The role of multi-agent systems in improving performance of manufacturing robotized cells

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Abstract. Present market conditions causes that modern control systems of robotized manufacturing cells should be characterized by the much greater degree of flexibility, self-organization and, above all, adaptability to emerging outer excitations. The phenomenon of information distribution is one of the most important features of modern control systems. In the paper is presented the approach, based on application of multi-agent systems, for supporting the operation of robotized manufacturing cells. The aim of this approach is to obtain the flexible response to outer excitations and preventing situations that might cause the delay of the production process. The presented paper includes description of the concept of an informatics system designed for controlling the work of production systems, including work cells. Such systems could operate independently if it would be equipped with the self-organization mechanism. It is possible in the case of the proposed multi-agent system. The implementation of the presented concept will follow the present analysis of the described concept. The advantage of the proposed concept is its hierarchical depiction that allows integrating different utilized informatics tools in one complex system. It allows preparing the final computer program.

1. Introduction

The increasing requirements of customers, shortening of the product life cycle, balancing between the production costs, the quality and timeliness of orders, the production of a wide range of products in batches of a low size and necessity for immediate response to the emerging demand are just some of the factors with which have to deal companies operating in the variables market conditions at the beginning of the XXI century. This involves, among others, the increasing complexity of information systems used in enterprises. Therefore, it becomes necessary to search for new ways of development, without which it is impossible to gain the sustainable competitive advantage. Increasingly decreases the odds of success of companies that do not operate comprehensively and rely only on the development of certain areas of their business. For example if they focus only on reducing production costs or controlling the profitability index (like in the case of General Motors). The task of complex data analysis could be accomplished by investing in machines that could work, round the clock, without supervision. It is only possible with the use of industrial automatics systems like industrial robots. These systems require also the automatic maintenance sub-systems that could ensure its maintenance-free operation.
In the age of advanced technologies, robotization has become an integral part of development of any production system. The increase of the physical work costs causes that the initial investments outlays on the purchase of robots are rapidly reimbursing. In the case of two-shift work they are reimbursing after about 2-4 years, while in the case of three-shift work after 1-3 years [1, 3-5]. The increase of availability and the dynamic development of industrial robots caused that they are implemented in almost every industry branch. Robots are increasingly replacing human workers in monotonous works or works requiring enormous precision that is not attainable for a man. Automation and robotization of technological/production processes affects, in a very significant way, all aspects of the enterprise business activity. Nowadays, the most robotized industry branches, in quantitative terms, are: the automotive industry, the electronic industry, the production of metal goods and the production of rubber and plastics goods [1, 5-11].

2. System architecture
The main objective of the implementation of multi-agent systems (MAS) is to create the virtual environment, which enables direct flow of data and information from the level of production management (strategic level) the level of a robotized manufacturing work cell (operational level). The information exchange, between these levels, is necessary to take appropriate action in response to changing conditions in the work cell and in the market as well as to allow flexible managing the operations realized in the work cell.

The data flow system, in an enterprise, is organized hierarchically what is shown in the figure 1. The information flows from the strategic level (management level) to the operational level (workcell). Basing on this description the problem of data flow between the presented levels/layers could be modeled using an agent system, with generally defined objectives. The MAS structure is formulated on the bases of precise defining the information flow in the enterprise information system. It is realized in the process of decomposition of the system into smaller agent-based subsystems, which are, in some sense, independent one from another.

![Hierarchical control architecture](based on [12]).

The complexity of the processes, taking place in the robotized work cell, causes that during the operation of a work cell it should be fulfilled, by the control system, many, often contradictory, requirements such as: enabling the access to data in real time, utilization of different communication media, or providing the uniform model for data presentation. Moreover, the decentralization of systems causes that the important problem is the distribution of control functions to its particular components. Hence, without the proper integration of various components, consisting robotized manufacturing workcells, it is very difficult to create the efficiently working system that realizes the tasks concerning the selection the appropriate technical and organizational solutions. The application of MAS systems allows generalizing complex problems, that is, to realize the problems that are abstract ones.
The agent, in the literature, is determined as an autonomous unit, embedded in an environment that acquires data from this environment through sensors and, basing on these data and the internal reasoning process, performs actions on that environment. The ability of an agent to act autonomously, also in the group, means the ability to participate in the high-level interactions such as, for example, cooperation [13-15]. The possibility of cooperation with other agents offers great opportunities associated with the implementation of multi-agent systems for the efficient functioning of robotized manufacturing workcells. The proposed approach is the extension of the concept presented in [2]. It assumes the use of the mechanisms of self-organization that allows organizing the independent information channels and providing different information channels what increases the efficiency of the information system.

The system consists of a user interface, a multidimensional database, and agents cooperating with each other. In the structure of the proposed system (figur 2) are distinguished four decentralized and partially independent units (agents) focusing themselves only on the key responsibilities. Each agent contains detailed information concerning the tasks assigned to them. Furthermore, each of the agents is equipped with a decision-making module. Between all groups of agents is established cooperation, which is considered one of the most attractive features of the multi-agent approach.

The analysis of the presented architecture the system allows distinguishing in it several basic units creating the multi-agent system. These include:

- **Coordinator agent** – its task is to coordinate and monitor of the whole manufacturing workcell.
- **Task order agent** – its task is to manage the sequence and allocation of realized tasks, in accordance with the current situation in the workcell.
- **Resources agent** – agent which is responsible for proper utilization of available resources, which are: technological tooling of a robot, machine tools, tools, buffers, auxiliary equipment, transport equipment and reorientation stands. Moreover, the agent controls the flow of elements manufactured using mentioned resources.
- **Robots agent coordinator** – it is responsible for selection and suitable work of a particular robot. In the structure of the robots coordinator, which plays a supervising part, it could be distinguished n agents responsible for planning the trajectory of an industrial robot (trajectory planner agents).
- **Trajectory planner agent** - its task is to plan the optimal trajectory of a manipulator movement, in a changeable environment of a robot scene, according determined algorithms basing on the information gathered using e.g. a vision system, force sensors as well as RFID (Radio-frequency identification) chips. After completion of analysis the returnable information is transferred to a robot, which generates, basing on suitable algorithms, the new trajectory of a manipulator movement.

![Figure 2. The proposed architecture of the system.](image-url)
At the strategic level of the proposed system are proposed two main agents responsible for supervising the work of the controlled work cell (figure 3). The task order agent is responsible for dynamical scheduling the production system, in real time, to obtain the highest possible production efficiency. The coordinator agent is responsible for solving resources conflicts, including the time conflicts of tasks realized in the supervised work cell.

![Figure 3. Strategic layer of the proposed system.](image)

At the resources domain the agent structure is organized according the resources structure (figure 4). There are assumed five main resources: physical ones, financial ones, human ones, information ones and time. The most important are agents responsible for physical resources and time. The physical resources agent is supervising all agents responsible for components of a work cell (machine tools, conveyors, auxiliary devices, industrial robots, etc.).

![Figure 4. Structure of resources agents.](image)

The schedules and task concerning industrial robots are clustered in the other group of independent agents (figure 5). These agents are responsible for planning the operation of industrial robots in the supervised manufacturing system (work cell) according to master production plan.

![Figure 5. Structure of agents responsible for industrial robots.](image)
Agent, which plans the trajectory, is one of the new proposals in the presented system. It is
designated for managing the work cell operations. This agent structure is based on the idea of an
intelligent agent [14]. Basing on the inner learning module it could modify its own base of knowledge.
In this manner the trajectory planner agent could adapt to changing work conditions, to changing work
environments and to changing work requirements. The adaptation process is dependent on the learning
module efficiency. The structure of the trajectory planner agent is shown in figure 6.

![Figure 6. Structure of the trajectory planner agent.](image)

The vision system may consist of one or multiple cameras, cooperating with each other, and could be
placed, for example, directly on the robot arm, in dependency on the nature of operations that should
be performed in a workcell. The purpose of vision systems is to identify the position and angular
orientation of elements which should be e.g. gripped by the robot arm. The use of force sensors
allows, in dependency, for identification the force or torque applied to the gripper. Whereas, in
relation to RFID chips the information stored on a data carrier, attached to the product or transport
pallet, could provide to the system the information about the type and characteristics of the object.

The proposed concept of integration could be used both in relation to one workcell, as well as to
several robotized workcells. In the second case, each workcell is treated as a separate agent, so called
workcell agent. Between workcell agents is programmable established communication and
cooperation. While the agent structure of a single workcell does not change.

3. Conclusions
The solutions integrating an enterprise should ensure the efficient flow of information between all its
components. From one side there is the flow of information for manufacturing workcells controlling,
while to the other side is transmitted information on the realization of ordered tasks, about material
flow, about problems encountered and about the system state. The proposed in the work the possibility
of application the multi-agent techniques for supporting the operation of a robotized manufacturing
workcell is designed to facilitate the flow of information within the robotized workcell production.
The use of agent technologies could also significantly speed up the flow of information within the
robotized manufacturing workcells.

The presented concept includes solutions that should be implemented in the prepared, specialized
MAS system. One of the requirements is considered with the need for utilization the already existed
and licensed software. The second is considered with the need for integration of different data format
as it is generated by different computer programs. These requirements should be realized by utilization
of common databases that are intended to be linked with particular supervising agents. The existing
computer program, using special program interfaces, could exchange data by these databases through
mentioned supervising agents. These elements could be determined as the main qualitative advantages
of the proposed concept of the MAS architecture.
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