-state systems (usually digital computers or relay systems). The investigation of such hybrid feedback systems has been pursued first in discrete-time and now also in continuous time. Qualitatively, discrete-time systems may exhibit large jumps between different regions of discontinuous behavior in one time-step, while continuous-time systems have trajectories that do not jump abruptly between regions of state space.

A crucial element in the study of discrete-time hybrid systems is the coding/decoding operations which may occur between continuous and discontinuous-state parts of the systems. The realization theory for coders which accept real input sequences and produce discrete-valued output sequences is now almost fully developed as a consequence of this research. A hierarchy of such coders has been revealed, ranging from simple (unitary) to complex (shift-finitary) in structure; they admit corresponding characterizations as real-language acceptors which are context-free, context-sensitive, etc. in analogy with finite automata theory. To make this advance, it has been necessary to develop appropriate notions of real languages, real grammars, acceptors, and other terms which are not trivial extensions of conventional automata-theory terms. These results have very significant implications for the future direct synthesis of digital signal processing equipment in military and civilian applications. Linguistic description of signal qualities may

be reduced to basic canonical forms and be converted directly into circuit designs by an automatic procedure analogous to the way in which purely linear continuous analog circuits or purely digital circuits are designed today.

Progress has also been made in the design of finite-state control systems for continuous-state plants operating in a sampled-data (discrete-time) mode. Previous methods required on-line construction of an ambiguity tree having a prohibitively large number of states. By pursuing an approach analogous to the observer-based-compensation approach for linear systems, the number of states in the controller synthesis may be dramatically reduced without detracting significantly from optimum performance. The largest class of systems for which results of this type may be achieved is currently being determined.

In the area of asynchronous coding and state representation (continuous-time systems), new results have also been derived. It has been shown that under certain conditions, multitask computer systems interacting with real-time physical processes can be described by equivalent real-state discrete-time systems, (although with a non uniform "sampling rate"). This indicates that in some cases asynchronous continuous-time switching systems may be equivalent to discrete-time hybrid-state systems. These results are of importance in the modelling of computer process control and manufacturing systems and serve to explain observed phenomena in such systems.

2. Reports and Publications (November 1980 - May 1981)

1. T.L. Johnson, "Stability of Diced Systems", Proc. 19th IEEE Conference on Decision and Control, Albuquerque, NM, December 1980.
2. D.N. Wimpey, "Towards a Structure Theory for Coders of Real Valued Signals", MIT LIDS-TM-1052, October 1980.
3. D.N. Wimpey, "Finite State Control of Discrete-Time Continuous Processes", MIT PhD Thesis Proposal, Dept. of Electrical Engineering and Computer Science, May 1981.
4. D.N. Wimpey, T.L. Johnson, and M.E. Kaliski, "Realization of A/D and D/A Coders", Proc. 1981 Joint Automatic Control Conference, Charlottesville, VA, June 1981.
5. T.L. Johnson, "Analytic Models of Multitask Processes", submitted to 20th IEEE Conference on Decision and Control, April 1981.

4. Other Activities

Dr. Johnson has organized an invited session on "Discontinuous Processes" at the 1981 Joint Automatic Control Conference (June 17-19, 1981), for the purpose of bringing together recent work in this field.

5. Future Plans

Professor Kaliski returns from sabbatical July 8 and will devote several weeks to research on acceptors and languages during the remainder of the contract period, as scheduled in the original budget and timetable. During the next several months numerical simulations of discontinuous systems and coders will be developed to provide examples of theoretical results and to initiate approximation methods required in subsequent research. Mr. Wimpey will complete his research on coding and finite-state control of discrete-time systems.

A proposal for future continuation of this research will be submitted in July.