Designing cyber-physical digital production of the Industry 4.0

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Abstract. The task is to design projection route of the Industry 4.0 item designing digital company. It is clear that existing projection solutions for production divisions cannot be applied to create smart factories. A creation feature of the new type company creation is cyber and physical systems semantic form representation implementation in production division functionality ways descriptions which are applied in the company virtual environment. An Industry 4.0 companies has equal representation forms in mathematical models and in ontology models. To project such companies they must apply the universal cyber and physical systems base models and the special cyber and physical systems of specific purpose models. There is a projection route of the Industry 4.0 cyber and physical production.

1. Introduction

Industrial activity digitalizing of industrial companies widely known as a German concept of the Industry 4.0 \cite{1, 2} requires to create the new types of item designing companies equipped with cyber and physical systems. The new type of production company idea is to create physical and virtual infrastructure of cyber and physical systems (CPS) interaction which together organize the full cycle of technological operations without human participation \cite{3, 4}.

The task to synthesize cyber and physical production divisions from the scientific point of view is like the task to synthesize complicated technical systems which components are industrial robots \cite{5}. The primary feature how to synthesize those systems in the modern stage is the presence of structural units of production division virtual component (company cloud environment) which contains the digital twin (model) of cyber and physical system \cite{6, 7}.

In this line the traditional approaches how to project the complicated systems are not suitable for synthesizing of cyber and physical automatic production \cite{8, 9}. The important task is to design new algorithms (routes) of digital companies projection to unite projection solutions to project the production divisions in physical level and also in the level of cyber and physical systems digital twins \cite{10}.

The primary ideas and solutions how to formalize the cyber and physical systems digital twins description the researchers see in semantic forms of production machines properties. CPS properties descriptions in statistical forms in practice are known as program code placed in the company virtual environment. Semantic ways to describe CPSs are based in digital production ontology and may
adequately represent the physical samples of technological equipment in the company digital environment of the item manufacturing production processes [11].

As a single project production the traditional methods of structure and parameters complicated technical systems mathematical models synthesis and cyber and physical systems semantic description methods synthesis may create the pass through algorithm of automatic production projection of the Industry 4.0 item designing companies.

2. Cyber and physical production projection route

To project the projection routes of complicated technical systems begins from projection object system research and existing methods and means of the company project activity. The first step of project activity is to create the projection process scenario and its realization stages in the company. System research of projection object requires an approach to organize project activity in which the quality criteria of complicated technical systems are being realized keeping in mind some components quality criteria (cyber and physical systems). Such approach to organize project activity can be realized by implementing to new type company of CAD (Computer Aided Design) systems creation all stages.

Digital production projection is an oriented process in an adequate description form of physical automatic workshop searching using a method (a sequence of designer actions) which is a fixed procedure how to transform the initial data (technical task requirements) to represent the object. In this case digital production projection method describes the logical sequence of designer actions oriented to realize the new type company creation project procedures.

Cyber and physical production division projection route is given in figure 1. Digital production designer project activity initial data is the requirements of technical task (TT) to project a company of new type. TT requirements are formed from the data bank known today in digital production creation.

TT requirements and digital production organization methods information help the designer to parameterize the industrial company condition space equipped with cyber and physical systems which together create a smart factory.

Together cyber and physical systems can be described in two models:

- digital production mathematical model which is formalized description of technological operations done with manipulator robots;
- digital production semantic model which is ontology of actions being done with the industrial machines.

Both types of cyber and physical production division descriptions must be decomposed which take it from the general descriptions of cyber and physical systems to the private descriptions of some production machines. Private types of CPSs descriptions are done semantically and mathematically to represent the base cyber and physical systems and cyber and physical systems of different industrial purposes. Complicated technical system models decomposition is based with methods of structural synthesis applicable to the different classes of CPSs.

Complicated technical system models decomposition is a procedure of function separation and digital production descriptions into functions and descriptions of some components (cyber and physical systems). In this case CPS self-organization requires that the models decomposition is done with informative, functional and structural redundancy of digital production technological equipment which provides safety against technological procedures completion failure. Model decomposition application of cyber and physical production description may apply some hierarchy to separate CPSs and hierarchy structure of CPSs where closed set of technological operations are being realized. Cyber and physical production structure hierarchy depth defines the complication of digital systems control in the company.

Digital company structural synthesis method is based on the family existence hypothesis (classes) of necessary functional purpose cyber and physical system. For those components of cyber and physical production the task of technical equipment workshop composition is based on the choice from each family of CPSs in quantity which is sufficient to complete the product manufacturing plan.
The primary quality of CPS semantic and mathematical models is its adequacy. The model adequacy keeps in its form and parameters equations of all CPS properties which are relevant for the digital cyber and physical production divisions projection. Model adequacy evaluation is done with the correspondent quality criteria. The division of digital production condition space into mathematical and semantic forms of descriptions describes automatic technological lines as organized sets of CPSs and sets of CPS behavior descriptions into physical and virtual levels while the product manufacturing.

Sets of models which describe in details CPS functions of different purpose and set of parameters can characterize with numbers the dynamic properties of CPS may form the space of project solutions

**Figure 1.** Industry 4.0 cyber and physical production projection route.
to choose the technical appearance of production division. The project solutions space is a set of formalized description methods how to interact cyber and physical systems of different purpose which have different to each other sets of passport technical characteristics. The space of project solutions has a significant size of technical and algorithm options of cyber and physical digital production consistency.

Each option of cyber and physical production which is a part of project solutions space has its own quality criteria which do not always correspond to the requirements of technical task to project digital production. Options elimination in its characteristics which do not correspond to the requirements of TT is done with primary rule which includes the elimination criteria of project solutions plurality. The elimination of project solutions plurality with value of size acceptability of the speaking plurality being formed may provide project procedures which are acceptable for the designer as a number of options which fully correspond in its properties to the requirements of TT to project digital production.

The second procedure of speaking plurality elimination is based on parametric optimization of quality private criteria of each project solution option. In practice they use different ways of private quality criteria convolution in particular additive and multiply convolutions which may calculate quality functions for each project solution. The best result is granted with additive and separable private quality criteria.

The division of CPS quality criteria into additive and separable criteria may define the parametric digital production space as the description of tensile fields which primary property is non-variability of physical values being used when the acceptable change of its projection in different coordinate systems (digital production quality criteria in general). CPS representation as additive and separable quality criteria grants invariability of parametric spaces changes to describe a digital production relative to linear transformations of its coordinates systems.

Two-stage procedure of project solutions space elimination is based on structural and parametric optimization may show one or several construction options of cyber and physical production which correspond to all requirements to project a smart factory.

Structural optimization provides the choice of cyber and physical system best topology which provides the extreme point of quality production division activity indication. Such quality indication could be connection between mass unit of the product being manufactured to the unit of length to which this product is being transported inside the workshop. The maximum point of this criterion provides the production division functionality with the best efficiency.

Parametric optimization helps the designer to choose the number value of cyber and physical systems functionality parameters in its dynamic properties which provides reliable, accurate and fast functionality of production division in automatic mode.

The creation of cyber and physical production divisions in modern stage can be done if there are no creation methods, norm documents (state standards) or existing prototypes. Given in figure 1 the base of knowledge and data bases of mathematical criteria, digital production data, semantic dictionaries and other is a type of mathematical and informative support of designer project activity being done automatized.

They must also know that the result quality evaluation is being formed in its final stage of digital production option which significantly depends on the methods of parametric (vector) optimization of project solutions. To improve the digital production quality criteria the projection is defined as a set of iterative procedures which may change the order and types of mathematical and semantic forms of CPS description which they have implemented in initial stages of projection. In this case the size can be changed for digital production parametric description and also the plurality of project solutions to choose the technical appearance of company. The space size defines the time of projection and project task solution accuracy.

3. Conclusion
The Industry 4.0 cyber and physical production division projection algorithm key procedure is decomposition of mathematical and semantic digital company description models. Decomposition of
models may transfer from the space of complicated technical system condition to the space of some production machines conditions.

According to its functional purpose all cyber and physical systems of industrial automatizing can be united into independent classes of equipment which are different from each other by the way of technological operations completion and types of informative technologies being used.

The analysis of perspective and existing today cyber and physical systems of industrial purpose may describe in its functionality the components which are general for each classes of CPS. Those components are the base for creation of mathematical and semantic descriptions of the base cyber and physical system. Unique components and technologies which are specialized for cyber and physical systems may augment the description of the base CPS and create the libraries of different purposes CPS description.

Such unified and standardized approach to describe cyber and physical systems models help the designer to create instrument means of automatic production projection based on formalized representation of different classes of CPS properties.

Instrument means of automatic production projection is a set of hardware and program components including the components of mathematical and semantic CPS description which automatize the project activity of designer which is oriented to find out the digital production option which will be realized in scheme and technical way.

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