CONSIDERATIONS ON THE DYNAMIC SYSTEM STUDY: FROM DEFINITION AND CLASSIFICATION TO ANALYSIS AND INTERPRETATION OF BEHAVIOR

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Abstract: *The purpose of this paper is to present in a current, synthetic and graphic form, the concepts specific to the field of system theory. System categories, from the literature, are presented in their dynamics and their particulates. At the same time, we naturally proposed a non-exhaustive classification of systems, depending on linearity, time behavior, number of input-output variables, interaction with the environment, ecological, technological and social aspects. Our research also tracks the behavior of vibration-induced mechanical structures even during their operation. These requests are nonlinear and involve, as a rule, many variables; as such, the graphical representations of their behavior are particularly complex. Current work techniques - program sequences, software, applications - allow for the realization of such representations with increasing fidelity, and the results. with proven applicability, increase the interest of research for dynamic systems in various fields of activity.*

Keywords: *systems theory, dynamic systems, interaction in the environment, modeling*

1. INTRODUCTION

Since ancient times, from the Babylonians, natural and social phenomena have been present in everyday activities of people, mathematicians and engineers alike. As human society has evolved, especially from a technical and scientific point of view, their importance has continuously increased [6, 9].

The study of natural and social phenomena has gradually led scientists to create mathematical models that embody their main features in an abstract formulation. Long-term surveys have shown that both natural phenomena and social phenomena are evolutionary phenomena, with their own dynamics. The fundamental methods of research in the field of natural and technical sciences are therefore instrumental observation and measurement (Fig. 1) [2].

The concept of a system has emerged and developed over time as a result of highlighting common relationships and behaviors for a number of processes and phenomena in different fields, which allowed them to be treated structurally and functionally, in a unitary, system integrator [1, 3].

The system concept is known to us and we frequently use it in everyday life. We often talk about economic, political, social, philosophical, and technological systems. We are also familiar with particular systems, such as the monetary system, computer systems, communications systems, etc. [4]. In the literature, there are several definitions for the concept of system, some reflecting the tendency of defining the system in a general scope, others the tendency to customize for a certain area of knowledge.

The notion of system therefore has a broad scope, being frequently encountered in science and technology in all fields of human thinking and action, but it is almost always associated with a specification attribute. For example, phrases such as "automatic system", "transmission system", "information system", "signaling system", "production system", "social system" [1, 4] are used as special terms.

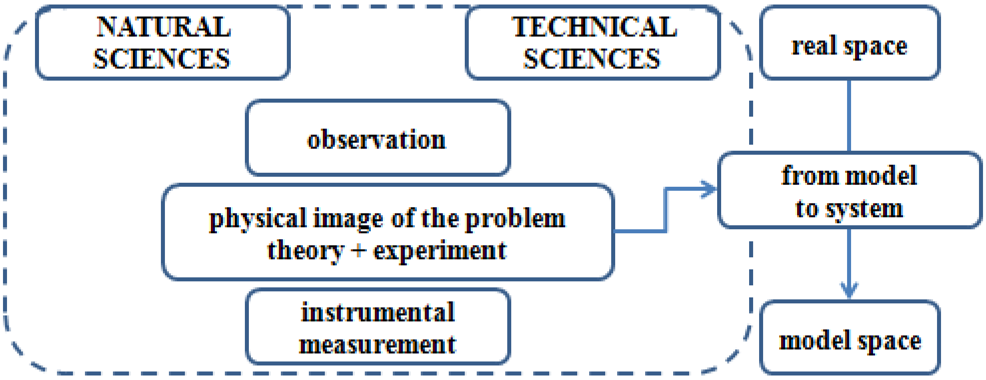


FIG. 1. Observation and instrumental measurement in relation to natural and technical sciences

In the sense of the present paper, we will understand through the system an ensemble of elements that interact both with each other and with the outside, on the basis of and with observance of laws and principles, in order to achieve a goal, a functionality. Interaction between the components of a system can give the system new properties, different from those of each component. In the case of physical (real) systems, interaction is performed on the basis of general physical-chemical laws, through mass and energy flows that carry information.

2. DEFINITION, CLASSIFICATION & MODELING OF DYNAMIC SYSTEMS

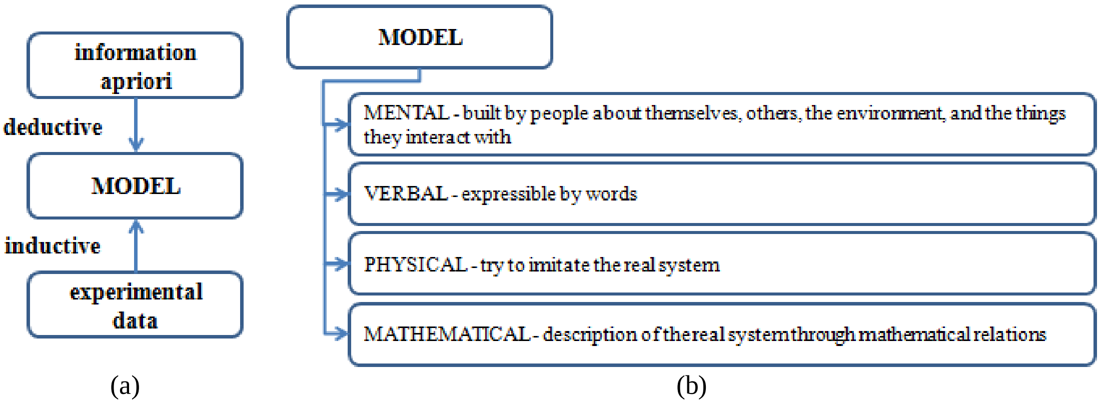
An almost equal importance to the concept of a system is the concept of building the model. The formulation of a theory can be called "model building". It is also possible to define the model as "a representation of the essential aspects of an existing system or of a system to be built, representing the knowledge of that system in a usable form."

Building the model can be based on two principles if there is knowledge and insight about the system. So we are talking about the white box component - if there is experimental input / output data from the system, and the black box component - if there is only a priori information (Fig. 2a).

In the vast field of science, there are few features that can not be described in mathematical terms or in few areas of interest that can not benefit models in the form of systems. The use of modeling and modeling has become an important tool in analyzing systems by enabling exploration of hypotheses that can not be easily tested by field or laboratory experiments.

Over time, representations of the model term have been proposed by many writers or researchers. Thus, Jackson et al. [7] propose an interpretation of the model by the idea of a particular representation of an idea or condition that varies in complexity from the simple form of attributing an action to a subject to the complex description of processes through mathematical equations.

From the perspective of other authors, the model is the formal description of the essential elements of a problem within a system of interest, sometimes even tools that help understand the way processes work and allow testing hypotheses in a systematic manner. On the other hand, Gillman [5] offers a simplified version, defining the model as a representation of reality. Another representation, this time much simplified, shows us four major categories of models, as shown in Fig. 2b.



(a) (b)

FIG. 2. a) Model construction options [2]; b) Various models and their representation [2]

It seems and it is really more complicated to classify systems. These are characterized by heterogeneity, variability in time and space, areas of thought and action, so one would expect a result of as many fields as possible. A classification and systematization of systems can be achieved by dualization as: *physical* and *abstract systems*, *dynamic* and *static*, *empirical* (*correlation*) and *mechanistic*, *simulative* and *analytical* etc.

Based on properties derived from the structural-unitary, causal-dynamic and informational nature of the systems, they can be divided into classes (categories). Systems belonging to a class have features, properties and similar behaviors [8]. In the following, according to [2, 8] we have structured, the main features for each mentioned systems:

- *linear systems* are those which under any circumstances verify the superposition principle (overlapping effects): the sum of the effects of the causes is equal to the effect of the sum of the causes. In other words, in a linear system the input signals are independent, so they do not interact within the system.
- *nonlinear systems* are those systems that do not satisfy the superposition principle in all cases. The nonconstructive way of defining nonlinear systems and the multitude of modes of manifestation of their nonlinearities lead to the idea of the impossibility of building a unitary theory of nonlinear systems.
- *continuous-time systems* are those systems in which input, status and output quantities take values at any time in the real-number set. Continuous time systems may be continuous (smooth or analog) or discontinuous. Continuous systems satisfy the property that for any initial state and any continuous input function (in mathematical sense), the state function X(t) and the output function Y(t) are also continuous functions. Continuous time systems that do not meet this property are discontinuous.
- *discrete time systems* are those systems in which input, state and output quantities only take values at certain discrete moments of time. Discrete time systems in which time discretization is uniform (constantly) are called discrete systems.
- *deterministic systems* are characterized by the lack of random variables and always provide the same predictions in the context of assigning a specific set of conditions.

- *non-deterministic* (*statistical*, *probabilistic*, *stochastic*) systems are characterized by the existence of a number of random variables and provide different predictions, in the context of assigning a specific set of conditions, the random variables within the model can take different values for each model run.
- *concentrated physical systems* are those where it can be considered with sufficient precision that physical quantities associated with any element of the system have the same value at all points of the element.
- *physical systems with distributed parameters* are those in which at least one physical dimension associated with a dimensional element of the system has values that differ sensitively from a point to another, it has distributed values along a line, plan, or space.
- *systems with constant parameters* (also called invariants or invariable over time) have a fixed structure and internal parameters constant over time, and *systems with variable parameters* (also called variants) have at least one variable that is internally variable over time. The state of a system with constant parameters initially in stationary mode can only be changed from the outside by the action of the input variables.
- *monovariable systems* have one input and one output. *Multi-variable systems* have at least two inputs and two outputs; In addition, at least one output is influenced by at least two inputs. Single-entry and multi-output systems as well as multi-input and single-out systems can be reduced to monovariable systems. Monovariable systems are also called single input-single output (SISO) systems, and multivariable systems are also called multi-input multi-output (MIMO) systems.
- *static systems* (called *non-memory systems*) are zero order systems (no state variables), with the output Y value at time t fully determined by the input value U at time t. In these systems, the output (in its totality) is instantly tracked (without delay) variations in time of entry. Static physical systems do not contain elements capable of storing and transferring significant amounts of mass and energy.
- *dynamic systems* (also called *memory systems*) have orders greater than zero and are characterized by the presence of transient regimes. Dynamic physical systems include elements capable of accumulating and transferring significant amounts of mass and energy at a finite speed.
- *open systems* are characterized by a one-way information flow.
- *closed systems* are systems where a bidirectional information flow can be highlighted, whereby the output size of a system element influences the future state of that element through other elements of the system.

3. PROBLEMATICS & NECESSITY FOR DYNAMIC SYSTEMS STUDY

An important category of systems with which literature is operated is the one inspired by natural phenomena and processes. These, as we know, have a pronounced evolutionary character [1, 2]. As such, the systems considered are dynamic and follow their own laws, defining for the researcher, to a greater or lesser extent, the status conditions of the evolutionary process itself that will retain our attention.

According to system theory, the study of such an evolutionary process involves selecting and then following a number of parameters that characterize the process or phenomenon (Fig. 3).

In mathematical language, this set of parameters represents the state of the system or process and forms a group of functions, always dependent on the time factor [3]. Dynamic systems are often described through the input-state-output formalism (pressure-state-response) as a set of first order differential equations. The choice of system states is the modeling process in which the created model will be verified [2].

The state of a dynamic and nonlinear system appears not only as an explicit function in terms of time, but also as a solution to an equation or system of equations that in fact describe a natural law that governs the phenomenon.

The number of status parameters required to be considered for a pertinent characterization of the status of a dim system is the number of degrees of freedom of the state. Time-varying dimensions, which define the degrees of freedom of the system, are called generalized coordinates.

The need to study dynamic systems appears as a result of attempts to better know and periodically control mechanical systems prone to destruction, damage or dysfunction as a result of the vibrations associated with their dynamic operation.

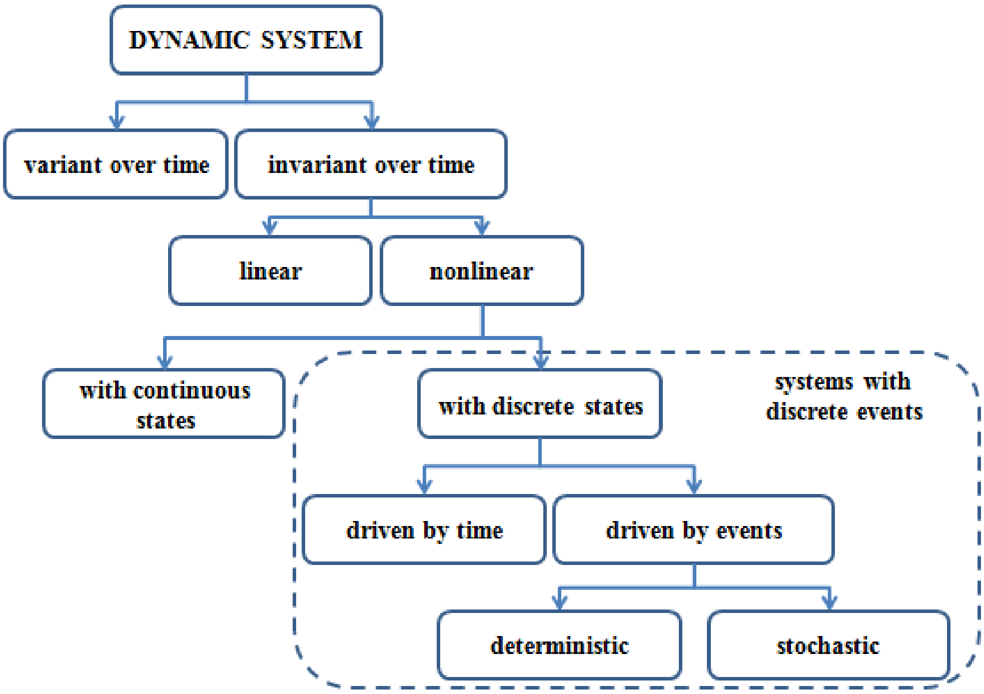


FIG. 3. Overall classification of dynamic systems

The main types of problems associated with the theoretical and experimental analysis of vibrations of mechanical systems derive from their shematic representation:

- *initial modeling of dynamic system behavior* - consists in determining the R system response to a known P disruption, knowing the block S (ie the structure of the system and the values of the parameters that define it).

This is of particular practical importance, especially in the design phase of structures, as it allows more or less accurate estimation of the dynamic demands to which the structure will be subjected in operation. This approach creates the possibility of optimizing by calculation (genetic algorithms) of the S block with respect to different reliability criteria and imposed functional performances.

- *identifying affected system elements* - consists of identifying on an existing structure model (block S) when it is known by direct measurement the R response to P-perturbations determined under operating conditions or laboratory conditions.

In this case, inverse methods are applied, ie one or more parameters of the analytical model are changed until the cost function adopted for comparing the calculated response and the measured response R for the same perturbation P is minimum or small enough from the practical point of view.

This process is intended to induce some vibrational modes. Their comparison with their respective proper modes and frequencies, obtained by calculation for the dynamic system, allows the correct dimensioning of some system parameters.

- *determination of disturbances* - presupposes the very accurate knowledge of the block S corresponding to a physical structure as well as the response R to the perturbation P to be determined.

In fact, this is a measurement problem, the structure being in this case even the tool that does not have to significantly affect perturbation, being calibrated and framed in a certain class of precision. In this regard, laboratory vehicles are used to determine the disturbances induced by the bumps of the transport ways. The description with a satisfactory approximation of the perturbations to which different types of structures are subjected is essential for the correct resolution of the problems encountered.

4. ANALYSIS & INTERPRETATION OF DYNAMIC SYSTEMS BEHAVIOR

The methods of analysis of the behavior of mechanical dynamic systems and associated random vibrations have been steadily developing over the last decades due to the high requirements of designing structures and equipment with superior functional performance with high reliability at complex loads during their operation. Examples of this are the demands caused by the turbulent flow of fluids, the dynamic loads caused by the movements due to earthquakes, wind, waves, and runway unevenness.

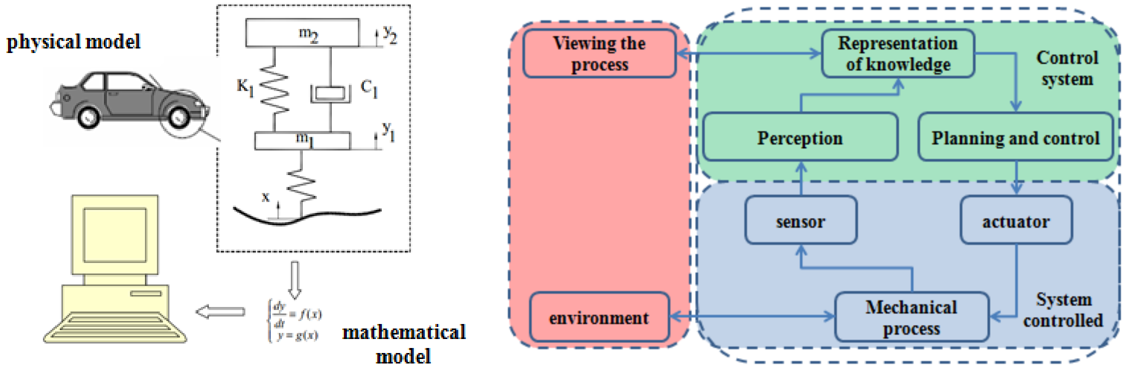
A common feature of these types of demands lies in the impossibility of describing their evolution in time deterministically as a result of the behavioral dynamics of the whole system (the black box concept) [2]. The dynamic behavior of random mechanical systems is also described by a series of stochastic differential equations whose treatment depends essentially on how random factors intervene.

Thus, the following types of equations were established [4]: *differential equations with random in situ conditions* - with an important role in statistical mechanics, statistical thermodynamics, a priori analysis of spacecraft trajectories; *differential equations with random coefficients* - used in the study of systems whose parameters have imprecise values due to material or execution imperfections, inherent or random variables, such as the case of objects on a conveyor belt; *differential equations in which the random part enters as a non-homogeneous term* - representing in fact the external disturbance applied to the system as a random function of time (random process).

Of these possible states, the last category of equations has the widest field of application, being used mainly in modeling the dynamic behavior of mechanical structures, namely road and railway vehicles, heavy-duty ships, aircraft, civil and industrial buildings, heavy machinery , machine tools, etc.

The whole approach of the system analysis methodology is based on the idea of the possibility to continuously improve and improve the performances of any system by analyzing the existing system and designing a more efficient system. In such a complex process, specific stages of analysis, design and calibration are considered, steps necessary to make the transition from the real physical model to the real mathematical model, as is also shown in Fig. 4a.

Of the methods currently known, simulation is the method that allows the analysis of complex processes, reproduced by generating events similar to those actually occurring. This method is used to test the project variants for the best selection, to evaluate the performances of the new system implemented, and to analyze and control the behavior of a system (Fig. 4b).



(a) (b)

FIG. 4. a) Systemic Analysis Methodology; b) Analysis and behavioral control of a dynamic system

The simulation requires a large amount of data, but it can reveal hidden links or system imperfections that may occur later in life. Informational methods - ubiquitous in analyzing and designing performance systems, as well as implementing expert systems and decision support systems - use or combine methods of analysis from classical methodologies, and successfully pass the transition from a partially controlled system to a totally controlled system.

5. CONCLUSIONS

Because most natural and technical systems are nonlinear dynamical systems, ie systems characterized by the presence of chaotic (non-deterministic) behavior, the study, respectively their definition and characterization, the classification and the analysis of the control possibilities require the use of the most diverse working methods. There are suitable methods of modeling, simulation, analysis-diagnostics - mostly informative, current methods and with the possibility of approaching some multicriterial analysis sequences.

Mechanical dynamic systems used in the technique for over a century (road and rail vehicles, ships, aircraft, civil and industrial construction, machinery, machine tools, etc.) have the mathematical formalism of input-state-output (pressure- answer). It refers to dynamics involving many state variables that make modeling difficult in itself. Current work techniques - program sequences, software, applications - make it possible to create more and more fidelity representations, and application results increase the interest of research for dynamic systems in many fields of activity to limit negative effects and dysfunctions, both in inside the system considered, and in the external environment.

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