RESEARCH CHALLENGES OF INDUSTRY 4.0

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Abstract: *The paper describes the definitions of industry 4.0 and the factors that influence their formation. It describes the areas that it affects and which are involved in the formation of a new generation industry. Paper also discusses problems that arise in areas related to industry 4.0 when combining them and possible ways to solve them, especially the organization of the production process. Making a focus on properties of software for industrial devices.*

KEYWORDS: *INDUSTRY 4.0, INDUSTRIAL ENVIRONMENT, ARCHITECTURE OF SOFTWARE SYSTEMS*

1. *Introduction*

Industry 4.0 is a very widespread term first used at the Hanover exhibition in 2011. It has many definitions, and combines a large number of different areas and technologies. Now it is often used as a synonym for the fourth industrial revolution.

The development of modern technologies brings this moment closer and closer, but there are still quite a lot of tasks. Which require attention, most of which are not related to any particular area, but to the way of organizing the interaction of these areas and integrating them into a single production system.

The paper considers the definitions for industry 4.0, the main areas and problems of their integration, including from the point of view of software systems.

2. *Definitions of industry 4.0*

Industry 4.0 is a fairly new term that includes many different areas. For this reason, there is no single definition of it and everyone interprets it differently. The wording often depends on the point of view of the author and the field that he is considering for use in the next generation industry.

For the first time, the term was used at the Hanover Industrial Exhibition in 2011 and denoted the strategy of the German government to computerize production, but it was very widespread and today is often used as a synonym for the fourth industrial revolution. It is believed that the first industrial revolution was the beginning of the use of the power of water and steam, the second - the use of electrical energy, and the third - the use of programmable logic controllers and the development of telecommunications.

Thus, the definition of industry 4.0 can be given in terms of the prerequisites for the fourth industrial revolution, for which it is necessary to highlight its main directions. These areas can be considered the Internet of things (IoT) and cyber-physical systems.

Today we are surrounded by a large number of embedded systems. They include room temperature controllers, water leakage sensors, various car systems. smartphones and more. However, all these systems cannot be called cyber-physical. All of them are designed as independent devices, and in cyber-physical systems a key feature is the integration of devices into a single network [1].

Cyber-physical systems can be described as a set of controllers to which various sensors or actuators are connected on the one hand, and to data transmission networks on the other. In other words, this can be seen as a set of embedded systems that can share the data and resources that they possess.

Also, often the definitions are based on modern areas of technology development, which also have a significant impact on production. This includes autonomous production systems that divide production into parts, the management and optimization of which can be carried out independently. The desire to store and transmit information in digital form leads to the emergence of a fully digital environment, which, in turn, opens up possibilities for modeling and using virtual and augmented reality. The physical reduction in the size of electronic components and the reduction in their cost also opens up new possibilities for their application, for example, the use of RFID tags in logistics.

On the other hand, differences in the production of a new generation can be determined from a managerial and economic point of view. This includes reducing development time, personalizing products up to batches from the same model, decentralized management and efficient use of resources.

Thus, 4 main points of view on industry 4.0 can be distinguished. which influence the formation of definitions: production, business, products, consumers.

From the production point of view, the key is to connect all devices (sensors, robots, conveyors, etc.) to a single network and the free exchange of data between them, the ability to automatically predict and maintain equipment, etc. various production processes have a modular structure, but are interconnected, which leads to the fact that decentrally controlled different systems can be controlled interdependently. Such an organization is called smart manufacturing [2].

From a business point of view, industry 4.0 implies a link between different companies, factories, suppliers, resource managers and consumers. Each part of the production should be able to change its configuration in real time in accordance with current needs and taking into account maximizing the efficiency of use of limited resources.

Production can also be characterized in terms of production. Industry 4.0 implies that each product will have an identifier that can carry some kind of information. This allows you to track not only the movement of products, but also their condition, as well as analyze this data to help optimize the production process.

And finally, from the point of view of consumers, industry 4.0 provides the opportunity to order any product modification of your choice, even in a single copy and leave the opportunity to freely make changes to it even during production.

It can be noted that it is impossible to choose any one technology or property that can be used to characterize industry 4.0. Each definition on one side or another describes the properties that a new generation industry should have, but does so taking into account the area to which the author of this definition belongs. Such an abundance of definitions leads to the fact that for each area a definition can be given in its own special way and that a generalized definition should cover all these particular aspects.

Summarizing the requirements for industry 4.0, we can conclude that industry 4.0 generally means a method of organizing production, in the form of decentralized managed subsystems connected by a single communication network, providing mutual reconfiguration depending on the properties of each product unit, taking into account efficient use of resources.

3. *Areas affected by industry 4.0*

In industry 4.0, a large number of different areas are used. Some of them appeared not so long ago, and some have entire sets of approaches and solutions that are successfully applied in practice. In one way or another, they all influence the development of modern technologies and, in particular, modern production, however, for their complex application, the question arises from joint interaction. The following are the main areas [1].

3.1 Big data analysis.

Not only in production, but even in everyday life, there is a huge number of devices that produce data volumes at high speed. Therefore, there are tasks of storing this data, their processing and analysis. Moreover, even the analysis of previously collected data can be useful to prevent errors that may occur in the future. For example, analyzing some properties of products at all stages of its production, it is possible to make changes to the production process to improve its quality.

3.2 Autonomous robots.

Using autonomous robots allows you to look from the other side at solving many problems. In addition to the fact that they can do the work very accurately, it becomes possible to shift other hard work to them, and since they are becoming more flexible and autonomous, tasks can be not only a hard-coded sequence of actions, but high-quality sensors and computer vision allow you to make the interaction of robots and humans safe. Often mentioning autonomous robots and their use within the industry, robotic arms are meant, but this is not true. A large role is assigned to robots involved in the movement of goods across the territory of a factory or warehouse

3.3 Simulation.

Of course, the simulation of various models of products or materials has already been introduced and is widely used, but in this context, “simulation” is meant in a broader sense, namely the construction of a full copy of the physical environment and processes in virtual space. This opens up new possibilities for tuning and debugging. Any change or assumption becomes possible to check in the simulator before applying these changes in the real world. This approach not only saves time, but also safely checks changes without stopping the production process [3].

3.4 System integration.

To date, usually all participants in the production process, ranging from resource providers to consumers, are rarely closely related. This prevents the creation of automated chains in production and creates bottlenecks in the moments of communication between its components.

3.5 IIoT (Industrial Internet of Things).

The industrial Internet of things, which is an industrial variation of the Internet of things, is also an area that has a significant impact on the new generation industry. All devices and sensors combined in one network and interacting with each other or, if necessary, with higher-level controllers allow for a more flexible production process. For example, having equipped each product with a unique RFID tag, each production unit can adapt its operations taking into account the unique features of the product [4].

3.6 Information Security.

This is one of the very important aspects that often stays away. Many companies ensure the security of their systems by making them completely isolated, but this approach is no longer applicable to industry 4.0. At the same time, often existing solutions aimed at the next generation industry are extremely vulnerable to cyber-attacks. Therefore, with the development of various communication protocols between the components of the production system, the issue of opposing attacks is very serious. Reliable and secure communication approaches are the key to protecting against unauthorized access to the production system.

3.7 Cloud computing.

Already, many companies are using cloud software for some enterprise applications. In the development of industry 4.0 and cloud technologies, they will increasingly be used to deploy production systems. This will simplify monitoring and data management. And some manufacturers have begun offering cloud solutions in the area of production management systems.

3.8 Additive manufacturing.

This term includes an approach to the production of various objects from a three-dimensional model by adding layer-by-layer material. The most obvious example of this approach is the 3D printer. With the development of 3D printing technology, this approach has ceased to be used only for prototyping. Now it can be used directly even in serial production of parts from various materials. High productivity, the ability to manufacture parts on one machine and almost any shape finds their application primarily in the aerospace industry, making it possible to produce significantly lighter, but at the same time, durable components.

3.9 Augmented Reality.

Now technologies of augmented reality are only entering our lives, but in the future they should find wide application. Since industry 4.0 does not exclude people from the production process, augmented reality systems will allow workers to see instructions directly in their field of vision using augmented reality glasses or work out actions in various virtual situations in the virtual world.

It is clearly seen that part of the described areas has already been touched upon earlier when describing industry definitions 4.0. This indicates the close connection of all these areas with the industry of the new generation. Some of them can be integrated quite easily due to the fact that it is a fairly independent solution, such as an additive approach to production. At the same time, big data analysis, cloud computing and the industrial Internet of things are the areas that largely determine the structure of new production.

The technologies on the basis of which industry 4.0 is built can be divided into three subgroups. Technologies aimed at hardware changes, technologies aimed at software changes and technologies that are located at the intersection. The former includes partially environmental recognition mechanisms, communication between devices, self-diagnosis of devices, and mechanisms of interaction with the environment. Software includes mechanisms for the joint behavior of robots, big data analysis, and self-learning systems. But the most part, representing the main vector of development, is technologies lying at the intersection, the first of which are cyber physical systems and the industrial Internet of things. This also includes the collection and preprocessing of data, man-machine interaction, and, including, augmented reality and simulation. Despite the fact that, it would seem, these are mostly software solutions, they are closely related to the physical objects of the production process.

Thus, the development of a new generation industry is influenced by a large set of technologies that, in their integrated use, can ensure the organization of production, called industry 4.0

4. *Analysis of problems and approaches to their solution*

Despite the active development of all areas that make up the next generation industry, when implementing industry 4.0, problems arise that in themselves in one area or another might not arise [5].

Modern machines with numerical control (CNC) are used everywhere, but their capabilities are not enough for industry 4.0. They are a simple automated cell whose only task is to process the work piece using some existing set of tools in accordance with a specific program - in fact, a rigid sequence of instructions. Also, this cell can include systems of loading, unloading and positioning of parts. Such machines, on the one hand, lack autonomy, and, on the other hand, the ability to interact with other components of production. Such devices should not act on the basis of direct instructions received, but be able to make independent decisions and negotiate with other devices in production. That is what is key in building a self-organizing production system. Research into the field of artificial intelligence can bring useful results to solve this problem.

Wireless data networks, when used in industry, are not sufficiently prepared to satisfy all the requirements put forward by them. Existing solutions either cannot provide sufficient bandwidth for intensive transfer of large amounts of data, or they can provide it, but are not intended for industrial applications. Perhaps the solution may be a hybrid network of a backbone wired network and wireless transmitters connected to it.

Big data analysis is a rapidly developing field today. Indeed, with the introduction of cloud computing, in the future, big data analytics will be of great value. But the main problem that needs to be solved is efficient data collection. That is, it is required to determine exactly what data needs to be collected, how it can be done, what it makes sense and how to analyze it. For example, to identify bottlenecks that reduce overall performance, you need to know the time spent on each operation. And an analysis of the state of the devices will determine the probability of their failure.

Computer security is also a big problem for modern information systems. On the one hand, it is required to ensure the preservation of confidential data, the disclosure of which can lead to huge material and reputational losses. On the other hand, it is important to prevent the possibility of unauthorized access to factory management mechanisms. Today, even using encryption and authorization mechanisms, there is no way to create a completely secure software system. Even well-known software contains various vulnerabilities. Therefore, for the new generation industry, it is required to develop special and modern methods, but it is also possible to use some classical methods, for example, storing especially important information in the company's private cloud storage.

Organization of production. Undoubtedly, today it is possible to build almost any conveyor system, but it will have a rather rigid structure. A new generation industry is required to have self-decision-making mechanisms and self-optimization and self-configuration mechanisms. These mechanisms, in turn, must rely on the physical ability to transport work pieces between any components of production, as well as the presence of devices for manipulating objects, for example, gripping devices. This will allow you to dynamically change the route of each product element in accordance with the operations required for it. As close as possible to these requirements, flexible production systems are now available, but they are intended for the production of a certain specific family of parts.

In addition to the technical tasks to be solved for building industry 4.0, many problems are caused by the integration of cyber-physical systems with various business processes. This includes interaction with suppliers of materials, delivery of goods, the formation of invoices, receipts, waybills, interaction with customers, the formation of product specifications, coordination of production dates. Each of these stages in each company is somehow formed and debugged, but the introduction of all of them into a single infrastructure of a new generation industry is not yet possible. The solution to this problem should begin by agreeing on uniform requirements for data models and the data exchange format.

Internal logistics. This is a large enough problem to highlight as a separate item. In industry 4.0, an important point is the ability to freely move parts between arbitrary points. It can be machines, storage systems or product loading points. Existing solutions using mobile robots usually impose strong restrictions either on possible routes or on the environment in which this movement is possible, for example, a pre-marked floor of a warehouse. To build a flexible and self-organizing system requires not only solving the problem of moving the robot in a dynamically changing environment from other robots, objects and people, but also a decentralized mechanism for planning movements. So, a group of robots can have a set of logistic tasks next to them that must be completed and distributed among themselves.

The emerging problems can be divided into three groups. The first group is hardware problems, which include the implementation of communication tools between devices, devices and the real world, various mechanical manipulators, and more. The second group is the integration of production processes with business processes, which includes the interaction of suppliers and consumers with the factory, monitoring the production process of each product. And the third group is the intellectual mechanisms of planning, decision making, changes in production processes and self-optimization [6].

5. *Characteristics of industrial environment industry 4.0*

Any production almost always in itself puts forward certain requirements for the environment and structure of the premises. This may be the requirements of sterile conditions, the presence of various types of doors or locks, while the placement should be quite compact, since large areas increase the cost of the factory, but it should. The correct geographical distribution of equipment by area and the availability of routes between them is a very important task, which is complicated by the individual requirements for each product and the fact that often different equipment can perform the same production steps. Thus, with the internal organization of production, the following factors should be taken into account: a large number of participants in the production process, a large number of production stages, the geographical distribution of equipment, processing time at each stage, total processing time, and some others [1].

When designing the production environment, you can resort to modeling the movement of products sequentially through all the equipment that must be visited by them. In the sequence, even for the same type of product, different equipment can be present, which makes it possible to distinguish equipment used in similar groups. This will not only determine the frequency of use of the equipment, but also the probability of using a particular type of equipment for the production of a certain type of product [1].

In general, the organization of the production process of industry 4.0 can be represented as a mechanism for the interaction of several types of agents. These are equipment:

1. Agents, which performs basic operations;
2. Transport agents, which include autonomous robots, conveyors, and so on;
3. Product agent, which is a product element.

You can pay attention that the product in this system is exactly the same agent as industrial equipment. Moreover, he is the initiator of all processing and moving operations [2].

To implement this approach, each product instance must have its own unique identifier, for example, an RFID tag, which will store, including the current state, a list of necessary operations and all other necessary information. All devices of the production process should be able to read tags from products, and have access to a centralized system that can tell what actions are required to be performed on the work piece and will track its progress along the production line [3].

This approach, in which each agent product has complete unique information about it, allows you to fine-tune the rest of the production process. For example, each engine nozzle has a mark on it, in which its individual characteristics and calibration data are encoded after testing. Agent equipment that will be engaged in the installation of these nozzles will be able to adjust their control system according to the properties of each of them [5].

The use of various transport agents also complements the requirements for the structure of production. The desire for flexible production leads to the abandonment of standard conveyor solutions in favor of autonomous vehicles that perform the tasks of moving products across the entire production area. The special requirements arising in connection with this can be divided into requirements for the physical organization of production and for an approach to management. From a management point of view, the key is the transition from centralized management to decentralized hierarchical systems. Thus, the product agent, knowing its weight, shape, and so on, can inform transport agents of the need to move between two points. Transport agents share this information with each other and make a general decision on its implementation. At the same time, planning tasks are already shifted to the agent itself. Such adaptive behavior of agents allows them to be used in dynamic and complex environments [4].

Since the agents in the new generation industry are autonomous devices, robots, this imposes significant restrictions on the organization of the production process. Much attention needs to be paid to the perception of robots around the world, both stationary robots and mobile ones. For stationary robots, the main task is to recognize the object, its position and orientation in space. Such problems have attempts to successfully solve using computer vision. For example, it is possible to equip each part with a visual mark, a code that can be found using the camera and obtain information about the part and its position, using this data to capture the part with a robot. The same labels can be used to mark pallets for goods, places on shelves and so on [3], [7].

For mobile robots, the task of perceiving the surrounding world is closely related to the task of navigation. On the one hand, indoor navigation is facilitated by the absence of natural factors, such as rain or fog, but may be complicated not by the uniform lighting of rooms, short distances and uniformity of rooms, which complicates the task of navigation. Restrictions on the physical structure of rooms often depend on the approach chosen to organize the movement of mobile robots, but one way or another, most decisions are based on some additional layout of rooms. This can also be done with visual marks on walls or floors [7], [8].

All the properties inherent in industry 4.0 described earlier also impose limitations in the design of production. All agents must be equipped with monitoring mechanisms that allow real-time recognition of their status and various current characteristics. There must be a computer network, including a wireless one, supporting the interaction of a large number of agents [2].

An important feature of the new generation industry is high efficiency and low power consumption. This is due to the negative impact of a large number of modern industries on the environment both in terms of global warming and pollution. Also important factors are the reduction in labor force and the desire for more careful spending of limited natural resources such as oil, coal and so on [9].

6. *Requirements for software systems architecture*

Structurally, in the architecture of industry 4.0, there are 3 main levels: physical, network, and cloud. The physical layer is represented by cyber-physical systems, devices related to the Internet of things. They have digital interfaces with factory equipment, including affordable sensors. In addition, equipment at this level can receive commands from the cloud level, according to which it can configure its work to increase the quality and productivity of production. All components of the physical layer are connected to the industrial network. The cloud layer collects information from the physical layer, analyzes it, passes feedback to the physical layer and provides an interface for managing and analyzing the state of the factory to the managing staff [2], [5].

Since all devices must be able to communicate with each other, they must support common protocols. Standards based on Ethernet, OPC-UAs may be good candidates even though they do not imply real-time transmission. A common interface and connection to a single network will allow you to create a connection between physical objects and their virtual representation, which in turn will make it easy to simulate processes in industrial applications in a single form [3].

Technologies that play key roles can also be divided into several groups: production device technologies, network technologies, cloud technologies, and client application technologies. Production technologies primarily relate to ways of interacting with the outside world, such as computer vision and RFID. URLs and the HTTP protocol can be used to unify access to various network devices. JSON can be used as a data exchange format since it is well compressed and makes it easy to work with. A cloud solution for the system user is presented using the Platform as a Service (PaaS) model. By viewing statistics and analyzing the current state of the factory, users can be provided with a web interface or mobile applications [1], [5].

An important task is to solve planning problems. In the conditions of a new generation industry, this task arises to a large extent, including in the matter of logistics. It is required to provide mechanisms to support autonomous cargo movement processes. In such restrictions, decision-making should not take place centrally, but hierarchically. Transport agents should be able to share knowledge using communication mechanisms with each other, which will allow agents to plan their actions and take into account the actions of other agents. In addition, the distribution of tasks between agents can also occur selectively. The idea is to combine a hierarchical and distributed control mechanism. A certain set of tasks can be issued to a certain group of agents selected by some criterion (for example, by location), and the final distribution will already be performed between the agents independently. The advantages of multi-agent systems are high speed, adaptability and scalability. Also, this approach is well suited for use in dynamic environments [4], [8].

Decentralized management, being one of the main ideas at the core of architecture 4.0, can also introduce features that should be considered. One of these features is the possibility of mutual blocking. This can happen, for example, when using multifunctional agents. When agent 1 can perform operations A and B, and agent 2, operation B. When processing a work piece stream, a situation arises in which agent 2 will wait when agent 1 is free to transfer to him a work piece on which operation B is required, and agent 1 will wait when agent 2 will be freed up to transfer to it a work piece on which operation B is required to be performed. Just as in the case of preventing deadlocks during parallel programming, simulation of the production process and its verification with using special software [2].

Thus, the software architecture in industry 4.0 can be represented in three levels: the device management layer, the network layer, and the cloud. Being a distributed system, devices must support monitoring mechanisms and network interactions with each other, while performing their main functions autonomously.

7. *Conclusion*

In the course of the work, various definitions for industry 4.0 were considered and a generalized definition was formed. The main problems associated with the unification of the areas affected by industry 4.0 are considered, and directions for solving these problems are also proposed.

To formulate requirements for the architecture of industry 4.0 systems, the features of the industrial environment and the technology stack have been described, which can be represented in the form of three levels: device management, network level and cloud.

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