

Transport system organization of an Industry 4.0 cyber and physical production company

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Abstract. The problem dealing with transport production system equipped with cyber and physical technological equipment is considered. The scheme of forming route production lines of an item designing component in the Industry 4.0 company with application of cloud services is given. Cyberphysical production transport system is based on robotized equipment (physical level) and algorithms for dispatching production tasks (cyber level). Information exchange between the level of physical equipment and the cyber one is done based on the protocol of the industrial Internet of Things. The paper gives examples of route sheets used for manufacturing instrumentation products at digital enterprises of the Industry 4.0.

1. Introduction

The organization of modern item designing production is based on information technologies using special cyber and physical systems in the frame of national industrial programs to digitalize the economy [1, 2]. Each cyber and physical system provides the completion of a limited set of technological operations which compose the general route sheet of an item manufacturing. Unification of cyber and physical systems in a single production section can be done to build a flow automatic line or maybe to build a production line functioning with self-organization principles.

Flow production lines characterize building of Industry 3.0 item designing companies which realize the automatic mode to manufacture the items and implement the CAD (Computer-Aided Design) systems and production control systems [3, 4]. Industry 4.0 digital companies (digital factories, smart factories, virtual factories) realize the substantial part of manufacturing production cycle of the item designing component production based on the self-organized automatic cyber and physical systems without operators participation.

The base of automatic cyber and physical system self-organization principle is mathematical methods of solving the tasks «about designation» (for example Daycstre algorithm, Floyd and Warshall algorithm, Johnson algorithm and others) being realized with cloud technologies application and the technologies of the industrial Internet of Things (IoT) [5-7]. The task solution «about designation» supposes distribution of production task to the available resources (cyber and physical systems) being realized in the dynamic mode or directly during the technological operations completion in a digital company.



To solve the task «about designation» it is necessary:

- to define the description of production cycle with mathematical methods;
- to define the participants of production interrelations in the level of physical machines (technological equipment) and also in the cyber level of cloud services;
- to implement principles and algorithms of production tasks distribution which provide the necessary criteria of optimal activity in an item designing company.

2. Technological routes formation principles

Figure 1 shows a scheme with examples how to realize the route sheets of item designing components manufactured at the production companies of the Industry 4.0 equipped with automatic cyber and physical technological equipment.

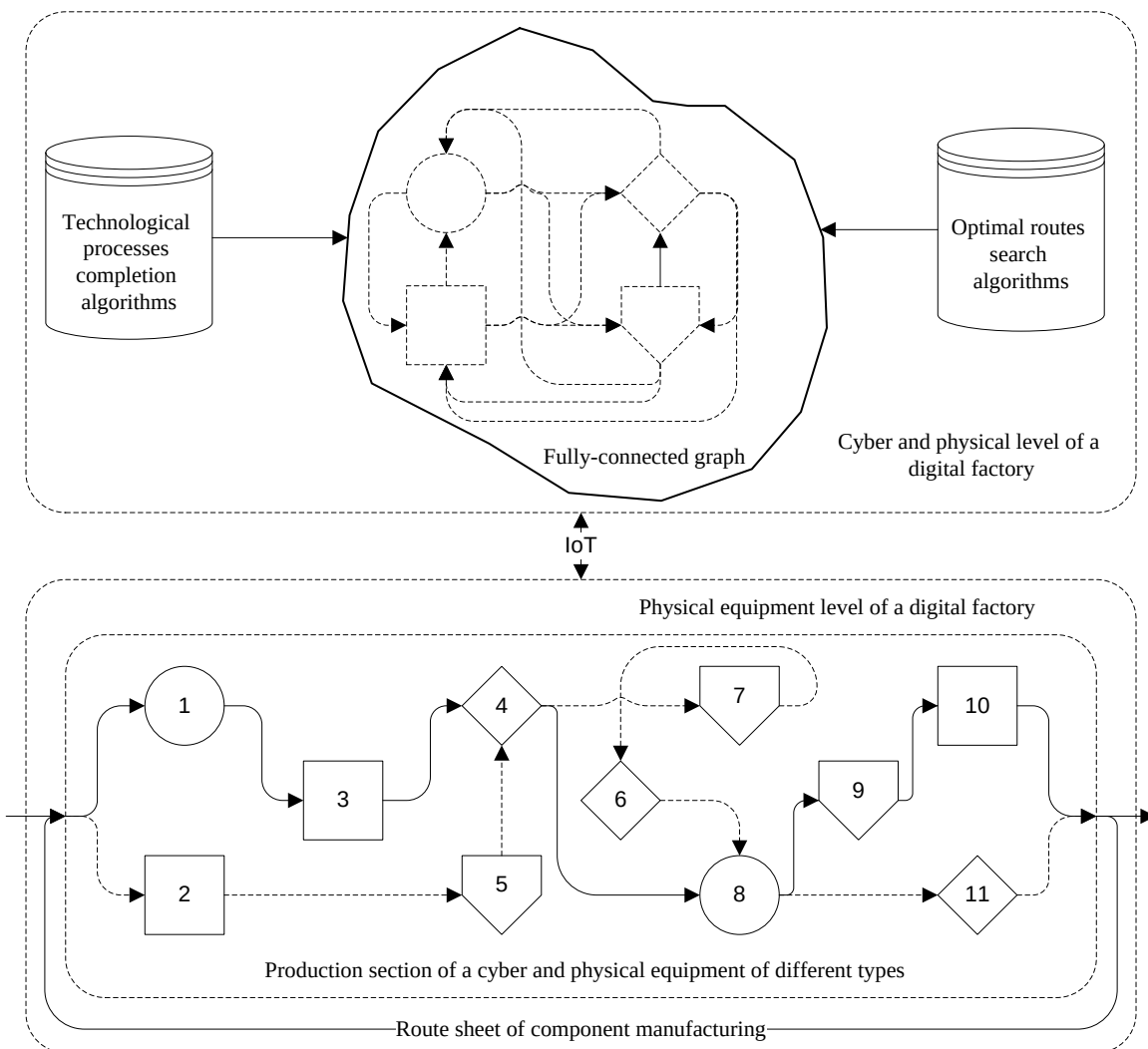


Figure 1. Route sheets realization scheme of the item designing components manufacturing in the digital production companies of the Industry 4.0.

Technological equipment in the level of physical machines is schematically given in figure 1 with numbered blocks in the form of the geometric figures: circle, square, etc. Different types of figures show different types of equipment [8-10]:

- 3D-printer (D-dimension);
- convection oven of solder trimming;

- solder paste application mechanism on a PCB (Printed Circuit Board);
- automatic placer of radio and electronics elements (microchips, resistors, capacitors) and others.

The trajectory of part and component movement as a fragment of production section of the Industry 4.0 company as a part of items manufacturing is shown in figure 1 with arrows connecting production equipment. Dot lines and simple lines are different algorithm completion of technological processes which are being carried out one after the other as a part of the general route sheet of manufacturing and which require the application of technological equipment of different types.

3. Production tasks distribution principles

Initially (the calm state of cyber and physical systems) parts and components movement route in the physical level is not defined. Depending on the type of technological operation to be performed (component montage operation; PCB washing operation; quality check operation of the parts manufacturing and others) in the cloud service, a cyber-physical connectivity matrix is formed at the cyber level, which determines the order of moving the part (component) from one technological equipment to another [8-10]. Matrix values of connection define the space and time characteristics of the parts being transferred in the production by the system.

In cyber and physical level a set of technological equipment of production system is described with mathematical model of fully connected graph. Algorithms for the execution of technological processes are library-based and in the cloud service they form working options for the implementation of the connectivity matrix, which exclude separate routes that are not involved in each specific technological process. The connectivity matrix is determined by the laws known in science and standardized methods for performing physical and chemical production operations:

- the procedure for electroplating;
- the procedure for applying a moisture protective coating to the board;
- the procedure for manufacturing metal parts using additive technologies, etc.

Optimal production route search algorithms are formed by known mathematical methods of optimal trajectories of transport system transferring in the production of parts to minimize the technological operation completion elapsed time and to minimize the distances on which the blanks must be transferred inside the workshop. So optimal routes search algorithm in the production looks for the minimum distance between separate specialized cyber and physical systems brought together to complete the necessary route sheet of item manufacturing. Mathematically each function (search of minimum distance) corresponds to the search of minimum distance in the oriented graph which limits correspondence of the transferring trajectory of blanks (the sequence of technological operations) and its tops - technological equipment. The weights that numerically characterize the edges and the component values of the connectivity matrix of cyber-physical equipment, characterize the spatial distances over which the parts must be moved at a given speed (production rate). For the model of a fully connected oriented graph supported by a cloud service, the Floyd-Worshell algorithm, which has the best characteristics for graphs with a large number of constraints, is suitable for the time criterion for performing task distribution operations.

It is obvious that for the implementation of various technological processes, combined into a single route list, there will be various combinations of the connectivity matrix of cyber-physical systems. Thus, cyber-physical systems through the interface of the industrial Internet of Things get access to the routes of various technological operations stored in cloud services, due to which the self-organizing function of the Industry 4.0 automatic cyber-physical production is implemented at each manufacturing stage.

4. Conclusion

The property of self-organization of automatic cyber and physical systems may provide a production process with given technical and economical characteristics of the company activity at digital enterprises of Industry 4.0.

Practical experience of automatic equipment exploitation shows that primary time expenses arisen during the item manufacturing can be explained with two circumstances:

- significant space distance between two pieces of technological equipment engaged one by one in the manufacturing route sheet after which transport robotized system must make part transferring (components) at large distances;
- non-functionality of equipment after a break-down of cyber and physical system primary components or by missing components (materials) which are necessary for this equipment functioning because of delayed delivery.

Implementation of self-organization principles of production systems could help significantly flatten the influences of those factors because of automatic exception of defected cyber and physical systems from the chain of route sheet (failure protection) and search for routes of minimal distance in the limit of automatic lines. Obviously, in order to implement the principle of self-organization of the production system, the deployment of cyber-physical systems in the workshop should allow the transport accessibility of a robot manipulator to each type of process equipment. This circumstance significantly influences the composition of cyber and physical equipment production.

References

- [1] Stef I D, Draghici G, Draghici A 2013 *Proc. technology* **9** 451-62
- [2] Almada-Lobo F 2015 *J. Innov. Managem.* **3** 16-21
- [3] Gurjanov A V, Zakoldaev D A, Shukalov A V and Zharinov I O 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **327** 022111
- [4] Gurjanov A V, Zakoldaev D A, Shukalov A V and Zharinov I O 2018 *J. Phys.: Conf. Ser.* **1050** 012032
- [5] Lee J, Kao H-A and Yang Sh 2014 *Proc. CIRP* **16** 3-8
- [6] Zhong R Y, Xu Ch, Chen Ch and Huang G Q 2017 *Int. J. Prod. Res.* **55** 2610-21
- [7] Shariatzadeh N, Lundholm Th, Lindberg L and Sivard G 2016 *Proc. CIRP* **50** 512-517
- [8] Gjeldum N, Mladineo M and Veza I 2016 *Proc. CIRP* **54** 158-163
- [9] Ruttimann B G and Stockli M T 2016 *Journal of service science and management* **9** 458-500
- [10] Kemeny Z, Beregi R J, Erodus G and Nacs J 2016 *Proc. CIRP* **54** 53-58