MODEL OF SMART FACTORY USING THE PRINCIPLES OF INDUSTRY 4.0

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Abstract

The article deals with the created model of a smart factory using the principles of Industry 4.0. It is the creation of an autonomous manufacturing system, which combines into one unit the means of production, such as machines, handling units, warehouses, etc., as well as human resources and information flows. The manufacturing system is not centrally controlled, but each unit has its own control system and communicates with others on the Internet of Things principle. The entire manufacturing system behaves fully autonomously, organizes itself, and adapts to the specified requirements in real-time. Its goal is to produce the products as efficiently as possible at a given time based on customer requirements. The benefit of such system should then be a significant increase in productivity, quick and easy reconfiguration of the entire system, which is crucial mainly in the case of small series production.

Keywords

Industry 4.0, smart factory, autonomous system, Internet of Things (IoT)

1 INTRODUCTION

The term Industry 4.0 is referred to as the fourth industrial revolution, which is to use the technological concepts of the Internet of Things, Cyber-Physical Systems (Physical Systems), and other modern technologies to bring complete digital interconnection of all production processes (from product development to product distribution). [ATP 2016, Kaminsky 2016]

This connection will lead to the creation of the so-called "smart factory" of the future. Various devices should implement computer chips capable of communicating wirelessly with each other over the Internet. Production would then take place in autonomous manufacturing systems, where all its parts, including the products themselves, would communicate and form a so-called Cyber-Physical System. [Hercko 2015, Prima 2016]

One of the main obstacles to the implementation of Industry 4.0 tools is the lack of standardization [Chromjakova 2017] of both products (material flow, Design for X, etc.) and processes (process thinking, information flow, Key performance indicators, etc.). Despite the talk of pressure for standardization and process thinking, in reality, it is more of an intention than a reality. It follows from [Koblasa 2019] that only 25% of companies in the automotive industry use standardization tools in a targeted and methodical way. The situation in other consumer industries is even worse. Only in 7% of the surveyed companies the principles of standardization are used systematically. In the field of logistics, which fundamentally affects the application of autonomous and automated systems in production, the situation is even more serious. Only 5% of the automotive and 0% of the other consumer industries use the principles of process thinking (e.g. Lean SixSigma, data standardization) systematically. Random resp. unsystematically in 70% and 20% of the surveyed companies.

For these reasons, it was decided to create our own small system on which it would be possible to test, implement and develop new things and algorithms for the development of a smart factory.

2 SMART FACTORY

The smart factory enables the digital interconnection of the manufacturing system, including machines, production lines, warehouses and supplier companies. Using methods of auto-optimization, autoconfiguration, self-diagnostics, or e.g. machine perception.

Modifications and changes to the products require a constant exchange of information. Therefore, communications take place interactively and in real-time according to customer requirements. Production is flexibly adapted to data from the Internet. The production process is closely linked to the purchase of materials, warehousing, logistics and trade. We are talking here about the replacement of classic mass production of the same products by efficient processing of individual orders while maintaining the same low price. [Ondra 2017, Fujitsu 2019, Rouse 2019]

A key element of digitization is also the so-called Logistics 4.0, even though it is not as popular as Industry 4.0 itself. It is revolutionary automation of logistics processes. Thanks to the interconnected system of people, machines and other devices, the supply chain operating on the principles of smart logistics can flexibly adapt to various variable conditions. The system will be able to evaluate the current situation and adjust production priorities based on it. This translates into much greater planning accuracy, shorter waiting times for delivery times and streamlining the entire logistics process.

The vision of smart logistics is to connect warehouse systems, internal logistics, transportation technology and planning software into one interconnected network that can automatically create and modify logistics processes for other links in the production chain.

Such automated planning saves time, manpower, energy and other operating costs. [Toyota 2019]

Only smart factories will be able to handle fluctuations in demand, they will be more resistant to defects, and they will also be able to produce as efficiently as possible. Machines, people and resources will not only communicate with each other but also cooperate. The machines report themselves to the maintenance staff, and they also precisely define the problem.

The product will be able to control its production flow with the help of a chip, it will know which parts it consists of and to which customer it is to be delivered. The product itself will therefore actively participate in the production process. [Singerova 2019, McKewen 2016]

Key technologies without which Industry 4.0 cannot be implemented and which complement each other include Cyber-Physical Systems (CPS), which connect the cyber and virtual worlds with existing devices and people. They monitor physical processes, transform them into digital form and enable their decentralized management. These systems are designed for the industrial integration of manufacturing systems and communicate and control the physical components that are equipped with the communication system via the Internet. Cyber-physical systems thus enable the control and reconfiguration of functions with a high degree of automation. [Singerova 2019, Leiva 2017, Harting 2018]

Another important technology that no smart factory can do without is the Internet of Things (IoT). It is a network reserved for all devices capable of receiving an Internet-based signal. This technology enables data flow and provides the ability to remotely monitor and manage processes and, if necessary, change production schedules very quickly in real-time. [Thales 2019, Raushan 2018]

The communication and identification of individual system components are streamlined by additional technology RFID (radio frequency identification), using chips, sensors, and other ID tags. These components will be part of all elements in the production. They give machines clear information about what is to be done with the product or part. In this way, it will be possible to remotely program and adjust the production itself as needed. [Singerova 2019, Orel 2015]

The intelligent factory is a leap forward from traditional automation to a fully connected and flexible system that can use a continuous flow of data from connected operations and production systems to learn and adapt to new requirements.

One of the most valuable features of an intelligent factory is its ability to self-realize, automatically adapt and autonomously manage manufacturing processes. This capability can fundamentally change traditional processes and management models. In many cases, an autonomous system can make some decisions without human intervention and shift decision-making responsibilities from person to machine or concentrate decisions in the hands of fewer people. [Singerova 2019, Sustr 2019, Logistici 2018, Nechanicky 2019]

Smart factories are therefore a key element in the transition to a digitized and automated business. They can autonomously manage the complete production process and at the same time make it more efficient. In smart factories, people, machines, and resources naturally communicate with each other, just as they do with social media communication. [Ondra 2017, i-SCOOP 2019]

3 SMART FACTORY MODEL

The topic of the concept of a 'smart' factory, as well as autonomous manufacturing systems, is currently very topical and undoubtedly awaits great development soon.

This concept's aim is to create a fully autonomous manufacturing system, the so-called 'smart' factory, where all levels of manufacturing are digitally interconnected (from product development to logistics). This should lead to a significant increasing in productivity, quick and easy reconfiguration of the entire system which is crucial mainly in the case of small series production.

Nowadays, there is no doubt that new automation technologies are gradually being introduced into production practice. Many companies are already experimenting with the possibilities and benefits of using augmented and/or virtual reality, the use of collaborative robots that can safely work with humans, complete digitization of production documentation, predictive maintenance, etc. However, to implement a fully autonomous manufacturing system with real benefits is still quite far. Therefore, it is necessary to create a test system on which it will be possible to test everything comfortably. Research must focus on the implementation of optimal solutions for the implementation of mutual communication at all levels of the system so that it is as simple and efficient as possible and works with the smallest (only necessary) amount of data, thus maximizing its benefits. The motivation for creating a model of a smart factory at the Technical University of Liberec is to create a fully autonomous manufacturing system, on which it will be possible to show the basic principle and all the advantages and benefits of applying an autonomous production system in practice simply and clearly.

4 SMART FACTORY MODEL COMPONENTS

The created model of a smart factory will consist of several different components (stations), which will be interconnected wirelessly. All components of the smart system were designed in our department, including their control systems. By keeping the design and control open, it will be much easier to adapt them to the needs of the entire system, especially communication with the surrounding components of the manufacturing system, but it is also assumed to modify the machine hardware, e.g. for automatic clamping of workpieces, etc.

4.1 Small three-axis CNC milling machine

The basis of the created production system is a small three-axis CNC milling machine. The milling machine is used for machining of easily machinable materials, such as artificial wood, plastics and aluminium alloys. The dimensions of the working space of the milling machine are 250 x 260 x 150 mm. The designing of this milling machine, including its control system, was described in [Sevic 2019].

The basic construction of the machine is made of aluminium profiles, which allows variability and sufficient rigidity and accuracy of the construction. A rolling prismatic guide is selected for the X and Y axes, cylindrical guide rods with rolling linear bearings with a diameter of 16 mm are used for the Z-axis. For the drives of the individual axes, rolled ball screws with a diameter of 12 mm and a pitch of 4 mm with a pre-tensioned nut are used. The spindle was selected based on the calculated values, the required spindle power, the cutting force and the torque on the tool during milling. No available spindle met the specified requirements, so the design of the actual spindle was started. The designed spindle uses a DC motor with a power of 400 W with a PWM controller, with speed control in the range of 3,000 to 12,000 rpm. The spindle is connected to this motor via a belt drive with a gear ratio of 1: 2. An adapter with an ISO 20 coupling is used as the tool holder, the largest tool diameter that can be clamped is 7 mm.

The milling machine is also equipped with a tool magazine. The tool change is fully automatic.

This tool magazine is designed for five tools. It is designed so that the magazine bar with unused tools does not reduce the working space of the milling machine. The magazine bar is thus located outside the working space of the machine in which it is tilted utilizing a parallelogram which is controlled by a stepping motor. Another four-joint mechanism is also attached to the parallelogram, which ensures that the protective cover of the tools is opened during the exchange.

The collet is used to pulling the tool into the spindle, and it is opened using a spacer ring when extended, and thus the tool is released from the spindle. Another part of the spindle is the spring, which exerts a pulling force on the tool holder.

The automatic tool change system consists of a spindle, a tool magazine and a mechanism for changing them, see Fig. 1.

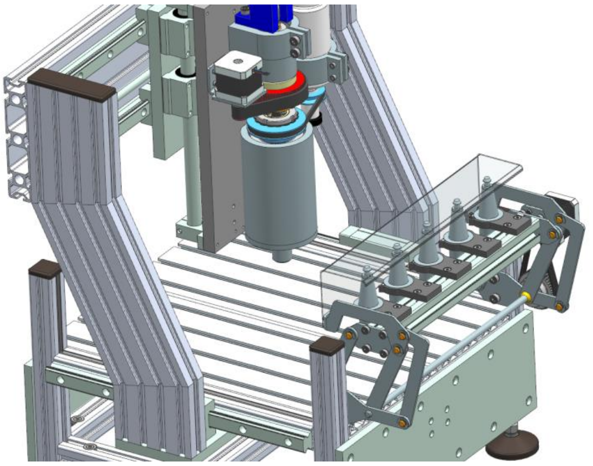

Figure 1 - *CNC milling machine with integrated tool magazine*

4.2 Operational and inter-operational manipulation

The purpose of handling the part is to transport it between the individual stations of the factory model. The part is transported clamped on a technological pallet. The pallet serves as a unified base with which individual sites can work. Manipulation with this pallet is divided into inter-operational, i.e. it is transported between the system stations and the operating one when it is manipulated within the given operation - e.g. clamping on the milling machine.

4.2.1 Operational manipulation

The task of operational manipulation is to ensure the correct positioning of the workpiece and its clamping in the working space of the given device, in this case, the CNC milling machine. A system was designed for taking over the technological pallet from the Automated Guided Vehicle (AGV) and its transport and firm clamping in the working space of the milling machine, see Fig. 2.

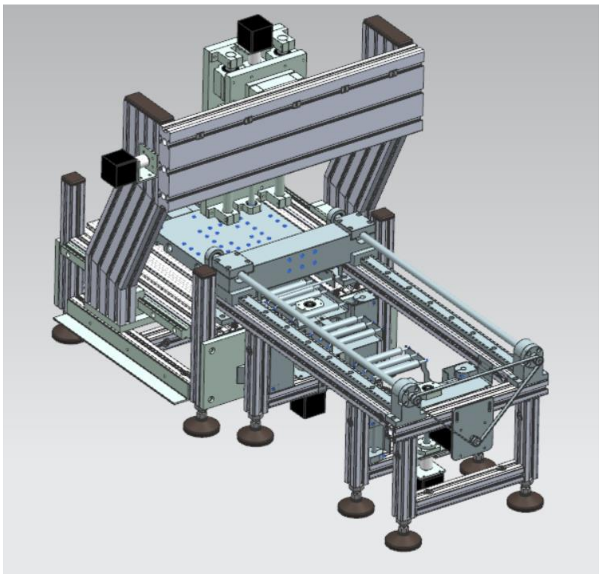

Figure 2 – Designed operational manipulation

The AGV brings the pallet with the workpiece into the operational manipulation device. Here, the pallet is automatically removed from the vehicle using manipulation levers and transported to the working space of the milling machine. There is the pallet with workpiece firmly clamped. After machining, the pallet is released and transported back to the loading area above the AGV. When the vehicle is there, the pallet is loaded on it and transported to the next operation.

4.2.2 System of workpiece clamping

A technological pallet, see Fig. 3, with dimensions of 198 x 198 mm, was designed for clamping the workpieces to the milling machine.

The technological pallet is made of duralumin EN AW-7075, this selected material ensures a low weight of the pallet with sufficient mechanical parameters.

To save as much space as possible, a variant with threaded holes is chosen from the common design variants. Compared to the most common design with T-slots, this design does not significantly disturb the rigidity of the technological pallet, which therefore may not be so thick. In this case, a pallet thickness of 20 mm is fully sufficient.

Precise positioning of the technological pallet on the milling machine is ensured using matching holes Ø8H7, which are located around the circumference of the pallet. The correct position of the pallet is then ensured by the guide pins which fit into these holes.

Within the idea of Industry 4.0, it is also necessary to ensure the identification of the technological palette. This is ensured by an RFID chip located on the underside of the pallet. Two holes on one side of the pallet will serve as identification of the rotation of the pallet. After setting the pallet in the machine, it will be possible to check its orientation using two-bit information from two micro switches.

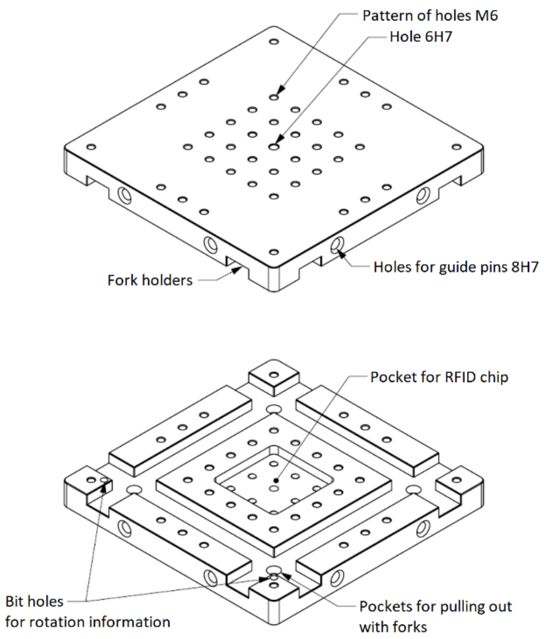

Figure 3 – *The technological pallet*

4.2.3 Inter-operational manipulation

The task of inter-operational manipulation is to ensure transport (semi-finished parts or already finished products) between individual elements of the system, i.e. between storage system, CNC milling machine, measuring equipment, etc. For inter-operational manipulation will be used Automated Guided Vehicle (mobile robot). It will be guided by a black line on the floor that allows doing changes in the manufacturing system layout easily. The device will be implemented as a separate unit that can both receive and issue instructions from/to other system stations.

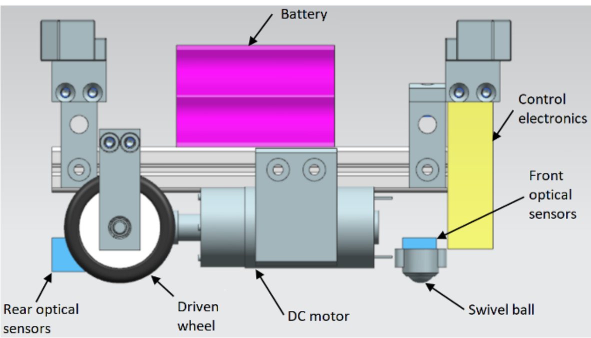

Figure 4 - Automated Guided Vehicle

The AGV, see Fig. 4, will transport the already mentioned technological pallet with the clamped semi-finished part. An RFID chip is placed on the technological pallet, which enables its unambiguous identification. The pallet is a separate element of the system. After transport to the destination, the pallet will be removed from the vehicle and clamped to the target station. The AGV then can perform additional activities and thus reduce the amount of required transport equipment.

4.3 Intelligent warehousing system

The design of the warehouse, see Fig. 5, is based on the requirement that the storage and removal of parts take place completely automatically. It is assumed that the parts for storage will already be clamped on the mentioned technological pallets.

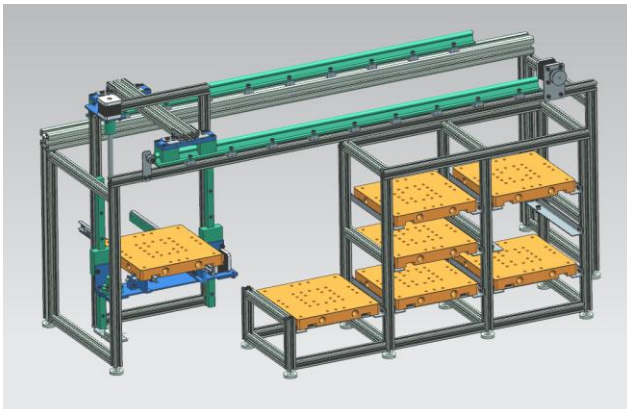

Figure 5 - *Warehouse system design*

The warehouse have to be largely universal so that it can storage parts of different dimensions. It must also communicate with at least AGV that is used to transport parts to another station.

The whole station consists of two parts, the warehouse itself and the manipulator. In the warehouse will be stored the technological pallets, on which the workpieces specified by the customer will be clamped. The manipulator provides transport between the warehouse and the specific position in the whole warehouse used for distribution or back for storage of parts. This specific place is served by the previously mentioned AGV.

4.4 Expected layout of the smart factory

Several criteria were considered when creating the layout. The first criterion is the size of the built-up area. Since the area on which the entire manufacturing process will be located is considerably limited, the layout has to be designed with maximum usage of space. The second criterion is the extensibility of the layout in the future, in terms of adding another manufacturing station without increasing the maximum dimensions of the layout. The next criteria include access to individual workplaces and the location of workplaces. The layout design is possible to see in Fig. 6.

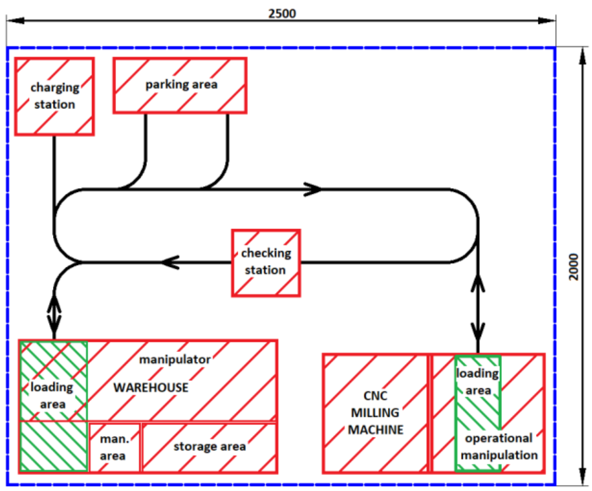

Figure 6 – Designed layout of smart factory

5 PRINCIPLE OF THE WHOLE SYSTEM FUNCTION

It will be possible to work on the optimization of control algorithms of individual parts of this system in the system described above. Furthermore, it will be possible to optimize communication between all members of the system and minimize and optimize the transmitted data. Individual members of the system will not be managed centrally, but each will have its control system. The components will communicate with each other on the principle of IoT.

The manufacturing process should then be as follows: in the basic user interface, the customer defines (configures) the product from possible variants. Then the NC program for the milling machine is modified for this specific product. The NC program should reconfigure itself according to the specific product specified by the customer. In this case, it can be, for example, a name tag into which a text or image will be engraved according to the customer's specifications.

Based on the customer's request, the software selects the ideal workpiece for a given product and passes this information on to the AGV. The AGV then asks the warehouse if it has this workpiece. If so, the warehouse will prepare it for collection. If the warehouse does not have the required semi-finished product, for example, the next possible size of the workpiece is selected.

The AGV together with the workpiece further queries the CNC machine for free capacity for the manufacturing of the required part. If the given machine is free, the AGV will come to it and hand over the pallet with the workpiece to it. Information about the required product is also transmitted with this pallet, the machine downloads the required NC program from the main database according to this information and then starts production. After the part has been manufactured, the machine requests inter-operational manipulation (AGV) for transport. The free vehicle arrives and loads the pallet with the finished part. It then takes it, for example, to the inspection measuring station, where the main (most important) dimensions of the part are checked. If all dimensions are in tolerances, the part will be taken to the warehouse for finished products. If the part is bad but repairable, it will be taken back to the milling machine, which will correct the required dimensions. The part is then moved again to the measuring station, where the dimensions are checked again. The measuring station also analyses the inaccuracy of machining and sends information to the milling machine for the setting of correct tool offsets. The third variant is that the product is bad and unrepairable, in which case it is then disposed of in scrap parts.

It will be possible to monitor the entire manufacturing process and the state of all system components also via an information application. So, customers will have access there, to know what stage of manufacturing their parts are in.

6 CONCLUSION

The work aim is to design a functional model of a smart factory based on the principle of Industry 4.0. It should be an autonomous production system with machines, handling units, warehouses, etc., where it will be crucial to correctly design the flow of information. To ensure easy change (reconstruction) of the production system, it is important that the management is not central, but each station of the system is separate and coordinates its activities based on communication with other elements of the system on the principle of the Internet of Things.

Due to the need for open design for possible later interventions and modifications, it was decided that all key elements of the smart factory model will be designed and manufactured by self-help, including control systems, based on available programs, but tailored to own needs. At present, the design of individual components of the entire system is completed at the level of CAD models (assemblies), the CNC milling machine is then in the phase just before the completion of the hardware part. In parallel with the design of the machine, the development of its control system is underway. It was decided that a so-called GRBL G-code interpreter will be used to control a CNC milling machine with a tool magazine, running and executing instructions in real-time on the Arduino platform. A program running on a standard computer is then created for its operation and communication with other elements of the system.

The other elements of the system are not so complex to control, so only a micro-controller will be used for their control and communication, e.g. again on the Arduino platform. The interface for communication with the customer can be made e.g. as a web application so that monitoring of orders would be possible from anywhere via the Internet. Alternatively, it can only be a program running on the local computer and communicating with the system, which may be easier in the first stage.

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