Control Theory and Forty Years of IFAC: A Personal View

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Control theory is a key ingredient in the progress of engineering and, in fact, of industrialised societies. Since its founding, IFAC has paid due attention to the developments of control theory. Now, when IFAC celebrates its 40th anniversary, it is tempting to review these fascinating developments as well as the role of IFAC.

Automatic control systems were first developed over two thousand years ago. The first feedback control device is thought to be the ancient water clock of Ktesibos in Alexandria, Egypt. Milestones among automatic control devices include the temperature regulator of a furnace (Drebbel 1620) and the centrifugal flyball governor (Watt 1785) used for regulating the speed of steam engines.

Most control systems of that time were based on devices that appeared during the industrial revolution and the governor mechanism was an integral part of these devices. Conditions for their stable operation were the main issue. Maxwell (1868) used differential equations to study the dynamics of control systems. Stability conditions were obtained by Routh (1874) and Hurwitz (1895). This demonstrated the importance of mathematical models and signaled the beginning of control theory.

The variety of control systems became extensive and feedback controllers were designed as separate or multi-purpose devices. Minorsky (1922) formulated the three term or PID control law. The major step in implementing these laws was the invention of electronic (Black 1927) and pneumatic (Mason 1928) negative feedback amplifiers. Field adjustable PID controllers became available (Ziegler-Nichols 1942) soon thereafter.

The aiming of anti-aircraft guns was at the advent of the theory of servomechanisms (James-Nichols-Phillips 1947) and in fact of the "systems" approach to the design of complex control systems. The importance of communication in control systems was emphasized by Wiener (1949) by drawing analogies to living organisms.

The design methodologies of the classical era were for linear single input, single output systems and were based on the frequency response techniques or the Laplace transform solution of the differential equations. The advent of computers and need to control ballistic objects for which physical models could be constructed led to the state-space approach, which replaces the general differential equation by a system of first order differential equations.

The stage was set for a tremendous development of systems and control theory, known as the modern control period. The emphasis was on the mathematical formulation of the control objective. The maximum principle (Pontryagin 1956) and the dynamic programming (Bellman 1957) laid the foundations of optimal control theory. Accordingly, the control system theory was given axiomatic foundations (Kalman 1960) using state-space concepts.

This fascinating period saw the formation of IFAC in Heidelberg 1956 and Paris 1957. This was
certainly no coincidence: the growing community of control scientists and engineers needed a global organization. The triennial congresses of IFAC have become important events of the community since 1960. The control theorists were active within the IFAC Technical Committee on Theory, one of the five technical committees originally established.

The fundamental achievements of the modern control era include the linear quadratic regulator (Kalman 1959) and the optimal state estimation given noisy observations (Kalman 1960). The state-space approach was instrumental in discovering the role of Riccati equations and Kalman (1960) showed that a deep and exact duality existed between these two problems. A culmination of these efforts was the LQG problem, which is an optimal state-estimate feedback control. The linear-quadratic synthesis has found wide application, especially for multivariable systems.

A geometrical approach to state-space analysis and design was developed by Basile and Marro (1969) and Wonham (1970). By using the abstract geometric concepts of linear spaces, a compact and coordinate-free formulation was obtained for many problems of interest. These include model matching, disturbance rejection, reference tracking, decoupling, and pole placement. The geometrical formulation proved to be a vehicle for extending the concepts of linear systems theory to nonlinear systems (Brockett 1983, Isidori 1989), with manifolds replacing linear spaces. Modern nonlinear control is no longer about particular problems but it is applicable to important classes of systems.

The success of state-space approach renewed the interest in input-output or transfer-function methods (Rosenbrock 1970). The key tool for the study of linear multivariable systems proved to be the concept of matrix-fraction-description (Wolovich 1974). These achievements paved the way to the parametrization of all stabilizing controllers for a given system (Kucera 1975, Youla 1976). This seminal result launched a new line of research in feedback system design. Optimal control problems were formulated as norm-minimization problems in Hardy spaces of transfer functions (Zames 1981). The underlying abstract-algebraic ideas facilitated extensions to more general classes of systems (Vidyasagar 1986).

A dramatic observation (Doyle 1978) that the separation property of state feedback is lost for perturbed systems renewed the interest in robust control design. Most attention was given to the problem of robust stabilization. The case of norm-bounded uncertainty was reduced to a norm-minimization problem (Kimura 1984). Robust stabilization under parametric uncertainty was made tractable using the appealing result of Kharitonov (1978) on the stability of interval polynomial families. The design for robust performance integrates the classical and modern approaches (Anderson-Moore 1990) and remains the subject of intensive research.

The absence of accurate and simple models on the one hand and the presence of large disturbances and variations on the other hand are typical in some industries, especially in process control. This has given rise to adaptive control systems. Various mechanisms are used for parameter adjustment: model reference control (Whitaker 1958), self tuning control (Kalman 1958, Peterka 1970, Åström 1973), gain scheduling (Shamma-Athans 1990), and backstepping (Kokotovic 1991). This is an active research area with many applications.

The increasing availability of vast computing power at low cost, and the advances in computer science and engineering, are influencing developments in control. Recursive algorithmic solution of control problems is possible as opposed to the search for closed-form solutions.

Control systems can be seen as decision-making systems. This leads to interdisciplinary research and cross-fertilization. Emerging control areas include hybrid control systems (systems with continuous dynamics controlled by sequential machines), fuzzy logic control, parallel processing, neural networks and learning. On the other hand, control systems theory benefits other areas, such as signal processing, communications, numerical analysis, transport, and economics.
IFAC was born with modern control theory. The control problems which were important at that time included the launching, manoeuvring, guidance, and tracking of missiles and space vehicles. Now, forty years later, the challenges include better understanding and controlling manufacturing processes, with an eye on safety and the environment. Control education should provide a broad view of automatic control. Application areas are increasingly more diverse. Accordingly, the original technical committee on theory has evolved into several specialized technical committees in order to promote any and all aspects of contemporary control theory. IFAC involves the best control theorists and continues to be on the cutting edge of progress in our fascinating field. The interaction with control engineers remains essential; this is the key role of IFAC today.

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