Information and thermodynamic fundamentals of cyber physical systems modeling

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Abstract. The issues of cyber physical systems modeling are considered. The criteria of information and energy efficiency for cyber physical systems as the main object of innovation are proposed. The creation of cyber physical systems is proposed to be considered within the framework of structured problem areas and related tasks of disclosing uncertainty when creating innovations. Structures of problem areas, including databases and knowledge bases, determine the possibility of composition and decomposition of cyber physical systems. It is proposed to use models of thermodynamic and informational entropy to formulate goals and evaluate the properties of cyber physical systems. The use of informational entropy is obvious, the use of thermodynamic entropy and energy efficiency estimates are determined by global problems and trends in innovation. These include, inter alia, the transition from energy-intensive technologies and industries to high-tech. The issues of the relationship of thermodynamic and informational entropy are considered. The transition to the presentation of the life cycle of cyber physical systems at the levels of the problem domain and the further transition to the end-to-end digital life cycle are proposed to be performed by decomposing the goal and applying system and process models.

1. Introduction

The creation of cyber physical systems (CPS) was a natural result of the development of cybernetics methods and technologies. The introduction of CPS into various physical environments of animate and inanimate nature or artificially created environments is limited only by the sufficiency of knowledge represented by mathematical models. Helen Gill introduced the term “cyber physical systems” in 2006 and defined the primary goals of their research as a forecast for 10 -20 years of development of engineering and controlled systems, as well as deep integration of physical and cybernetic components in the design. Edward Lee [1] stated: “... The term “CPS ” is more fundamental and durable than all the popular terms of Industry 4.0, because it has no direct reference either to the implementation of the approach (for example, “Internet ” in IoT) or to specific applications ( for example, “Industry” in Industry 4.0). It focuses instead on the fundamental intellectual problem of conjoining the engineering traditions of the cyber and the physical worlds. One can talk about a “cyber-physical systems theory ...” In the same article [1], as well as in the works [2-5] and in others, substantial attention is paid to the creation of models and modeling of CPS. Consideration of CPS models under various conditions of probabilistic representation, the transition from graph models to functional blocks or typical
elements of Industry 4.0, the concept and classification of CFS and their components, is certainly relevant. It is also relevant to create, in the terminology of Industry 4.0, “big data” and this is implemented in the form of databases (DBs) and knowledge bases (KBs). Further aggregation of information corresponds to the terms “subject area” and “problem area”. The article does not specifically address issues of relevant terminology, simplified concepts are presented to demonstrate the process of continuous and consecutive development of the CPS in a single direction. A subject area is an area of activity that is considered to be considered separately and which contains facts, phenomena, processes and their relationships in the framework of achieving goals and meeting accepted criteria. The problem area includes the subject area, as well as all knowledge about its occurrence, condition and development. In well-known publications, the modeling of CPS is considered, as a rule, in relation to local objects. In the proposed setting, issues related to the CPS are considered within the framework of problem areas. This allows you to create them with long-term goals in the face of uncertainty and to purposefully perform their composition and decomposition. The achievement of information and energy efficiency criteria is considered as the most important goals.

2. The essence and attributes of the cyber physical system within the framework of the problem area

The modeling of CPS as a part of problem areas can be represented as a sequential disclosure of the uncertainties of the physical environment. At the same time, the innovative nature of CPS leads to the need to formalize their creation as part of an innovative project (IP). IP management is always associated with the disclosure of uncertainties [6] and the emergence of new entities and their attributes. Here, the essence is understood as “any concrete or abstract thing of interest, including the union of things” in accordance with [7], and an attribute as a characteristic of an entity, in accordance with [8]. Under conditions of uncertainty under in the absence of statistical data, the development of a problem area is carried out using databases and knowledge bases supplemented with artificial intelligence. The terms “essence”, “attribute”, “Internet of things”, “industrial Internet of things”, “big data” are defined in international and harmonized in national Russian standards “Artificial intelligence” and others. These terms are necessary for an accurate representation of the CPS and related phenomena and processes.

3. Models of thermodynamic and informational entropy

Mathematical models focused on CPS features are used depending on the problem area in which specific CPS are created. Such models are used in optimization problems and in quality theory to solve the problems of analysis and synthesis of products, services and processes. An analytical review of the models in each problem area presents separate tasks. Innovative activity always develops explicitly or implicitly in at least two directions at the same time. The first direction includes the generation of innovations and the creation of innovations of different levels in the face of uncertainty based on the collection, processing of information and the development of managements within the framework of innovative mono-, multi- and megaprojects. Corresponding models and methods are presented in cybernetics and in information theory. Information in all aspects is the basis of both the sixth cycle of Kondratiev and the concept of Industry 4.0. The second direction is traced at the “macro level” according to the laws of increasing energy efficiency in the sequence of Kondratiev’s cycles and in the sequence of industrial revolutions from “Industry 1.0” to “Industry 4.0”. These processes require additional research. Considering specific examples, it can be argued that each subsequent innovation created to solve a specific problem has the best energy efficiency, understood directly or indirectly. Possible exceptions are military innovations and intermediate innovations that are improved in the process of innovative development. These global and local processes represent the basis of the theory of innovative development. Equally important global processes are the increasing demand for energy and global warming. The classical laws of thermodynamics and their “engineering” interpretations can be applied to the analysis and synthesis of CPS in problem areas.
A group of concepts of “entropy”, introduced in general and quantum physics is used to represent and characterize thermodynamic and information processes. The conditions and limitations of applying this or that interpretation of entropy are controversial and not the subject of the article, however, there are general trends that apply to the creation of CPS. Entropy determines the measure of irreversible energy dissipation in thermodynamics. In statistical thermodynamics, Entropy is expressed by the number of microstates for the implementation of the macrostate. Entropy it serves as a measure of uncertainty in information theory. Entropy reflects the properties of the physical subsystem and serves as an object of influence on the part of the cybernetic subsystem representing a measure of disorder and characterizing uncertainty. The application of the conservation law of energy and its particular cases for different environments provides targeted behavior of the CPS. Information entropy increases with the disordered distribution of information resources and decreases with their ordering.

Determining the relationship between thermodynamic and informational entropy is a debatable task. The joint use of criteria built on their basis contributes to the disclosure of uncertainties using the CPS. In this regard, it is interesting to cite the foregoing in [9]: “The quantum theory of information directly relates information to energy through von Neumann entropy, which can be considered the main physical characteristic of the energy-information process. Changing information is accompanied by a change in energy, and the exchange of information is directly related to the exchange of energy (the reverse is also true) - an important conclusion that has been made in the physics of quantum information”.

4. Formulation of the goal of the cyber physical system
The purpose of the system can be determined by the achievement of the system of values of its basic parameters or the achievement of the desired state. There are other definitions of the purpose of the system. The concept of a goal is always associated with the concept of a function leading the system to its achievement.

It would be right to present the goal of CPS as an optimization of interaction with the physical world. The physical world here means objects of animate and inanimate nature or artificially created. Since the main categories in the global representation are matter and energy, the formulation of the primary goal of the FSC is carried out using energy criteria. It is appropriate to name the most important source of primary energy - the sun. All human activity, including the creation of CPS, is directly or indirectly associated with the energy of the sun. The book [10] considers the tasks of formulating the primary goal, including the theological one, and many religions identify all principles with the sun. Therefore, the primary goal of CPS when interacting with the material world is to achieve energy efficiency of such interaction.

5. Compositions and decompositions of cyber physical systems
Composition of CPS in problem areas is carried out both by creating new systems, and by complementing existing components presented in the concept of "Industry 4.0". Examples are given in [11,12]. Synthesis of objects containing CPS features can be performed on the basis of structured databases and knowledge bases [13]. CPS and the problem area as a whole are subject to structuring.

The decomposition of CPS, where the primary goal is to achieve maximum energy efficiency, can be based on the decomposition of this criterion into dependent ones, which indirectly provide optimization in accordance with the selected mathematical model. A typical example is the increase in energy efficiency of buildings and structures. When creating CPS for technical purposes, the formalized functional decomposition apparatus IDEF0 can be supplemented with the functions of artificial intelligence, the Internet of things, machine-to-machine interaction, etc.

6. Life cycles of cyber physical systems
The life cycle of CPS can be described on the basis of well-known standards, process and system approaches. However, the digitalization task covers all the elements of the CPS and all processes of
the life cycle. Digitalization processes should lead to a complete end-to-end life cycle. In this direction, the tasks of minimizing the human factor continue to be problematic. They are successively resolved by moving to supporting decisions, developing databases and knowledge, transferring individual functions to a computer based on training, and introducing artificial intelligence.

7. Conclusions
The approach presented is an attempt to systematize the concept of CPS. The close connection of the cybernetic and physical world and the inherent dynamic development should be presented at all levels created by the CPS. The article proposes to consider the FSC not only as a set of tools for performing a specific task, but also as part of the problem area associated with it informationally and participating in achieving a global goal.

CPS in many aspects is a model, including a global model. Therefore, when modeling them, it is proposed to turn to informational and thermodynamic foundations for subsequent decomposition and composition when creating technical applications.

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