Modelling of Robotized Manufacturing Systems Using Multi-Agent Formalism

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Abstract. The evolution of manufacturing systems has greatly accelerated due to development of sophisticated control systems. On top of determined, one way production flow the need of decision making has arisen as a result of growing product range that are manufactured simultaneously, using the same resources. On the other hand, the intelligent flow control could address the “bottleneck” problem caused by the machine failure. This sort of manufacturing systems uses advanced control algorithms that are introduced by the use of logic controllers. The complex algorithms used in the control systems requires to employ appropriate methods during the modelling process, like the agent-based one, which is the subject of this paper. The concept of an agent is derived from the object-based methodology of modelling, so it meets the requirements of representing the physical properties of the machines as well as the logical form of control systems. Each agent has a high level of autonomy and could be considered separately. The multi-agent system consists of minimum two agents that can interact and modify the environment, where they act. This may lead to the creation of self-organizing structure, what could be interesting feature during design and test of manufacturing system.

1. Introduction
In the beginning of 20th century, Henry Ford introduced revolutionary manufacturing system and the era of mass production has been started. The early production or assembly lines were tied to the particular product: the plant had to be shut down in order to change the assortment and the line had to be completely redesigned. Next years have brought changes and the production lines have become more flexible. New machines could be quickly switched from the one task to another. The real industrial revolution has come along with the first application of a logical controller and an industrial robot.

Falling costs of flexible machinery and electronic equipment have caused the faster evolution of production systems. Modern industry follows the vision of flexible, multiproduct manufacturing, lowering the costs and putting emphasis on the quality [1]. The flexibility has allowed quick reactions to the changing market situation. Nowadays, the industry uses the advanced equipment along with the new technologies, new methods of management and diagnostics [13, 14]. This translates into completely different, new methods of production processes modelling, which often have their roots in information technologies.
Another challenge is connected with the distributed manufacturing and Distributed Production Systems (DPS). According to Lima et al. [2], “A Distributed Production System is a production system composed by a network of autonomous processing elements, with the capability of rapid dynamic reconfiguration”. It is worth to emphasize the word “autonomous”, because it determines the new method of process organization and management. This implies the necessity to use different and individual approaches to an enterprise on every level of flexible production.

This paper discusses the use of agent-based formalism to represent the robotized manufacturing system. In the first part, the multi-agent philosophy will be compared to the other modelling methodologies that have similar objectives. Later, the issues of using the multi-agent methodology for modelling of the robotic workcell will be discussed.

2. Overview of selected methods used in manufacturing systems modelling

The researches have proposed several paradigms for describing the relations between parts of manufacturing systems. Among others there are Holonic Manufacturing Systems, Bionic Manufacturing Systems, Fractal Factory and the models based on multi-agent systems (MAS). These concepts are quite similar, because are based on the common assumption: the units, which create the system, have some level of autonomy.

The idea of Holonic Manufacturing Systems (HMS) is based on holons – the abstract entities that are introduced by the writer, Arthur Koestler in order to explain how the biological and social system evolves. The holon is certain part that – together with other holons – forms a larger unit of organization. On the other hand, the same, considered holon could be a hierarchy itself, containing the other holons. The hierarchy of holons is called holarchy and the holarchies may be recursive – the top level holarchy contains sub-level holarchies that contain sub-level holarchies etc. The main assumption of this idea is the holon’s independence and the ability of solving problems on its level of existence without the help from higher-level holons (but it may be controlled by them). This should ensure the resistance for the disturbances that comes from the environment and adaptation to changes. The single holon may be a member of many holarchies and could change the membership during the time. The concept of use of the holons in the manufacturing system is explained by Botti and Giret in [3]: “Holons in a holonic manufacturing systems assist the operator in controlling the system: holons autonomously select appropriate parameter settings, find their own strategies and build their own structure.” The idea of Holonic manufacturing Systems could be used in connection with multi-agent systems [4, 5].

The Bionic Manufacturing Systems mimic the behaviour of living organisms. The theory is based on the biological paradigms, where the basic unit is a cell. Cells form the biological system and build structures, organs and the whole body. The activity of cells is regulated by enzymes and hormones. The enzymes control the metabolism rate, while the hormones initiate specific physiological actions. Such model has been transformed and adapted to the manufacturing systems. The cells have been replaced by manufacturing units, so called coordinators correspond to enzymes, eventually strategies and policies act like hormones [2, 6, 7].

The Fractal Factory concept [2, 6, 7] comes from the fractal theory. One of the major properties of fractal is its self-similarity. In the other words it means that the fractal is based on the recursive pattern. A manufacturing company could be represented as a set of fractal units that have specific features (like self-organization), dynamics (can adapt to the environmental changes) and self-similarity (similarity of goals).

Another possibility of build the manufacturing system model is to use the agent-based modelling. This method will be the subject of the further part of this paper.

3. Agent-based modelling and multi-agent systems

All of the models, which were mentioned earlier, have common property that is a certain level of autonomy. This attribute is also very important when the agent-based system is considered. The term “agent” could be defined in many ways depending of the agent’s form: it could be a piece of software
or hardware, but the hardware agent will consist of information processing part (PLC, computer etc.) and actuators (motors, grippers etc.). The software agent is a sophisticated program that co-exists and cooperates with the other, similar programs in order to achieve a common goal. Franklin and Graesser [8] have formulated more general definition of an agent, which could be also used for description of the hardware agent: “An autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future.” According to the cited definition the agent autonomy consists in some kind of environment monitoring. The results should be then collated with the objectives and the impact on the environment should be consistent with the goal of the whole system.

In order to speak about multi-agent system, there must be minimum two agents inside the common environment and the primary goal for the system must be specified. The achievement of the common aim is possible only when agents interact with the environment and with each other. Although from the definition comes the fact that an agent is autonomous, the application of agent-based method uses several kinds of organization, where the agents’ autonomy is restricted by inner constrains or organizational structure. According to Lima et al. [2] and Shen & Norrie [9, 10], the agents can be organized in one of the following manners:

- **hierarchy of agents** – the agents on the lower level of hierarchy are controlled by the higher level agents and the autonomy is restricted in some degree because of “master-servant” relation,
- **federation of agents** – individual agents or group of agents communicate through the channels provided by special type of agents (facilitators, brokers or mediators) [9],
- **autonomous agents** – individual agents can communicate with one another without any mediators; autonomous agents are not controlled or managed by other agents or human being, have its own goals and set of motivations, have the knowledge about other agents and environment; this approach is suitable for systems with a small number of agents, where technical measures are represented by individual agents – it is also very useful to represent robotic systems with multiple, autonomous robots [9].

The basic structures of agent-based systems are shown in the figure 1. Similar shapes indicate similar types of agents.

![Figure 1. Basic structures of agent-based systems: hierarchy (a), federation (b) and autonomous agents (c) [10]](image)

Shen [10] has also described the federated architectures. It is worth to mention about two of them: facilitators- and brokers-based structures. The facilitator (figure 2a) is the agent that provides the communication interface for a group of related agents. It establishes the connection between group of local and remote agents by routing the messages to the other facilitators. The broker (broker agent) is somewhat similar to the facilitator, but the broker is not designated for specific group of agents – any agent can contact any broker in the same system. For this reason the group of brokers are depicted as a “cloud of brokers” or as the one agent that contains all of the brokers (figure 2b). In that manner the
utilization of the brokers could be balanced, because the clients ask the “cloud” for service and then the least loaded broker could be selected.

Apart from organization, agents should have an “action plan” – strategy. Yan et al. [11] define two main strategies with reference to multi-robot environment:

- collective or cooperative strategy – robots have a common goal and work together to “win the award” (accomplish the task),
- competitive strategy – robots are “selfish”, compete against each other for the resources; typical example of such strategy is two-player, zero-sum game like chess or soccer.

The industrial robots and machines use cooperative strategy to achieve goal – a market-ready product. This type of strategy is tightly connected with the communication between objects. The communication helps the machines to be cooperative, but strongly depends on the access to the communication medium (industrial networks). It involves the use of a separate strategy for access to the communication medium.

The selection of the agents’ organizational structure type depends mainly on the factory size and production volume. The hierarchical structure is used by number of industrial application that uses the multi-agent approach. In such distributed system, each agent could represent a machine or even the whole department. However, the hierarchical model is often criticized because of its centralized character.

The federated structure partially resolves the centralization issue of hierarchical structure. It is regarded as a compromise solution. Using facilitators, it simplifies the communication between agents and because of direct communication between facilitators it can be compared to the autonomous agent architecture. On the other hand, the group of agent uses common facilitator, so in some aspects the structure is still analogous to the hierarchy. The federation of agents ensures more efficient communication than hierarchy and simultaneously provides scalability [10, 15].

4. Multi-agent approach to the robotic workcell model

From the organizational point of view, a robotic cell could be considered as partially isolated environment. This induces the use of mixed architecture organizational model. The cell consists of limited number of machines (including robots) and could be organized as a group of autonomous agents. Simultaneously, the cell is a part of a larger manufacturing system, which in turn can be built on the basis of a different organizational model, like hierarchy of agents or federation of agents.

It is obvious that the large systems require specific organization of the information flow and it would be advisable to use the “federation of agents” model, in which brokers or mediators control the

Figure 2. Federation architecture: facilitators-based (a) and brokers-based (b) [10]
flow of the data stream and – in this way – minimize the resources allocated to communication. Also the holonic model could be used. According to Botti et al. [3] and Christensen [12], a holon consists of two parts: one for information processing and the other for physical processing. Using the holonic approach, it can be realized that the workcell may be depicted as a “black box” with the data interface and input/output ports for physical processing. The use of separate channels for messages and processing conforms to modern, numerically controlled machines — considering a machine as an agent, it communicates with the other machines (agents), but also exchanging data with the databases, SCADA systems etc. The described approach is illustrated in the figure 3.

The rest of manufacturing system is depicted as a cloud, because from the workcell’s perspective, there is no need to have complete information about the whole environment. The workcell is rather closed, specialized system, where the inner agents cooperate in order to realize the task. Because of limited number of machines (agents) inside the cell, they can communicate directly, as autonomous agents do. However the workcell cannot act without the information from the outside, from manufacturing system: what to process and how. On the other hand, the outer environment should have the information about the workcell’s condition, but not necessary about particular machine. The interaction between the agents inside the cell and the rest of manufacturing system requires a mediator or – in the more elaborated form – a facilitator or a broker. Such approach ensures that the cell’s agents do not need to know where to address the message. What’s more it is almost impossible for the local agent to know everything about the large system – it requires the large amount of data space to keep this information. In contrast, the knowledge about the local system, inside the workcell boundaries, could be kept using reasonable amount of data storage space.

The presented approach has more important advantages, like scalability and modularity. Both of them allow designing manufacturing systems based on multi-agent methodology, which could be easily expanded. What is more important, using the holonic approach, the workcell is regarded by the manufacturing system as “a whole” and the use of mediators, facilitators or brokers allows creating of some kind of universal interfaces, so the any workcell may be replaced by other, compatible one – only if the compatibility occurs on the message protocol level, as well as on the part processing level.

5. Conclusions
The agent-based modelling and multi-agent approach are the centre of attention of many scientists around the world. Many papers concern the use of these methods in the modelling of manufacturing processes and solving the certain problems with organization, efficiency and smoothness of production process. In this paper some aspects of such approach has been discussed. Particular attention has been paid to the problems concerning the architectures of agent-based systems. It should be concluded, that there is no exact definition of an agent and no strict way of use the agents in the modelling process.
The mentioned formalism of agent-based models, along with the holonic, fractal and bionic approaches gives the possibility of evolving the new methods of manufacturing systems representation.

Another part of the paper was dedicated to the problems of representing the workcell’s model using the multi-agent formalism. In this section the general, agent-based model of the workcell has been discussed. Because the cell is a part of large manufacturing system, the attention has been also paid to the communication issues and the modularity problems.

As a result of the considerations, there are some open problems concerning the modular approach, evolution of agent-based manufacturing systems and – particularly – the application of different architectures within the same model. The other important problem is the integration of different modelling methods with the multi-agent formalism. These points can be the basis for future research related to the application of the multi-agent formalism in modelling of manufacturing systems.

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