Decoupling. A Long-Standing Open Problem Resolved[1]

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Biography

Vladimír Kučera was born in Prague, Czech Republic in 1943. He graduated with honors in electrical engineering from Czech Technical University, Prague, in 1966 and obtained his research degrees in control engineering from the Czechoslovak Academy of Sciences, in 1970 and 1979, respectively.

During 1967-2017 he was a Researcher, and from 1990 to 1998 Director, of the Institute of Information Theory and Automation, one of the research institutes of the Academy of Sciences of the Czech Republic. Currently, he is an Emeritus Scientist of the Academy of Sciences. Since 1996 he has been a Professor of Control Engineering at the Czech Technical University, Prague. He served the university as Head of Control Engineering Department, Dean of Electrical Engineering, Director of the Masaryk Institute of Advanced Studies, and currently as Distinguished Researcher and Vice Director of the Czech Institute of Informatics, Robotics, and Cybernetics.

He held many visiting positions at prestigious European, American, Asian, and Australian universities. His research interests include linear systems and control theory. He contributed to the theory of Riccati equations and pioneered the use of polynomial equations in the synthesis of linear control systems. His well-known result is the parameterization of all controllers that stabilize a given plant, known as the Youla-Kučera parameterization, which became a new paradigm in robust and optimal control. Recently, he has resolved a long-standing open problem of linear control theory, the decoupling by static state feedback.

He is an Advisor, Fellow, and a former President of IFAC. He is a Life Fellow of IEEE and was a member of the IEEE Control Systems Society Board of Governors. His awards include the Prize of the Czechoslovak Academy of Sciences in 1972, the National Prize of the Czech Republic in 1989, and the Automatica Prize Paper Award in 1990. He is an Honorary Professor of the Northeastern University, Shenyang, China, and received honorary doctorates from Université Paul Sabatier, Toulouse, France and Université Henri Poincaré, Nancy, France. He is a Chevalier dans l'ordre des palmes académiques, a national order of France for distinguished academics.

Abstract

The recent solution by Kučera (2017) will be presented to a long-standing open problem of linear control theory, the diagonal decoupling by static-state feedback. The earliest known investigation of system decoupling dates back to Voznesenskii (1938), a rigorous state space formulation of the problem appeared in Morgan (1964), and a solution for square and invertible systems followed (Falb and Wolovich, 1967). All past solutions were obtained under restrictive assumptions on system and feedback such as same number of inputs and outputs, regular state feedback, or specific internal couplings.

[1] Supported by the European Regional Development Fund and the Project AI&Reasoning CZ.02.1.01/0.0/0.0/15_003/0000466.

Decoupling is a problem of compensating a multi-input multi-output system in such a way that each system output is independently controlled by one system input and not influenced by the other inputs. The system is assumed to be linear, time-invariant, and giving rise to a proper rational transfer matrix. Decoupling can always be achieved using dynamic compensation, which increases the order of the system. The static-state feedback, however, does not increase the order and therefore may involve only the internal dynamics.

The mechanisms for the comprehension of the solvability of this very complex problem are presented. The formulation avoids restrictive hypotheses concerning system and decoupling feedback. The existence of a solution is shown to depend on the existence of three lists of nonnegative integers conditioned by and only by structural system invariants with respect to the group of permissible transformations, which include state feedback, input and state transformations and output permutations. The invariants are conveniently captured by a matrix of a unique structure, called the interactor. The solvability conditions are necessary and sufficient. The necessity proof is based on existence results whereas the sufficiency proof is based on constructive arguments and provides an algorithm to determine a (nonregular) decoupling control law.

When a system is decoupled, it is broken down into single-input single-output noninteracting subsystems. That is why decoupling is also called noninteractive control. Such a structure is desirable in a number of applications, since considerable computational as well as conceptual simplicity can be accrued for subsequent system design. Indeed, the interactive loops are the source of major complications, whereas the decoupled structure is amenable to simple single-loop control system design techniques.

When diagonal decoupling cannot be achieved, it may be of interest to investigate the possibility of block decoupling. A block-decoupled system is broken down into smaller multi-input multi-output noninteracting subsystems so that partial noninteraction is achieved. The problem was formulated by Wonham and Morse (1970) and solved for several special cases. A complete solution, however, was not obtained until recently (Kučera, 2018).

The mechanisms for the solution of the block decoupling problem are shown to be the same as for the diagonal decoupling problem. The only new concept needed is that of the block interactor. The interactor of the system to be block decoupled is modified so that its principal submatrices, each corresponding to the output coordinates of one block, are made diagonal by nullifying their off-diagonal entries. This reflects the fact that the interaction within each block need not be eliminated while the cross-block interactions need be. The solution of block decoupling is then given by that of diagonal decoupling with the interactor replaced by the block interactor. If the blocks are not specified from the outset, the method to be presented permits a search to determine the sizes of the smallest blocks attainable.

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