Centralized, decentralized, hybrid principles of cyber-physical systems control of the Industry 4.0

D A Zakoldaev¹, A V Gurjanov², I O Zharinov¹ and O O Zharinov³

¹Saint Petersburg National Research University of Information Technologies, Mechanics and Optics, 49, Kronverksky Av., Saint Petersburg, 197101, Russia
²Stock Company “Experimental Design Bureau “Electroavtomatika” named after P A Yefimov,” 40, Marshala Govorova St., Saint Petersburg, 198095, Russia
³Saint Petersburg State University of Aerospace Instrumentation, 67, Bolshaya Morskaia str., Saint Petersburg, 190000, Russia

E-mail: mpbva@mail.ru

Abstract. The task is to develop a control system for multi-agent cyber and physical systems in the Industry 4.0 production. The company control systems components are cyber and physical systems of production purpose, cloud services and applications, server equipment and industrial data transmitting channels based on the protocols of Ethernet and Internet of Things. Three scheme options are available for cyber and physical systems control: a centralized control, a decentralized control and a hybrid one. There are schemes ready for implementation into exploitation of control system different options in cyber and physical production. Advantages and disadvantages of each option are described for the computerized control system building.

1. Introduction

The Industry 4.0 production company organization requires [1, 2] to create a specialized information environment to support multi-mode access for cyber and physical systems (CPS) to cloud services and applications. In fact, cloud services and applications made as programs are located in the server equipment which is remote from the CPS [3, 4].

Cyber and physical systems wide nomenclature being used in the item designing digital companies [5, 6], and some CPSs with integrated calculation system and program applications dictate the need for designing a computerized control system for the Industry 4.0 smart factory. The smart factory computerized control system is a program application with some functions located in the server equipment.

The main functions of the digital production computerized control system are [7, 8]:
- aggregation and analysis of program and machines diagnostic information for cyber and physical systems engaged in the item manufacturing;
- aggregation and analysis of item manufacturing technological operations completion state production data in cyber and physical systems work chambers;
- CPS topology formation, including the task of CPS production tasks and their configuration, including integrated software renewal options according to the item manufacturing routes defined in the technical documentation;
- production operator information given interactively about technical and economical features of the smart factory activity which characterizes the company business processes and other.
Depending on the accepted in the company way of cyber and physical systems control, the following options can be realized in the computerized control system [9, 10]:
- CPS control centralized scheme where the server single-handedly manages all the CPSs;
- CPS control decentralized scheme where the server and CPS are equal in their rights agents of the control system and they can initiate the production tasks;
- CPS control hybrid (mixed) scheme which has the elements of the centralized and decentralized control schemes at the same time.

Thus, this is a topical issue to develop such a system of cyber and physical systems computerized control in the Industry 4.0 smart factory which has all three schemes (principles) of CPS control done.

2. Cyber and physical system centralized control

The building principle of centralized control systems for cyber and physical systems is based on underlying one (primary) control component and a set of controllable components united in a single informative environment. The cyber and physical systems centralized control scheme is given in figure 1.

![Figure 1. Centralized control system scheme for cyber and physical systems in a digital production.](image)

The computerized control system central core is the server which has all cyber and physical systems connected through the Ethernet channels. The server software, based on the production data processing results received from a CPS, forms a production tasks chart and distributes those among multi-operation CPSs and transport CPSs. In such a control scheme, cyber and physical systems execute the production tasks.

The cyber and physical system centralized control system primary advantages are:
- CPS calculation net scaling which may increase the smart factory production potency without significant changes in the company structure (connection of new production sections equipped with CPSs to provide additional links with expanded control system address space);
- relative low cost of machines and programs to create the cyber and physical production informative environment (the components being used are typical, and their servicing does not require special knowledge of specialists or a significant expense);
- the possibility to change configuration parameters of CPS functioning by program modifying from the operator in the cloud services and applications characteristics.

The cyber and physical system centralized control system primary disadvantages are:
- low reliability of digital production because there is only one control component (the central server), and if it fails (no matter the reason, including cyber-attacks), the entire company will be stopped;
- digital production engineering support complexity, where a separate room is necessary for the
server equipment and the length of cable routes for the CPS and servers to be commuted;
- low productivity of the company informative environment calculation net even if a high-
production server and production data optical fiber transmitting lines are used.

The application of the cyber and physical systems centralized control scheme can be recommended as the first step to modernize the existing companies of the Industry 3.0.

3. Cyber and physical system decentralized control

The principle of the cyber and physical systems decentralized control scheme is the idea of not to rely on a single (primary) control device, but to delegate the control properties to all cyber and physical production elements which are capable to calculate. The cyber and physical systems decentralized control scheme is given in figure 2.

![Decentralized control system scheme for cyber and physical systems in a digital production (IoT – Internet of Things).](image)

Production data information exchange between CPSs and the server equipment (cloud services and applications) in the decentralized control system is done with the communication environment of the industrial internet of things. Each CPS with an integrated controller and software application can be an active internet agent of the cyber and physical production calculation net. Roles distribution (a control agent or an executive agent) between different CPSs and the server is done dynamically (in each moment of time), depending on the production task completion state and the condition of the company production infrastructure in general.

The cyber and physical system decentralized control system does not contain a fixed system controller device to control all the digital production components. The cyber and physical systems decentralized control helps the robotized transport CPS to form the dynamic CPS topology to provide digital production fail-safe.

The cyber and physical system decentralized control system primary advantages are:
- high reliability of cyber and physical production because there are algorithms of CPS self-
organization during the product manufacturing;
- low complexity of digital production engineering support because there are some wireless ways of production data transmission with standardized protocols, applied in the company;
- CPS autonomous functionality because of the CPS components information interaction on physical and virtual levels (CPS mathematical and semantic models).

The cyber and physical system decentralized control system primary disadvantages are:
- low pass through ability of the data transmission communication net because of the radio channel of information exchange that is hardly protected from disturbances, and the company CPS
address space restrictions;
- cloud services and application software high cost to support the technologies of artificial intelligence for a cyber and physical production;
- cyber and physical production information security low level because the standard protocols of production data transmission are available for many mobile devices which support the technology of IoT and which is the part of company infrastructure.

4. Cyber and physical system hybrid control

The hybrid way of cyber and physical systems control requires the components of the central controller device (server) and intellectual components (CPS) which are capable to initiate production tasks, to be used simultaneously in the company calculation net. In fact, the hybrid way of control is a combination of centralized and decentralized approaches. The cyber and physical systems hybrid control scheme is given in figure 3.

![Figure 3. Hybrid control system scheme for cyber and physical systems in a digital production.](image)

Cyber and physical control system commutation environment, server equipment, cloud services and applications are made with two types of nets in the hybrid control system:
- the wireless net of industrial internet of things;
- the wired optical fiber Ethernet net which is connected to each CPS.

The wireless IoT net is being used by all types of the production CPSs to transmit the data about CPS conditions and about the manufactured item technological parameters. In this case, the IoT net is a distributed CPS sensor net. The Ethernet wired net is used in the hybrid control system to upload dynamically new program applications and updated versions of existing programs and other data (3D-models, production tasks and other). Data transmission control in CPS optical fiber lines is done by the server. Data transmission control in the IoT sensor net is done by a CPS.

The cyber and physical system hybrid control system primary advantages are:
- high reliability of cyber and physical production because a lot of elements are reserved in the calculation net on the level of a CPS as well as on the level of information transmission channels;
- high flexibility of automatic production lines because there is a possibility to dynamically change production tasks being delegated to a CPS without significant change of the CPS topology;
- the scaling of company production capabilities on the horizontal level (the implementation of new CPSs to the existing company calculation net) and on the vertical level (unification of calculation nets from different smart factories into a single net of a virtual factory with the same cloud services and applications) which provides the CPS super-integration and digital informative technologies.
The cyber and physical system hybrid control system primary disadvantages are:
- high cost of digital production machine components, including intellectual CPSs and software components to support the CPS multi-agent control;
- high requirements for the production operator qualification because of specialist multi-disciplinary knowledge and skills in the advanced informative technologies and poly-technical character of the item being manufactured;
- high requirements for informative (functional) security of the digital company because of the high level of the technological operations being completed automatizing and the possibility of remote control (connection to the informative environment) of cyber and physical production.

5. Conclusion
The available options of cyber and physical systems control schemes in a digital production are project solutions with the property of transportability (machine independence). The machine independence of the control ways may create the rated (widely applicable) computer systems for typically integrated automatic production divisions.

The projection of the computer control systems along with the projection of cyber and physical systems gives the harmonic (equal in speed) development of the scientific base and software and machine components of digital production. Cyber and physical systems automatic control is the smart factory artificial intelligence component which provides the self-development of digital production. And the creation of the first test fields of the Industry 4.0 must be understood as the prototyping for the automatic production projections in the future.

The proposed schemes of cyber and physical systems control are oriented to implement the Industry 4.0 smart factories into the production infrastructure, which have some flexible production modules, flexible production cells and flexible production systems.

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