The comparison of the use of holonic and agent-based methods in modelling of manufacturing systems

K Foit\(^1\), W Banas\(^2\), A Gwiazda\(^3\), P Hryniewicz\(^4\)
\(^{1,2,3,4}\)Silesian University of Technology, Faculty of Mechanical Engineering, Institute of Engineering Processes Automation and Integrated Manufacturing Systems, Konarskiego 18A, 44-100 Gliwice, Poland

E-mail: krzysztof.foit@polsl.pl

Abstract. The rapid evolution in the field of industrial automation and manufacturing is often called the 4\(^{th}\) Industry Revolution. Worldwide availability of the internet access contributes to the competition between manufacturers, gives the opportunity for buying materials, parts and for creating the partnership networks, like cloud manufacturing, grid manufacturing (MGrid), virtual enterprises etc. The effect of the industry evolution is the need to search for new solutions in the field of manufacturing systems modelling and simulation. During the last decade researchers have developed the agent-based approach of modelling. This methodology have been taken from the computer science, but was adapted to the philosophy of industrial automation and robotization. The operation of the agent-based system depends on the simultaneous acting of different agents that may have different roles. On the other hand, there is the holon-based approach that uses the structures created by holons. It differs from the agent-based structure in some aspects, while the other ones are quite similar in both methodologies. The aim of this paper is to present the both methodologies and discuss the similarities and the differences. This may could help to select the optimal method of modelling, according to the considered problem and software resources.

1. Introduction
The “Fourth Industrial Revolution” is the term often used in relation to the significant contribution of computer technology in the industry. It is connected with the emerging technology breakthroughs in a number of fields, like robotics, artificial intelligence, Internet of Things etc. Introducing of new technologies to the manufacturing sector has led to the need for new methods of manufacturing processes modelling and machine management. For this reason, some methods – previously used in the field of computer science – have been adjusted to the industrial environment demands. Among the many methods tailored to the needs of the industry, the agents-based and holons-based methodologies were selected and will be described in the further part of this paper.

The will to resign from the hierarchical organizational structure of the manufacturing process came with the development of distributed computing and open systems architectures (especially computer networks) in the 80's of the last century. Duffie et al. [1] pointed out that the change of approach to the manufacturing systems (i.e. nonhierarchical control systems) may decrease the complexity of control structure, reduce the costs of control software development, improve reliability, increase maintainability and modifiability of such system. On the other hand, Hatvany [2] has claimed that the possibility of distributing the computing power across the network and the growing importance of
local area networks have opened the way for completely new structures with a high degree of machine intelligence that will be able to cope with some unexpected and unforeseen situations. At the same time, Hatvany notes that such approach will need the development of new architectural tools and new methods of synthesis of such systems. As it can be seen, the cited sources describe the plans of creation of the population of structures that have the ability of making the decisions, cooperation and some degree of autonomy. In both cases, the assumptions are very similar to the ones, used in the case of the agents- or holons-based methods that were developed some time later.

2. The definition of agent and the multiagent system
The concept of the agent is not new. For many years this term is used in the medicine and chemistry. The Medical Dictionary from Merriam-Webster website defines agent as “something that produces or is capable of producing an effect” or “a chemically, physically or biologically active principle”. It is significant that in both definitions appear the words like “produce an effect” or “active principle”. In the early reports in the literature, relevant to the agent systems in the computer science, the word “agent” was used in the similar way. Burkhart and Millen [3] in their paper introduced many types of agents that have assigned specific tasks, realized in the IT system. This can be considered as the initial form of a multi-agent system, because not only the tasks carried out by agents, but also the relationships between agents was described. Franklin and Graesser [4] have analyzed different approaches to the definition of "software agent" and on this basis, they introduced their own definition: “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”. In the case of industrial systems, the definition of an agent is based directly on the notion of an agent in terms of computer systems. Unland [5] defines it as “an agile and robust software entity that intelligently represents and manages the functionalities and capabilities of an industrial unit”. Later, he lists the industrial agent features such handling the interface and functionality of industrial devices, communicating in an efficient, collaborative and goal-oriented way, being autonomous unit etc. These attributes of an agent are shown and described in more detailed form in the figure 1. What’s more, Unland also points out that industrial agent must follow the company guidelines together with being dependent on the directives that come from higher levels. The autonomy of industrial agent may be abolished in some scenarios – especially in the case of emergency.

![Figure 1. The attributes of an agent.](image)

The multi-agent system (MAS) can be regarded as a set of agents that play different roles, but work (act) together in order to reach the common goal [6]. Although their strategies may be different, the final result is always specified at the start of the task. The concept of an agent determines its independence in some way, but in the multi-agent systems agents can create different types of structures, where individual entities are mutually dependent in some way, and therefore their independence is limited by certain rules that apply for the whole community.
3. The concept of the holon and the Holonic Manufacturing Systems

The term “holon” comes from the philosophy. The idea was introduced by Arthur Koestler, who attempted to present an unified theory of physical systems in order to explain its self-organizational behaviour [7,8]. The word “holon” has its origins in Greek: “holos” means “whole”, while the suffix “-on” stands for “part” [8]. The meaning reflects the dualistic character of holon – it is a part of some bigger whole, but consists of parts. The best examples of holons can be: a cell in the living organism, the organ in the human/animal body, the galaxy in the universe, fractals etc. The holons create the structures that Koestler has called holarchies. The noteworthy fact is that holon could belong to more than one holarchy at the same time and its membership can change with the passing of time.

The concept of holons has been successfully exploited in the business and the manufacturing domain. It fits perfectly in these domains because of their hierarchical organization (enterprises, companies, divisions etc.). Using holon as a model in the manufacturing systems has started the use of the new term: Holonic Manufacturing Systems (HMS) [8,9]. Botti and Giret [9] state that “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.”

Considering the role of holons in the manufacturing systems, it can be said that the whole system consist of independent, autonomous parts with the distributed control. The holarchy architecture suggests that the structure is rather hierarchical and thus has rigid character, what makes it less flexible [10], but it should be noted that holarchy combines the hierarchical and horizontal organization and in this way the system is more predictable and better reacts to the disturbances.

\[\text{Figure 2. The inner architecture of holon (a) [18] and the example of IEC 61499 representation (b).}\]

The model of a holon is described in the literature in better way than the manufacturing agent. First of all, the holon consists of two parts [11]: information processing part and physical processing part (figure 2). Both parts are connected through internal interface. The information processing part of holon enables the communication possibilities (interfaces) with the other holons as well as with the human sitting in front of computer. On the other hand, the physical processing part is responsible for controlling the particular resource, represented by that holon. The holon as part of the holonic manufacturing system is perfectly formalized in the form of so-called Function Block, which is formalized in the IEC 61499 standard (figure 2). The use of the IEC 61131 programming languages facilitates the implementation of holons philosophy during modelling of production systems.
4. Agents and holons in modeling of manufacturing systems

Although agents and holons are formally distinguished, it is not easy to say where is the border between one and another. The comparison of agents and holons was in detail carried out by Giret and Botti [12]. The most important outcome has been that the holon is the special case of agent. The authors also point out some strong differences between holons and agents. The most important one is that agents have not internal seperaration between information processing and physical processing part, like holons have. The other is that agents have not been intended for creating complex structures, however Horling and Lesser [13] list several examples of agents organizational paradigms with holarchy among them. Giret and Botti [9,12] also draw attention to the recursiveness, what is a special property that allow the holons to be a whole and a part of some whole simultaneously. It is not typical architecture for agents, but it is possible to simulate such structure in a special way, using the definition of the abstract agent [9]. The other difference concerns the cooperation: the holons are inherently cooperative, while agents can be cooperative as well as competitive.

The similarity between agents and holons causes that the researchers have been mixed both methods. Barbat et al. [14] discussed pros and cons for the agent-based and holon-based approach and decided to use the both methods in order to achieve best results. The author claim that holonic approach overcomes the agent limitations in the field of forming multi-level hierarchies or creating the temporary structures in the dynamic environment. The similar opinion was expressed by Unland [5], who claimed that “the holonic paradigm, extended by agent norms and policies, offers a starting point for MAS-based systems that also support hierarchical (control) structures and decision making” and introduced the term “agentification of holon”. Vrba et al. [15] go further and use the term “holonic agent”. On the other hand, there still are papers, where the authors uses “pure” agent-based approach [16,17].

Referring to the problems of modelling of production systems, a large number of software solutions, both commercial and freely available, should be mentioned. One of the common areas of application of this type of software is the analysis of efficiency of the production line in cases of different scenarios [19] and simulation in the virtual workspace [20]. Most of the commercial software is based on a graphical interface, while the model processing engine is not explicitly specified. On the other hand, most of the freely available software is based on Java language and needs the Java Runtime Environment (or even Java compiler) to run. It is worth to mention the JADE and WADE environments, NetLogo, FBDK etc. The last one is intended for working with the IEC 61499 block, while the rest is related to the agent-based modelling. The NetLogo environment offers another method of model description – System Dynamics Modeller. Based on the interaction and mutual impact of entities in the virtual environment, the SDM can generate the NetLogo code, using visual representation of the system’s model. However, in general, free agent/holons-based modelling software requires average or even good experience in programming.

5. Agent-based vs holonic approach in modelling of a manufacturing system

As it was mentioned earlier, the differences between agent-based and holon-based models of manufacturing systems were sometimes very subtle. The evolution of agent-based methods has blurred the borders even more. In case of complex models, the mixed methods are often used, which enable the synergy of agent- and holon-based approach.

In order to illustrate the difference between both domains, the simple system will be considered. Such system consists of manipulators, two identical assembly stations, storage and two outputs (conveyors), as it is illustrated in the figure 3. The fragment of manufacturing line is intended for assembly of two different types of toys: a car and a dump truck. The car is assembled from the following parts:

- a frame,
- a body,
- four small wheels,
while the dump truck is assembled from:

- a frame,
- a body,
- six large wheels,
- an open-box bed.

Both stations are capable to assemble any type of the toy. The type of the next toy is designated by order that comes from the higher level. The process proceeds as follows:

- the idle one of two input manipulators gets the parts from the storage and delivers them to the idle station, one by one,
- the idle machine starts the assembly process,
- after the station finished the process, the output manipulator places the toy on the proper conveyor in order to deliver it to the packing station.

It should be pointed out that the model of assembly cell is simplified and does not take into account any other, optional extras like sensors, holders, actuators etc. In the further part of paper agent-based and holonic approaches will be presented.

5.1. Agent-based approach

First of all it should be checked what functions are realized by the machines and what information are needed to achieve the goal, which is “to assemble a toy”. Because there are two types of toys, the agents must be ready to dynamically change their behaviour – they must act to fulfil the order demands, but also must analyze the signals from the environment, in order to use the available resources in the optimal way. As a result, the model contains the following agents:

- Order agent (O) – the higher level agent that delivers the information about the sequence of toys,
- Delivery agent (D) – supply the storage on demand,
- Supervisor agent (Su) – watches the whole process, passes the information about order to the cell and about process status to higher level agent,
- Storage agent (S) – keeps the information about components availability and their position,
- Manipulator agent (M) – moves the part or product between two places,
- Assembly station agent (A) – assembles the toy,
- Conveyor agent(C) – delivers the toy to the packing station.

Figure 4. The agent-based model of considered assembly line.

The dependence and relation of agents are shown in the figure 4. The heterarchical architecture allows the agents to cooperate while keeping the rules of communication and dependency. As it can be seen, the number of communication channels between agents are reduced due to presence of Supervisor agent. In this way, only the neighboring agents “talk” directly, because there is no common interest between – for example – Conveyor and Storage agents. The proposed network is only one of possible solutions, but it clearly illustrates the border between cooperating agents and the environment in which they act.

5.2. Holon-based approach

The same process will be presented in the form of holon-based model. Keeping in mind that the holons are scalable and recursive entities, the model may contain one holon that represents the assembly cell. At this level of generality, the cell is the “black box”: we “pour” the parts into it, press the proper button and get the ordered toy. In general three types of holons could be listed:

- Order holon (OH) – process the task, interacts with the other holarchies,
- Resource holon (RH) – resources (equipment) used for processing the parts: assembly stations, manipulators, conveyors, storage,
- Product holon (PH) – the entity that is processed in the cell,

The proposal of holarchy is presented in the figure 5. The most important fact that makes the difference between holon-based and agent-based approach is that the product is the active part of the system, not the part of environment. The other, worth to mention, thing is that the assembled toy is a set of holons and during the process the parts create temporary holarchies that evolves to the fully featured product. Moreover, the parts (holons) actively change the adhesion to the holarchies (resource
holons) – they may also exchange information with resource holons by visual properties (shape, color) or by identification markers (eg. barcode). In that way, the resource holon “knows” what to do next, and the core of self-organization of the process is the product holon.

The Order Holon plays the special role in the presented model of assembly cell. Being a member of more than one holarchy, it may be seen as the “representative” of the Assembly Cell holarchy and is responsible for the outside interaction. This approach is often used in the holon-based models, because it is easy to implement and reduces the number of communication channels and communication network load.

6. Conclusions
The competition in the market of goods forces manufacturers to increase the production efficiency, while assuring the diversity and high quality of product. This requires the reliable background of the entire process at the planning stage, taking into account the control and information infrastructure. At the same time, the dynamics and speed of production processes involve the rapid response to unforeseen events. For this reason, the possibility of implementing a certain level of machine intelligence becomes a necessity.

The beginnings of the agent-based and holons-based methods are dated back to the 80’s of the last century, but the recent years of dynamic IT market evolution and growing customer demands have made them increasingly popular in the field of industry. The purpose of this article was to compare both methods, their assumptions and practical application. Among other things, there is a lot in common between the two methodologies and the consequence of this fact is the use of mixed methods in order to achieve synergy. As a summary, two models of the same manufacturing process are presented, using the formalism of agents and holons. It is impossible to expressly draw the conclusions about the superiority of one method over another or the specify the guidelines for selecting and applying one of the described methods. The indication of certain facts may, however, be helpful in choosing the right approach during the modelling of production systems.
7. References

[1] Duffie N A and Piper R S 1986 Nonhierarchical control of manufacturing systems J. Manuf. Syst. 5 141.

[2] Hatvany J 1985 Intelligence and cooperation in heterarchic manufacturing systems Robot. Comput. Integr. Manuf. 2 101–4.

[3] Burkhart H and Millen R 1989 Performance-measurement tools in a multiprocessor environment IEEE Trans. Comput. 38 725–37

[4] Franklin S and Graesser A 1997 Is it an Agent, or just a Program?: A Taxonomy for Autonomous Agents Intelligent agents III agent theories, architectures, and languages Lecture Notes in Computer Science ed J P Müller, M J Wooldridge and N R Jennings (Springer Berlin Heidelberg) pp 21–35

[5] Unland R 2015 Industrial Agents: Emerging Applications of Software Agents in Industry ed. P Leitão and K Stamatis (Morgan Kaufmann)

[6] Lesser V R 1995 Multiagent Systems: An Emerging Subdiscipline of AI ACM Comput. Surv. 27 340–342

[7] Horling B and Lesser V 2005 A survey of multi-agent organizational paradigms Knowl. Eng. Rev. 19 281–316

[8] Christensen J H 1994 Holonic manufacturing systems: initial architecture and standards directions Proc 1st Euro Wkshp on Holonic Manufacturing Systems (Hannover)

[9] Botti V and Giret A 2008 Holonic Manufacturing Systems BT - ANEMONA: A Mutlit-agent Methodology for Holonic Manufacturing Systems (London: Springer London) pp 7–20

[10] Dilts D M, Boyd N P and Whorms H H 1991 The evolution of control architectures for automated manufacturing systems J. Manuf. Syst. 10 79–93

[11] Bussmann S 1998 An agent-oriented architecture for holonic manufacturing control Proceedings of first international workshop on IMS, Lausanne, Switzerland pp 1–12

[12] Giret A and Botti V 2004 Holons and agents J. Intell. Manuf. 15 645–59

[13] Horling B and Lesser V 2005 A survey of multi-agent organizational paradigms Knowl. Eng. Rev. 19 281–316

[14] Barbat B, Candea C and Zamfirescu C 2001 Holons and Agents in Robotic Teams A Synergistic approach In proceedings of ENAIS’2001, Dubai pp 654 – 660

[15] Vrba P, Tichý P, Mafík V, Hall K H, Staron R J, Maturana F P and Kadera P 2011 Rockwell automation’s holonic and multitagent control systems compendium IEEE Trans. Syst. Man, Cybern. Part C (Applications and Reviews) Rev. 41 14–30

[16] Sękala A, Ćwikła G, Kost G 2015 The role of multi-agent systems in adding functioning of manufacturing robotized cells IOP Conf. Series: Materials Science and Engineering 95 012097

[17] Rodrigues N, Pereira A and Leitão P 2013 Adaptive Multi-Agent System for a Washing Machine Production Line Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) vol 8062 LNAI pp 212–23

[18] Wang L and Haghighi A 2016 Combined strength of holons, agents and function blocks in cyber-physical systems J. Manuf. Syst. 40 25–34

[19] Golda G, Kampa A and Paprocka I 2016 Simulation model of robotic manufacturing line Annals of Computer Science and Information Systems vol 9, ed M Ganzha, L Maciaszek and M Paprzycki pp 107–13

[20] Ociepka P and Herbuš K 2016 Determining of a robot workspace using the integration of a CAD system with a virtual control system IOP Conf. Ser. Mater. Sci. Eng. 145 52010