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Modeling and visualization of the Industry 4.0 cyber and physical productions

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Abstract. An actual task is to design the modeling and visualizing components of the Industry 4.0 production division activity. The Industry 4.0 production division as a part of smart factory functions automatically with special cyber and physical systems (CPS). The smart factory projection is done as a program of the industrial economy sector prioritized development. To project a production division they use the systems of automatic projection (CAD) installed in a designer PC. Smart factory CAD components are CPS graphical models means, which includes the production division graphical models and the models of product being manufactured. All graphical models have the full information similarity to the physical devices. There are components and description schemes of their interaction to create CAD software to project automatic productions.

1. Introduction
Industry development in the Industry 4.0 paradigm defined new project tasks to create special automatic production divisions functioning as smart factories [1, 2]. New type production projection tasks is a multi-parameter task with no single solution [3]. To generate and research projection solutions to select the content and technical appearance of automatic production must be [4] developed and implemented into specialist project activity a system of automatic projection being done as a software.

Smart factories automatic projection systems are an instrument placed in technical means of designer automatic work places [5, 6] and which helps the designer to project the models and make visual the processes of item manufacturing technological operations completion in a production [7].

Modeling and visuals of production processes the completion results of which gives the smart factory designer the visuals in an instrument PC which helps the designer make calculation and evaluate the automatic production functionality characteristics which later will be used to create technical project documentation for the Industry 4.0 smart factory [8, 9].

To realize in practice the modeling and visuals procedures of production processes adequate real cyber and physical systems graphical models production infrastructure objects must be developed which include [10]:

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all types of cyber and physical systems graphical models including multi-operation production machines, robotized transport systems, storage systems and other;
• production lines graphical models including production rooms graphical models, cinematic interaction models among CPSs and other;
• being manufactured in smart factory product graphical models which are third dimensions objects level each of which has the unique characteristics.

Graphical models attributes, which helps to give object properties in the level of parameter and variables to create the necessary condition to visualize production processes being done in CPS in the PC model time. Technical solutions of smart factory designer for cyber and physical productions modeling and visual results are the digital projection sketch projection end results [11, 12].

2. CPS models graphical visuals
CPS graphical models are technological processes visuals primary components being done in cyber and physical production. CPS graphical models are visual third dimension picture of a production machine which has the full information similarity to the CPS physical device. CPS graphical model is induced to the PC screen by the Industry 4.0 smart factory designer into isometry object format. In figure 1 there is a scheme of components interaction necessary to form the CPS graphical models.

![Diagram of CPS models components interaction](image-url)

**Figure 1.** Components interaction scheme necessary to form CPS graphical models.

CPS graphical visual models are done as a specialized software (Smart factory automatic projection system) for different CPS classes (3D-printers, solder reflow ovens, transport system manipulators and other). Each CPS class as a software different marks of automatic technological equipment with their own nomenclature of CPS physical devices models are done.

CPS graphical models composition of different classes are done with software code application of the following components:

• technical and exploitation CPS documentation which define technical and tactics CPS characteristics;
• CPS mathematical models as differential and recurrent equations to describe CPS automatic functionality (technological operations being completed in the CPS chamber);
- CPS cinematic models to describe movable trajectory dynamic properties of CPS movable parts;
- CPS geometrical models to describe appearance and connection dimensions of cyber and physical systems and other.

CPS graphical model sets in the level of parameter property description of production machines to form CPS classes library in the smart factory system of automatic projection. Parameter change to describe CPS properties to set optional and to regulate CPS functionality dynamic properties as a production line visual models.

CPS graphical models as a software automatic projection system are the appearance and inner structure of cyber and physical system. The CPS graphical model appearance is CPS physical device. The CPS inner structure gives details of CPS component units visual characteristics. The CPS graphical model primary objective is to give the smart factory designer visuals of the company production infrastructure real component.

3. Production division visual graphical models
Cyber and physical systems of different purposes united into a single technological line to create a closed loop production division technological section. Smart factory production processes visuals are done with some CPS graphical models to interact. In figure 2 there is an interaction components scheme to form production division graphical model.

![Diagram](image)

**Figure 2.** Interaction components scheme to form the Industry 4.0 smart factory production division graphical model.

Production division graphical model visual base is a production room floor plan within which technological equipment is installed. Smart factory automatic projection system helps to evaluate geometrical distances to which assembly units transportation among CPSs is possible by the robotized transport system. CPS placement in a smart factory is to avoid collisions when the trajectories of two movable CPSs coincide. To avoid collisions in automatic projection system there is a special calculation module.
To model automatic production division functionality the smart factory designer in the system of automatic projection with discrete and event technological processes algorithm models (routes) of the item manufacturing. The initial data to form the discrete and event models of the production are:

- all types of CPS functionality temporal diagram describes production processes of robotized machines including models and processes of CPS data exchange with the Internet of Things (IoT) protocols with cloud services and applications;
- some technological operations private algorithms models being completed automatically in a CPS and other.

Discrete and event models of automatic production division is described in terms of graphics and analytical models of the Petri nets theory mathematics apparatus. Petri nets production model gives the smart factory designer an opportunity to step by step research each technological operation, its synchronism with other related technological operations and other which correspond the task of the Industry 4.0 digital production projection.

Production procedures modeling and visuals project procedures results are:

- calculation of permitted and prohibited zones for neighboring CPSs and maintenance personnel which are used to solve the tasks of smart factory production equipment placement;
- moving trajectories calculation of assembly units and movable parts of robot manipulators being used by the smart factory designer to evaluate dynamic properties (rhythm, pace and other) of automatic production division robots and other.

4. Item graphical models visuals

To project the Industry 4.0 automatic production means to create smart factories specialized in particular purpose item manufacturing. That could be optical and electronic item designing components, micro and mechanical item designing and other. Smart factory item manufacturing is done with electronic construction, program and technological documentations prepared in digital factories. Electronic documentation quality is proved with model tests and item digital certificate.

Item representation in electronic form is done in formats of being developed in time digital models (digital replica, digital shadow, digital twin) of the item. Item graphical model is a 3D-object (item representation in isometry) which has a set of 3D-objects each of which is an assembly unit and a part of the item.

![Figure 3. Components interaction scheme, which are necessary to form the item graphical model.](image-url)

The 3D-model electronic visuals of the item being manufactured in the system of automatic projection is necessary to represent for the smart factory designer the production processes done in the company. The CPS movable parts trajectory moving transmits the item being manufactured among working positions of CPS it is necessary to calculate mass and dimensions characteristics of assembly units. In figure 3 there is an interaction components scheme which are necessary to form graphical model of the product being manufactured in a smart factory.
5. Conclusion
Automatic production smart factory object is a complicated technical system where CPSs interact with different tactical and technical characteristics. CPS interaction methods and means research is done in the automatic projection system which help the designer to complete modeling and visuals project procedures of the cyber and physical production functionality in an instrument PC.

Projection system primary component is a set of graphical 3D production infrastructure objects models received after the physical device digital copy. For cyber and physical production modeling and visuals in the sketch and technical projection stage which can be used as CPS digital replica and the item being manufactured as the production objects representation initial form. When the calculations become more complicated and it require a more detailed project solution level (functioning projection stage) to visualize smart factory functionality it is necessary to use the object digital shadows. The smart factory project documentation final version can be obtained only after some model experiments in an instrument PC when the production infrastructure object digital twins are applied.

Implementation of new type item production for the existing (developed before) smart factories would require from the designer a conduct of model tests with CPS digital twins application installed in a company and the item digital twins obtained from the digital factory technical documentation archive. Those procedures must be completed in a specialized automatic projection system in a smart factory during the production technological preparation before the new set of items manufacturing.

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