Cloud services of digital and smart factories of the Industry 4.0

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Abstract. Consideration is given to a relevant task of organizing cloud services for building the factories of the future: a digital factory and smart factory Industry 4.0. The digital factory majors in design activity resulting in preparation of technical documentation for an article. The smart factory majors in the production activity, which results in article manufacture following the unattended technology. Both types of enterprises use the cyberphysical equipment in the activity thereof, which function on the basis of cloud technologies, including the following cloud services: infrastructure, platform, virtual machine, program, with the user’s access thereto provided on the basis of interfaces of the Industrial Internet of Things. Presently there are no ready technical (technological) solutions providing for integration of cloud services into design and production infrastructure of the factories of the future. The schemes of interaction of components of the cloud services for design activity for the digital factory and for production activity of the smart factory majoring in instrument-building in the field of radio electronics are offered. The properties and assignments of components featuring practical application as part of automated stations of designers of digital factory and operators of the smart factory are described. The decisions on substantiating contents and description of methods of integrating heterogenous cloud services for information support of activity of factories of the future are the main research results.

1. Introduction

The implementation of the instrument-building article life cycle supposes the use of cloud services [1, 2] in the companies of Industry 4.0, which can be accessed through interfaces and according to the protocols of the Internet of Things (IoT) [3, 4]. The companies of Industry 4.0 are formed by three types of design and production activity [5, 6]: digital factory, smart factory and virtual factory.

The digital factory is intended for designing the article technical documentation being prepared in electronic form, including the stages of the article digital model testing performed by means of computer modeling and visualization of design solutions [6]. There are two stages of the article life cycle at the digital factory: article marketing research and designing. The smart factory is intended for the article manufacturing process based on unattended lean production with the use of automatic cyber-physical equipment [7]. The smart factory functionality [8, 9] will be provided on the basis of integration of digital additive technologies, sensory technologies, Big Data technologies of processing...
huge data arrays, etc. The stages of life cycle from production preparation to the package and storage of finished product are implemented at the smart factory. The virtual factory implements a full life cycle of an article of instrument-building and features a territorially distributed structure.

The cloud services [10] help effect development and operation of virtual models of design and production processes and equipment in the companies of Industry 4.0 at the cyber level. The virtual models are the digital twins of physical devices of cyber-physical systems. In order to organize joint operation of physical world components (process equipment) and cyber world components (cloud services with models), it is necessary to determine the composition of future equipment used at the factories and carry out integration of heterogenous cloud services into a unified digital environment of the companies.

The practice of using cloud services for organizing operation of industrial enterprises shows that the main directions of research in the field of organization of instrument-building production facilities are as follows:

— building individual virtual models of cyber-physical systems of versatile application based on mathematic equations describing the dynamics of operating systems as part of the production complex [11];

— improvement of the existing and development of new data exchange protocols of wireless high-rate communication channels providing interaction of cyber-physical systems at the digital production facility [12, 13];

— development of new and improvement of the existing standards and formats of storage and processing of the production data as well as formats of data exchange between different information systems being independently incorporated at the enterprises [14, 15].

The individual results of work of the researches in these areas of focus create an opportunity of step-by-step modernization of the existing industrial instrument-building production facilities, functioning in the paradigm of Industry 3.0 with the aim of building the factories of future of Industry 4.0. The step-by-step way of modernizing production facilities of Industry 3.0 are resource-intensive, it demands investment of tangible costs exceeding several times the costs for setting up new production facilities of Industry 4.0 ‘from zero’. In order to organize production facilities of Industry 4.0, the ready technical (technological) decisions are to be developed and incorporated to provide collectively the solution of design-and-production objectives of digital factory and smart factory.

The purpose of research described in the article is the building of infrastructure of design-and-production environment functioning on the basis of interaction of components of cloud services as part of digital factory and smart factory of Industry 4.0. In order to attain the goals, the following objectives have been met:

— composition and purpose of the components of cloud services required for organization of the factories of the future majoring in radioelectronic instrument-building have been defined;

— infrastructure of design environment based on cloud services has been defined to organize the work of digital instrument-building factory of Industry 4.0;

— infrastructure of production environment based on cloud services has been defined to organize the work of smart instrument-building factory of Industry 4.0.

2. Types of cloud services for Industry 4.0 companies

The following types of cloud services (given in the order of increasing complexity of technical implementation) have acquired the most extensive proliferation for building components of digital companies of Industry 4.0 in practice [16, 17]:

— software (program) intended for automation of solution of design-and-engineering and experimental tasks, objectives of audit and financial accounting of company’s activity, etc. The software is a completed design project tasks (for example, to prepare design, software and process documentation for an article of instrument-building in the system of automated designing developed earlier);
— virtual computation machine (virtual computer) intended for technical support of the user in solving the design-and-production tasks. This level of cloud service provides a user with a possibility to use the necessary with respect to productivity calculation resources with remote access and functioning on the basis of resources of program-type cloud service;

— technological platform intended for building, research and incorporation of digital models of the developed articles and digital twins of cyber-physical equipment of the instrument-building enterprises. This level of cloud service provides the user with a possibility of development of software applications, which are specialized with respect to the object of designing. The technological platform service is focused on the support of automated development of new software applications unlike the program cloud service. Apparently, that the implementation of technical platform service can be provided by means of program-type and virtual computer cloud services;

— technological infrastructure intended for building, research and incorporation of digital twins of the instrument-building enterprises in general. The service can also be used for the development of models of virtual factories ecosystem. This level of cloud service uses the cloud services of hardware, including cloud net resources (connection switches, routers), cloud models of data storages, etc., which are necessary for simulating production processes of digital factories, smart factories, and virtual factories. Apparently, that the implementation of technological infrastructure service is provided by means of cloud services of program type, virtual computer type and technological platform type. A distinctive feature of the cloud service of infrastructure type is the availability of the system of resources control in it being implemented with a separate virtual machine.

3. Cloud services of digital factory

The diagram of interaction of cloud service components of infrastructure type for implementation of design activity at the digital factory is given in figure 1.

The infrastructure cloud service has two levels of computation system formed by three virtual machines. The lower level is provided by two technological platforms. One technological platform supports designer activity aimed at preparation of technical documentation for an article of instrument-building in electronic form (article digital model). The following software is installed on the virtual machine of this platform:

— CAD (Computer-Aided Design);
— CAE (Computer-Aided Engineering);
— CASE (Computer-Aided Software Engineering),

for automated development and completion of design, software and process documentation for an article. The computer-aided design systems of this platform belong to a group of program-type cloud services.

The second technological platform provides a designer with the cloud service function to perform the procedures of virtual tests of the article digital model. The virtual tests of a digital model are based on the principles of simulation-type modeling. The tests will be used to assess the robustness and resistivity of the future physical article to comply with the requirements of the Terms of Reference (ToR) represented in the virtual machine by the specialized software (SW) components. Thus, this technological platform at the digital factory of Industry 4.0 makes it possible to replace physical tests being carried out with the actual article at the enterprises of Industry 3.0 with the mathematical equivalents thereof, the virtual tests. The virtual test features a full information similarity with the physical tests and will be carried out at the stages of designing, where an article exists in the form of a digital model only. This method to perform the design stages reduces significantly the expenditures for article designing and increases the quality of technical documentation being prepared in an automated way.
The technological platforms are controlled in the process of designing activity by a designer from its automated working station through an upper-level virtual machine. The software (PDM — the Product Data Management system) is installed on the upper-level virtual machine to control the article engineering data. A designer may implement an access to the upper-level cloud virtual machine through an interface and via IoT protocols. The informative support of the process of CAD designing of the instrument-building industry article will be provided with the libraries of regulatory and technical documentation and special methodologies of virtual tests.

The technological infrastructure corresponding to the cyber level of digital factory of Industry 4.0 features a model of deployment according to an individual cloud type. An access to design solutions being shaped by the designers in the process of designing can be granted to the specialists of the design company only. The final versions of design solutions (electronic design, software and process documentation) for the instrument-building industry articles will be submitted to the company’s archive, the data cloud storage of the digital factory. Depending on the purpose of an article being designed the cloud data storage may have the following deployment model:

— according to the type of cloud community (technical documentation data is available to series manufacturers, the smart factories);
— according to the type of hybrid cloud (operational documentation for articles of mass production available to all users, which is a property of public cloud; a full set of technical documentation for an article is available to series manufacturers, which is a property of a community cloud).

4. Cloud service for smart factory
The diagram of interaction of infrastructure-type cloud service components for implementation of manufacturing activity at the smart factory is given in figure 2.

The infrastructure cloud service is composed of a two-level computation system formed by five virtual machines. The lower level is composed of four technological platforms providing the cyber-level informational support of carrying out production processes at the smart factory at the stages of article life cycle: production preparation, manufacturing, control (testing), storage. An individual virtual calculation machine makes a core of each technological platform, where the following is installed:

— special software with the article digital models and digital twins of process equipment engaged at the corresponding stage of the article life cycle;
— software to control the manufacturing process (systems of PDM, SCM — Supply Chain Management, CAM — Computer Aided Manufacturing, CNC — Computer Numerically Controlled,
S&SM — Sales and Service Management) at the smart factory at the corresponding stage of article life cycle.

![Diagram of interaction of infrastructure-type cloud services components for implementation of manufacturing activity at the smart factory.](image)

**Figure 2.** Diagram of interaction of infrastructure-type cloud services components for implementation of manufacturing activity at the smart factory.

The control of technological platforms in the process of article manufacturing is performed by an operator at the production facility from its automated working station through the upper-level virtual machine. The designer’s access to the upper-level cloud virtual machine is implemented via the user’s interface of a phone, tablet or personal computer (PC) according to IoT protocols. The following software is installed on the upper-level virtual machine:

- PLM (Product Lifecycle Management);
- MES (Manufacturing Execution System);
- ERP (Enterprise Resource Plating);
- MRP (Material Requirements Planning);
- SCADA (Supervisory Control and Data Acquisition),

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for the company’s specialists involved in monitoring activity at the smart factory and production process control only. The operational documentation for the articles being manufactured is available to consumers from the cloud storage of the smart factory:
— deployment model of public cloud for mass production (domestic appliances, automobile industry, machine-building, etc.);
— deployment model of cloud community for a restricted number of article consumers (aviation, naval, missile instrument-building, etc.).

5. Conclusion
The organization of design and production activity of the instrument-building company is effected nowadays with the use of digital cloud technologies. The practical experience of cloud technologies incorporation into industrial production shows that the implementation of activity of companies of Industry 4.0 of the smart factory type and digital factory type can be effected with the use of cloud services: infrastructure, platform, virtual machine, program, which can be accessed by the user on the basis of interfaces of the Internet of Things.

The digital factory and smart factory within the life cycle of the instrument-building article provide the stages from research (marketing) to package and storage of the instrument-building article at the manufacturer’s inclusive. The stages of article transportation to a consumer, article operation and maintenance, article repair, modernization and disposal are implemented at the digital enterprise of virtual factory type.

The full life cycle of the instrument-building article can be implemented at the virtual factory with the use of infrastructure-type cloud service integrating the capabilities of cloud services: platform, virtual machine, program. The cloud services integration into a unified infrastructure is carried out to provide the informational support to the user when solving the tasks of situational control at the virtual factory.

The main results of the conducted research are two infrastructures corresponding to the design-and-production sphere of the factories of the future focused on the development and manufacture of the instrument-building articles. The description of composition and purpose of components used in the infrastructures has been provided at the level enabling the production organizers to changeover directly to the stage of practical incorporation of the offered ideas at digital enterprises.

The scientific and practical significance of the results obtained in the process research consists in the following:
— generalization of theory and development of automation facilities for fulfilling design work and production processes at the hitech enterprises of the instrument-building profile;
— development of scientific problem-oriented fundamentals for shaping and investigating design solutions for selection of variants of functioning of the design-and-production enterprises of Industry 4.0 performing the activity thereof under digital economy conditions.

The development of ideas offered in the paper is aimed at the development and investigation of algorithms, models and criteria of automated designing of technical concept of mechanical assembly production facilities focused on manufacturing the instrument-building articles.

References
[1] Aljoumah E, Mousawi F, Ahmad I, Al-Shammri M and Al-Jady Z 2015 International Journal of Grid Distribution Computing 8 7–32
[2] Zanoon N, Al-Haj A and Khwaldeh S M 2017. International Journal of Applied Engineering Research 12 6970–82
[3] Hwang G, Lee J, Park . and Chang T-W 2017 International journal of production research 55 2590–02
[4] Qu T, Thurer M, Wang J, Wang Z, Fu H and Li C 2017 International journal of production research 55 2622–49
[5] Lee E A 2015 Sensors 15 4837–69
[6] Zhou P, Zuo D, Hou K-M and Zhang Zh 2017 Sensors 17 2580–95
[7] Zuehlke D 2010 Annual reviews in control 34 129–38
[8] Babiceanu R F and Seker R 2016 Computers in Industry 81 128–37
[9] Radziwon A, Bilberg A, Bogers M and Madsen E S 2014 Procedia engineering 69 1184–90
[10] Shariatzadeh N, Lundholm Th, Lindberg L and Sivard G 2016 Procedia CIRP 50 512–17
[11] Qian Zh, Yu Y and Fan G 2015 Applied mathematics & information sciences 9 1981–92
[12] Stef I D, Draghici G and Draghici A 2013 Procedia technology 9 451–62
[13] Gjeldum N, Mladineo M and Veza I 2016 Procedia CIRP 54 158–63
[14] Plinta D 2017 Robotics & Automation engineering 1 555554
[15] Jeong H-Y, Jeong Y-S and Park J H 2014 Sustainability 6 8510–8521
[16] Charan N R G, Rao S T and Srinivas P V S 2011 International Journal of Advanced Computer Science and Applications 2 119–25
[17] Bouchenak S, Chockler G, Chockler H, Gheorghe G. Santos N and Shraer A 2013 ACM SIGOPS Operating Systems Review 47 6–19