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Abstract. Cyber-modelling is the information models simulation process describing in a mathematical and formal logic languages (phenomenon models) how cyber-physical systems interaction mechanisms are united with different control laws and parameter values. The equation complexity represented in different levels of cyber-physical production systems hierarchy and non-equations of algebra, logic, end-subtraction, vector and matrices form in a discreet and uninterrupted times are defined with an aggregated number in the industrial automatics element control loop. The cyber-modelling is done for statistic and dynamic processes and equipment states being monitored in a virtual environment fixating actual in a time interval technological data. The cyber-modelling is done with integrated calculation equipment systems with parallel physical production processes of item manufacturing. The model time faster than physical processes let prognosticate the corrections modifying control signals and phase variables of cyber-physical systems united in an assembly conveyor. The cyber-modelling advantage is an expanded number of cycles to optimize the technological processes, which are calculated with integrated calculation systems using consecutive approximation method. They describe the cyber-modelling technology and propose the information models based on phenomenon cyber-physical production processes descriptions with general control theory terms, calculations and connection for hierarchy controlling structures.

1. Introduction

A cyber-physical production (CPP) is a type of modern industrial object where in parallel they function cyber-physical systems (CPSs), the infrastructure control digital means, the product quality control means, transport machines and other connected to the information and calculation data transmission computer nets virtual environment [1, 2]. The industrial automatizing methods and means complex application is to keep in count the determined CPP indications, to control CPS editable characteristics and to work out stochastic disturbances, which action the equipment randomly [3, 4].

An ordered industrial infrastructure objects plurality and relations among them forms the hierarchy CPP structure and CPS technological chains united as a product transportation conveyor. The CPP hierarchy structure net model reflects mathematically the CPS properties and has the control means

according to the automatizing element priority level in the technological environment [5, 6]. The automatizing loops hierarchy justified with CPS co-subordination in the digital company control system may be reflected in the hierarchy model where the starting and edge states are defined with being completed technological processes physical laws and cyber-modelling results [7, 8].

The CPS private models integration and CPP dynamic system model is done in the level of edge, fog and cloud net units program codes using calculation procedures and knowledge bases to form industrial object digital twin for the product manufacturing. The information models hierarchy let them be divided in a CPP virtual environment and shorten the calculation volume for a correspondent CPP communication net unit [9, 10].

The CPP control system hierarchy structure organizes the company information space with correlation data connection for the processes and CPSs being controlled within the general production object technological task. To evaluate the current and prognosticated CPP states being calculated with a digital twin are formed in the technological virtual environment components with cyber-modelling means [11, 12]. The CPS being controlled parameters values being received are used to provide the technological environment non-conflict control, which orient the digital company production data. The information models similarity within the different groups, which describes a technological object and processes are in the control function unique for a particular CPS type [13, 14].

The CPS control loops putting in mechanism is identical to the information model structures and uses the technological system static and dynamic characteristics in the cyber-modelling environment to solve the production processes parametric regulation tasks. Physical and logical CPS interaction principle in the CPP information model are based on parallel calculations technology, which include the synchronized net transmission of different physical and virtual nature appearance data [15]. The information model CPP properties parametric representation accuracy is defined with the CPS mathematical description adequacy, which control procedures follow the industrial object dynamic system hierarchy scheme, which is true for its all possible states [16, 17].

2. The CPP information model

The CPP information model is a way of the item manufacturing technological processes phenomenon description according to their completion sequence in a real industrial object. As much as technological processes the information model objects are CPSs with a complicated structure organization. The real objects and processes information model similarity is reached with its adequate description in mathematical languages and formal logics with automatics elements dynamic equations united in a system of non-linear dependencies. The CPP system models reflect the CPS being passed physical control laws, calculations and connections in the parameter edges of the industrial object efficient functioning. The CPP information models are used to describe the CPS joint actions and their industrial environment completion states and technological operations interconnections.

The CPP technological process formal description for the quality heterogeneous in their nature but being completed with the same type of CPSs is based on private algebra and logical equations with given edge states being solved out with number means. The CPS models are a part of the Industry 4.0 information technologies and shows a CPP with a dynamic system with different degrees of processes detailing. The CPS models dynamics is considered with equations coefficients parametric settings of physical and information item manufacturing processes.

A given set of technological operations completion ending is seen by the information model as an event that changes the CPP state vector, which characterize the true behavior of CPS working modes. The CPS settings and technological data processing processes value coefficients updating synchronizing provides the CPS intersystem interaction, which describes the net units calculation load-up and traffic transmission in the CPP communication channels.

The information models, which is the CPP description core have an isomorph property and include the following technological features [18, 19]:

- each CPP model element is equal to physical or virtual heterogeneous CPSs components divided

in the state parameters;
- the CPS technical specifications and CPS intersystem interaction technologies quantity representation aggregated in the general plant process is defined with parametric model settings;
- logical states, which reflect the being completed technological processes sequence are marked in the equation system number solutions procedures, which are adequate to the item manufacturing CPP chains description model and other.

The CPP system and their elements simulation procedures are based on parallel data application principle in the virtual environment (model) and physical environment (technological). Parts conveyor transportation in the production process with material tides organization rules confirmed with cyber-modelling positive results. Item transportation particular routes work-out and technological complex working harmony is evaluated generally with a digital production operation indications system calculated after being manufactured item processes data and for CPS resources, which functions are defined with operations being completed content. Information models and cyber-modelling software tools are smart factories provision types perspective for the Industry 4.0 production safety standards implementation.

3. The technological environment cyber-modelling

The CPP mathematical monitoring system aggregates information to analyze the data and synthesize the industrial object processes regulating actions. The production control CPS and equipment real state is formed after some measuring tasks solutions registering fact process parameters. The CPP virtual image reflects the company physical and information space is based on industrial object properties and characteristics representation with process mathematical models as equations and automatic control theory terms. Ways to describe the automatics elements, which participate in all CPP technological processes chains is given in table 1.

Table 1. Ways to describe the automatics elements, which participate in all CPP technological processes chains.

Industrial infrastructure object	Information model	CPP properties and technologies
Technological complex	Systems of discrete automatics equations in vector and matrix form	The augmented reality net centering control, multi-agent system, cloud calculations, BigData, vertical hierarchy structure
Cyber-physical production section	Automatic regulation discrete equation with a control channel delay	Intersystem interaction, discrete control, fog calculations, horizontal hierarchy structure
Cyber-physical system	Differential and end difference automatics equations for a closed control loop	The Internet of Things wireless communications, adaptive control, edge calculations
Executive mechanisms, calculation or net units	Algebra and logic recurrent type equations for an open automatics loop	Stochastic regulation, machine vision and machine learning, sensors, additive technologies

The CPP system dynamics combines the components of small and medium automatizing and is controlled with parameters being measured, which measuring true state is of the real time scale. Technological processes parameters distributed in CPP calculation net units are transmitted in the modelling virtual environment, which controls a discrete hierarchy system of industrial purpose. The cyber-modelling environment tools are alternative measurement devices, which provides virtual

«dissections» of the company information model to control production relations forms and technological equipment functioning parameters. The technological processes modelling cyber-function implementation in the production environment adequate for the Industry 4.0 organization and technical concept, which is justified with:

- the CPS process core calculation potency resource restrictions;
- the CPS net communications topology change high dynamics;
- the combination of CPS control system elements with continuous and discrete interaction principles and other.

The cyber-modelling is applied for the automatics elements, which were never before in the industrial infrastructure — CPSs, which in parallel complete the physical process and its software calculation. The cyber-modelling tools are used for CPS information models to prognosticate the equipment behavior in the technological environment changing states. The software set to model the technological processes is placed in edge, fog and cloud net units engaging calculation resources, which equal in the calculation accuracy with the CPS process core capabilities.

The processes to be modelled correspond the CPS static states (in a fixed moment of time) and CPS dynamic states (in a given time interval). The modelling initial data are CPS technical specifications and experimental statistics collected in the CPP functioning. The cyber-modelling results are control signals related to the industrial technologies of the CPS executive mechanisms movement synchronized for the item manufacturing technological task group completion.

4. Conclusion

Automatizing and the Industry 4.0 technological tasks optimal regulation is based on approaches to construct a CPP using CPS and processes information models based on the general control theory, calculation and connection, which target function is to create quality parts (items). The more rational tools choice to define a way of technological production and CPS control laws is done with numeric solution for a recurrent equations set of dynamic system information model represented in a discrete time of analytical dependencies uniting conveyor processes. Technological processes stable realization scheme is done in a cyber-modelling environment to calculate the balance relations parameters of variables, which control the CPS modes.

The cyber-modelling objects are industrial CPSs and current technological processes, which are described in a CPP information model with a controlled variables set, restrictions system and mathematical equations, which are true for space and time tides of the item being manufactured conveyor movement. For the digital company virtual environment the cyber-modelling tools are a universal mean to provide monitor-ability, control-ability and technological processes uninterrupted state evaluating situation information done in a CPP in some particular starting and intermediary or finishing moments of time. The CPP workshops states modelling in time intervals is done to control the manufacturing order or item assembly, the conveyor item tides movement, by-operation technological processes characteristics and other properties and parameters of an industrial object reflecting in the company virtual space for a chain how to create a new item.

The production regulation process equations solution based on a cyber-modelling is an information model program simulation for different sets of initial data establishing CPS functionality parameters and conveyor parts transportation movement. A possibility to realize production processes mathematical analysis with available digital company resources for information model equations calculation transform the CPS control signal into several interconnected tides being transmitted in a communication net and containing the regulating actions values in messages. The CPP tasks control algorithms require processing of technological data measuring results in a model environment where the processes being analyzed are given in more details (by-operation).

The presence of several control equations proper for a CPP hierarchy structure justifies the information model application of vector and matrices equations and non-equations not approximated to

a scale. The CPS autonomous control done in an isolated closed loop is performed under not fully CPS regulator definition about the general technological environment states. Because of this the production process control for CPS separate parts and workshop assembly items must engage some new not used before technologies such as a cyber-modelling in the company virtual environment. The process equations strong mathematical dependencies connecting CPS controlling variables in neighbor steps of a technological route, which may transfer the system to the discrete in time operations and quant in level signals to describe regulator information model with a higher priority level in the hierarchy scheme.

Today there is a number of program products in particular like Tecnomatix plant simulation oriented to model the digital production technological processes. The used modelling tools let monitor collection and consumption of materials and goods stocks technological operations, which may also control the conveyor item tides movement and define the production process type and its properties and study CPS statistic models with determined characteristics and pass to its dynamic models and other. With this the CPS functional capabilities related to the virtual control in the modern state of the Industry 4.0 are factors to restrict the ready program tools application. The CPP designer interest is oriented to synthesize new program components and CPS information models supporting discrete control with the industrial Internet of Things nets and modelling being done in a CPS in parallel with physical processes.

References

[1] Osterrieder P, Budde L and Friedli T 2020 *International journal of production economics* **221** 107476
[2] Walia J S, Hämmäinen H, Kilkki K and Yrjola S 2019 *Computers in industry* **111** 108-20
[3] Antons O and Arlinghaus J C 2020 *Procedia CIRP* **93** 316-22
[4] Napoleone A, Macchi M and Pozzetti A 2020 *Journal of manufacturing systems* **54** 305-35
[5] Komoto H, Kondoh S, Furukawa Y and Sawada H 2019 *Procedia CIRP* **81** 334-9
[6] Lee J, Lee Y C and Kim J T 2021 *Journal of materials processing technology* **290** 116972
[7] Won J Y and Park M J 2020 *Technological forecasting and social change* **157** 120117
[8] Zakoldaev D A, Gurjanov A V, Shukalov A V and Zharinov I O 2019 *IOP Conference Series: Materials Science and Engineering* **582** 012008
[9] Liu B, Zhang Y, Lv J, Majeed A, Chen C-H and Zhang D 2021 *Robotics and computer-integrated manufacturing* **70** 102128
[10] Peng H, Liu C, Zhao D and Han J 2019 *Physica A: statistical mechanics and its applications* **532** 121865
[11] Jeon B and Suh S-H 2018 *Procedia manufacturing* **26** 1094-106
[12] Li M, Jiang M, Lyu Z, Chen Q, Wu H and Huang G Q 2020 *Procedia manufacturing* **51** 1229-36
[13] Afrin M, Jin J, Rahman A, Tian Y-C and Kulkarni A 2019 *Future generation computer systems* **97** 119-30
[14] Padovano A, Longo F, Nicoletti L and Mirabelli G 2018 *IFAC-PapersOnLine* **51(11)** 631-6
[15] Liu W, Kong C, Niu Q, Jiang J and Zhou X 2020 *Robotics and computer-integrated manufacturing* **61** 101842
[16] Wang Q, Liu X, Liu Z and Xiang Q 2020 *International journal of production economics* **220** 107458
[17] Lin Y-J, Wei S-H and Huang C-Y 2019 *Procedia manufacturing* **39** 389-97
[18] Gao R X, Wang L, Helu M and Teti R 2020 *CIRP Annals* **69(2)** 668-92
[19] Wang P and Luo M 2021 *Journal of manufacturing systems* **58(A)** 16-32