Classification of Cyber and Physical Systems of Industry 4.0

D A Zakoldaev¹, A V Gurjanov², A V Shukalov¹, I O Zharinov¹

¹ Faculty of Information Security and Computer Technologies, Saint Petersburg National Research University of Information Technologies, Mechanics and Optics, 49, Kronverksky Av., Saint Petersburg, 197101, Russia
² Director, Stock Company «Experimental Design Bureau «Electrovaytomatika» named after P A Yefimov, 40, Marshala Govorova St., Saint Petersburg, 198095, Russia

E-mail: mpbva@mail.ru

Abstract. The actual task is to create the classification system for cyber and physical technological equipment for smart factories of the Industry 4.0. Smart factories are a new type of production companies which work automatically. To project a smart factory they need to choose samples of cyber and physical systems of different purpose to unite them in automatic sections. To solve the choice task of production machine samples they need to create libraries of technical and tactical characteristics and its ontology description the base of which is the system to classify cyber and physical equipment. There is a classification scheme of industrial cyber and physical systems to work in a smart factory of item designing. The classification systems base is types of technological operations being realized in a company and also methods and technologies which the cyber and physical systems use. Cyber and physical systems functionality is described for mechanical treatment and assembly workshops of item designing company.

1. Introduction
To provide high-tech cyber and physical technological equipment is [1, 2] an actual development of economy industrial sector. The cyber and physical systems market offer today a wide nomenclature of machines which may solve the tasks of automatic production with its characteristics [3].

Each type of cyber and physical systems [4] is capable of producing only some technological operations using one or several digital technologies [5, 6]. Each types of cyber and physical systems has some machines for a particular task only with their methods [7-9] and technologies. To divide cyber and physical systems with technological operations being done and methods and technologies being used creates cyber and physical systems classification of industrial purpose.

This classification system is the base for automatic technological equipment systematization and can be developed in digital [10] production companies which are today viewed as the Industry 4.0.

The Industry 4.0 creates [11] in machine and item designing special companies to realize the item manufacturing production without human participation. Those companies of humanless and paperless technologies are called smart factories.

To synthesize [12, 13] the Industry 4.0 smart factory they need to implement criteria of company functionality and to find parameters of the production assets. So the classification system of cyber and physical equipment is an information resource to create the libraries of tactical and technical characteristics of automatic machines and its ontology to describe production processes being placed in the smart factory cloud.

2. Cyber and physical systems of industrial purpose
Cyber and physical systems are a new type of technological equipment with calculation resources to complete production tasks in automatic mode. Each cyber and physical system is for a limited number of operations only. To unite some cyber and physical systems and their cinematic interaction and agreement of their production data exchange protocols helps to create new flexible automatic
productions. Flexible automatic productions (production sections) are the base for the Industry 4.0 smart factories.

The Industry 4.0 smart factories are a new type of item designing (machine designing) companies with closed loop of technological operations to produce high-tech items without humans. Self-organizing cyber and physical systems in the Industry 4.0 is for technological operations from technological maps and routes with algorithms from the smart factory clouds.

In the item designing the cyber and physical equipment is placed within two production workshops of a smart factory:
- the workshop of mechanical treatment for production operations of additive technologies to prepare the items (assembly units);
- the assembly workshop for production operations with technologies of Machine-to-Machine, Systems-to-Systems to prepare assembly units (surface montage of electric and radio components on the printed circuit boards) and to finish the item assembly.

Assembly units transportation among the workshops and within a workshop among cyber and physical systems is done with manipulator robots under the computerized system. Control algorithms and production tasks for robots and cyber and physical systems are formed in the smart factory cloud using the analysis results (BigData algorithms) for standard operative plans of technological equipment.

The classification of industrial purpose cyber and physical systems is done with technological operations from mechanical treatment and assembly workshops of the Industry 4.0 smart factory. The main classes of item designing automatic production equipment are:
- additive production equipment to complete the technological operations of 3D-printing and to cover the assembly units with lacquering and electrotyping covers;
- surface montage equipment with standard set of technological operations to place electric and radio components on printed boards, components soldering and other with subsequent washing of mounted assembly units from the flux residue, solder or other contaminations;
- transport production system equipment to load (unload) trays of cyber and physical systems to mark the items being produced to storage the items, assembly units and finished products;
- production control equipment to check the quality of humanlessly produced items with necessary technological operations.

3. Cyber and physical systems of additive production

The main purpose of cyber and physical systems in additive production is to complete technological operations of layer by layer adding (growing) of materials on the base plate. In the item designing this technological operation is done with three different types of cyber and physical systems (see figure 1):
- 3D-printers to print out the items automatically;
- production machines of lacquering which lacquers the assembly units (printed boards with mounted electric and radio components);
- electrotyping production machines to put the necessary covers of electrotyping on the made of metal items to grant them the necessary physical and chemical properties (anti-corrosivity, high electric conductivity, anti wearing out the surfaces which are necessary rugged, the surface preparation for soldering and other).

3D-printer is a complicated technological device (machine) which works automatically with numeric control (calculating device controls the process of the technological operations completion). The 3D-printer functionality is based on layer by layer creation (printing) of an item from a solid powder.
There are several methods of 3D-printing and some additive technologies that could be supported by a 3D-printer. The most popular in practice are the following technologies:

- extrusion or layer by layer creation of a solid object (item) with the method of melt-down. The melted down material is being placed on the base with drops of small size which are rapidly cooled down and united with each other and this is how the current layer is formed (printed layer);
- photopolymerization or layer by layer creation of a solid object (item) with the method of laser stereolithography. The liquid material of polymer is being placed on the base which is cooled down with a laser beam in the ultraviolet range;
- direct (selective) sintering or layer by layer creation of a solid object (item) with the method of electron beam melt-down, heat melt-down or laser sintering. The material is melted down (metallic powder) with a heating head of a 3D-printer, with an electron beam in vacuum or a laser beam. Step by step sintering of the metallic powder is for layer by layer creation of the item. Unlike the photopolymerization where the base material is the liquid polymer (organic material) sintering use the metallic powder as the base material and the cover refusing method is the same — the influence of laser emission. And the laser emission range in both cases of those additive technologies and its output power are quite different.

In practice they use additive technologies of 3D-printers based on melt-down of gauze material under the electronic emission (the method of welding), tide printing and printing with liquid glue (gluing of a powder material) being conducted automatically and other.

Production machine of lacquering is a complicated technological device which functions automatically with numeric control. The lacquering machine puts protective cover on the printed board surface with installed radio and electronic components. This protective cover is to prevent the printed board surface being influenced with negative environmental effects (Very high or very low environmental temperature, very high level of the air humidity and other) on the electronic components installed on the board or materials from which the board is made.

There are several methods of lacquering cover putting on the printed circuit boards surface. The most popular methods in practice are the following:
- lacquering putting with pulverizing method. This kind of additive technology is used compressed air of excessive pressure in the spray and this how the pulverization is being done on the printed circuit board surface with liquid lacquering material;
- application of lacquering with the immersion. This kind of additive technology uses special bathes with lacquering material in liquid state where the printed boards are submersed with the manipulator robot. The lacquering material viscosity creates protective cover on the printed board after the submersion. In practice for a quality cover they submerge the boards two or three times (But before the next submersion the applied cover must be hardened);
- application of lacquering with selective (tidal) technology. This kind of additive technology in practice apply the lacquering cover on the limited in square sections of the printed boards (After the elements repair when the original lacquering cover was damaged in a small area) or to apply lacquering covers on the assembly units which are non-standard in construction.

The number of lacquering layers and their thickness affects significantly the assembly unit weight. In practice the maximum number of lacquering covers is three. If they apply more it may damage the final cover (In some places the air bubbles could be formed which may result in equipment damage). After application of each lacquering layer on the PCB (Printed Circuit Board) surface it is necessary to reject them and for that purpose the Industry 4.0 company they use automatic oven of rejection.

Electrotyping automatic machines are a kind of cyber and physical systems to support additive technologies of electric and chemical processes to process mechanical units. To apply good electrotyping covers on the metallic surfaces they apply work chambers of cyber and physical systems after the electric current passing through the electrolyte in the bath where the item is placed. The power (density) of current the electrolyte is chemically chosen (by the Law of Faraday) to make the molecules of metal layer not just to bombard the item surface but to penetrate the upper layer of the item. And this is how the applied electrotyping cover is secured in surface.

The most popular methods of electrotyping contain nickel, chrome, gold, silver and other metals. Electric and chemical properties of electrotyping are done with the same cyber and physical equipment. The difference how to apply the cover of different metals is based on the containing of electrolyte, its temperature and the mode of completion of some electric and chemical processes. The choice of modes, electrolyte work temperature and other details how to complete the technological operations of electrotyping is done with electrotyping cyber and physical system controller under its software placed in the cloud (libraries of technological processes completion algorithms).
The final stage of electrotyping over metallic items is the procedure of electrolyte residue elimination from the part surface. This procedure is done in special bathes of hot (cold) parts washing. The washing bathes are a kind of cyber and physical automatic equipment where the program controls the work modes of manipulator robots which submerge parts into washing liquid.

Electrotyping is a hazardous production which affects negatively the human health. To organize a production division with cyber and physical systems of electrotyping in automatic mode (without humans) may increase the quality of finished product and the level of operator personal security in a smart factory.

4. Cyber and physical systems of radio and electronic components surface montage

The surface montage of electric and radio components is done over the printed boards with cyber and physical equipment which is a part of assembly workshop of the Industry 4.0 smart factory. The surface montage includes the following technological operations:

- the application of soldering paste over the printed boards (sample printing);
- the placement of radio and electric components over the printed boards (element outputs are connected with PCB pads which were already soldered);
- solder trimming for an electric contacts of element outputs and printed boards pads and element mechanical fixture (to make the fixture stronger elements may have some ceramic bases for support, glue, mastics and other which was installed or applied before);
- PCB washing from the flux residue, solder and other contaminations which are formed after the item manufacturing technological cycle.

The solder paste is applied with special cyber and physical system:

- solder paste dozer to form a dose of solder which will be applied on the pads of the printed boards (the dosage depends on the pads linear sizes and radio and electric components output step);
- sample creation printer which produces technological masks with holes from metal which is placed over the board when the solder is being provided. The mask holes are the same with the PCB pads of the upper and lower layers of the board;
- soldering paste application machine which precisely put together the printed board and the mask (sample) to apply some doses of soldering paste over the printed board. The roller with solder presses the surface of samples with which holes the solder is being penetrated on the printed board pads.

The placement of electric and radio components over the printed board surface is done with the special type of cyber and physical equipment which can be classified with the components they install:

- the placer of output components or electric and radio items with the package type of DIP (Dual In-line Package);
- the placer of planar components or electric and radio items with the package type of SMD (Surface Mount Device);
- the placer of ball output components or electric and radio items with the package type of BGA (Ball Grid Array).

All type of placers work automatically and support one side or two sides component placement type on the printed board. Placer gears put away the electric and radio components from the belt feeder (a bobbin which cells have components already pre-arranged) with a vacuum nozzle and transfer the elements on the printed board surface (on the necessary scheme place). The element positioning precision on the printed board surface is a technical specification of cyber and physical system and may define the minimum step of elements output to work with which the system was created. The controller controls the cyber and physical system gears which memory has a program with digital description of the board geometry and the board collective scheme in its digital form.

In multi-nomenclature production technical documentation of the smart factory product (item) which is placed in company cloud and being extracted from there automatically. The transfer of technical documentation and control program into the memory of cyber and physical system according with requirements and terms which is in operative plan of the item manufacturing in company.

Solder trimming in item designing company to create a secure electric connection of electric and radio component output and PCB pad. Technological operation of solder trimming is done with the following types of cyber and physical equipment:

- convection oven of solder trimming inside of which the solder is melted down under the heat convection beam with the necessary temperature stability. The oven has work modes where the
temperature beam profile can be changed with the program which depends on the board area where the components are placed (elements have different specifications as the robustness and body stability to the temperatures of soldering);

- the vapor solder trimming oven where the solder is melted down with steam. There are the technologies of soldering in the steam phase and steam phase systems of soldering. The heat transferring on the board surface helps the selective soldering of components. The selective way divide the printed board into areas and creates special modes of soldering in each area;

- wave soldering machine where the PCB bottom is submerged into a bath of prepared solder. This machine is for montage of the components which have the DIP-bodies (pin outputs for penetrating montage). After the PCB bottom is submerged into a bath of prepared solder (the prepared solder is administrated to the bottom part of the PCB as a wave) on the elements outputs there is solder residue which can penetrate to the holes between layers. With the capillary effect the solder reaches the upper surface of the board which makes a pass through solder connection which touches the pad of transfer hole and element output.

After technological operation of solder paste application, components placement and solder trimming there are some contaminations on the PCB surface which makes the item designing components to be of lower quality. To prevent a scrap to be produced after those technological operations there is the procedure of printed boards washing.

The printed boards washing is done with cyber and physical systems which differs in board and washing liquid way of interaction. There are the following types of automatic technological equipment to wash out the printed boards:

- tidal washing bath where the printed board is washed with the cleaning liquid under pressure which helps to take out all the mechanical contaminations from the board;
- ultra-sonic washing bath where the washing out of the printed boards surface is done with amplitude movements of the cleaning liquid of ultra-sonic frequency. Those movements provoke contractions of the liquid which spreads to the printed board surface;
- bubbling bath to wash out the printed board surface is done with air bubbles generated in cleaning liquid with special device.

Washing bathes are to delete contaminations from the printed board surface and from the sample surfaces which are used to apply the solder paste. When the item washing is done (PCB, sample) it is necessary to dry it out with hot air in the drying case.

5. Cyber and physical systems of smart factory transport infrastructure

Item transportation (assembly units, products) in the production division of an item designing company which functions automatically is done with robot manipulators which are a part of the Industry 4.0 smart factory transport infrastructure. The Industry 4.0 smart factory transport infrastructure has the following cyber and physical systems:

- loading (unloading) machines of parts (assembly units) with the following functions: item transferring and reception to the production machine pallets to complete technological operations (for example, components montage) and the item evacuation from the machine pallet to transport it to the next cyber and physical system;
- product marking machines put special barcodes on the items to identify the number of item being manufactured, number and containing of the technological operations done with the item and other. Barcodes are used for marking the products, radio frequency marks and other;
- machines of item turning where manipulator robots with function of linear rotation around the axe to complete some technological operations (for example, one by one montage of electric and radio components on the both surfaces of the printed boards using the equipment of one side montage);
- cases of components dry storage, parts and products (finished products) which is the part of the storage systems inside the workshop of the items being manufactured in the company.

To unite cyber and physical systems of smart factory transport infrastructure with production machines may create in item designing companies the assembly conveyors which function automatically and collective systems to organize the warehouse storage of the finished products.
6. Cyber and physical systems of production control

Production control is to monitor the quality of the item designing company product. Production control has the following types of cyber and physical systems:

- machine of optical (infra-red) control to evaluate the quality of montage and how much the given assembly units is according to its requirements, the item size and how much they correspond to the item technical documentation and other;
- ultra-sonic control machine to evaluate the quality of the given item and to find out the hidden defects which cannot be found visually with the machines of optical range (with the machines of ultrasound control can be found micro-fissures of metallic items produced with additive production);
- machines of X-ray control to evaluate the quality of the given item and to find out the hidden deep defects in the thickness of materials and parts (The X-ray control machines may find fissures and breakdowns of printed conduits deep inside the PCB layers);
- quality control machines of the soldering paste application to evaluate the volume the paste applied on the pads of printed boards (the volume is defined after multi-frequency measurement with mathematical calculation of the paste parameters; the height is evaluated, square, volume, paste displacement from the pads and other);
- the machines of inner-schemes control (flying probes) to evaluate the quality of electric connection after the soldering electric and radio components on the printed board surface. After the verifying they may control the parameters of item functionality in different areas of the board electrical scheme. In some points defined with the controller program they apply detectors (probes).

7. Conclusion

To classify cyber and physical systems of industrial purpose is the base to systemize the equipment and technology to complete automatically technological processes of item designing components manufacturing. Given in figure 1 production machines are industrial objects which must be computerized first.

Computerized control system coordinates cyber and physical systems interaction on the algorithms of self-organization production machines. The algorithms of cyber and physical systems self-organization placed in a smart factory cloud and they function on the data analysis of:

- results of theme and production orders completion in an item designing company;
- well functionality of cyber and physical technological equipment;
- the availability of materials and parts which are necessary to complete technological processes and other.

Computerized control system in production has calculation resources of physical world and calculation resources placed in virtual (cloud) part of the smart factory. Smart factory production activity control is done with operators and interface of computerized control system interaction with the software of production processes completion automatizing.

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