MODELLING OF PRODUCTION PROCESS USING MULTIPLE ANT COLONY APPROACH

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Abstract: Artificial intelligence systems are often used to model production processes. One of the most commonly used methods are the swarm algorithms. Currently, different types of biologically inspired optimization algorithms (swarm ones) have been proposed for solving optimization problems, such as: genetic algorithms, differential evolution algorithms, ant algorithms (Ant Colony Optimization), the particle swarm optimization algorithm, bee algorithm. Latelythe new version of the last algorithm has been developed called the artificial colony algorithm (ABC). It is used for numerical optimization, which involves simulating the behavior of a honeybee swarm. The ant algorithm was proposed by Marco Dorigo, It is a probabilistic technique of solving problems by searching for good roads in graphs. It is inspired by the behavior of ants looking for food for their colony. In the real world, ants move randomly; when they find food, they return to their colonies leaving a trace consisting of pheromones. When another ant encounters this trail, it stops moving randomly and follows a trace towards food. In this paper it is described the application of the multiple colony version (MAC) of the ant algorithm for logistics problems optimization in production system.
Key words: swarm intelligence, ant colony optimization

1. INTRODUCTION

The original ant colony algorithm (ACA) was proposed in 1991 by Marco Dorigo in his Ph.D. thesis, which was published one year later [1]. The idea of the algorithm bases on a natural behavior of ants. Seeking food ants can find the shortest route between ant nest and the food source. Following this remark the inspired by the food-seeking behavior of real ants, ACA was proposed [2]. ACA is a meta-heuristic algorithm, which could be applied to any optimization problem. Among others it was applied to the travelling salesman problem (TSP), to Quadratic Assignment Problem (QAP), to Job-Shop Scheduling Problem (JSP), to Network Routing Problem, etc [3].

ACA approach bases on stochastic searching of the optimal solution being the result of specific evolution of an ant colony during the process of parallel simulating the behavior of particular ants, fulfilling the role of agents of the evolving system. So the collective behavior of ants, emerging from the interaction of the different individuals, leads to solving the analyzed optimization problems. In this way ACA is a form of multi-agent systems, where ants take part of agents, homogenous in their form but heterogynous in their behavior [4-6]. Moreover their rules base is very simple.

ACA has the advantages of strong robustness and universality. On the other side hand it has the limitations in the form of poor convergence hence it is easy for ACA to fall in local optima and stagnation. This is why it was put out many improvements which make ACA more efficient. One of possible extension is the multiple ant colony system (MACS) allowing solving multiple objectives problems [7, 8]. Colonies in MACS are hierarchically linked. Each colony is responsible for one optimized problem (e.g. optimizing the number of vehicle and optimizing the travelled distance as in [8]). Both colonies use independent pheromone tracks. On the other hand the hierarchical relations allow collaborate by exchanging information through pheromone updating.

2. ANT SYSTEM PROCEDURES

The algorithm of the Ant System (AS) is the simplest solution of the ant colony optimization process. In this system ants move randomly according identical procedure. After single iteration take place the updating of pheromone tracks. Let τ_{ij} be the value of the pheromone left on the floor pixel *ij* assuming that the floor is a grid of pixels. This value is updated according the next relation:

$$\tau_{ij} \leftarrow (1-\rho)\tau_{ij} + \sum_{k=1}^{m} \Delta\tau_{ij}^{k} \quad (1)$$

where:
ρ – evaporation rate,
m – number of ants,
$\Delta\tau_{ij}^{k}$ – quantity of pheromone laid on the pixel *ij* by the given k^{th} ant.

It is visible that the power of the pheromone route depends on its exploitation time (evaporation process) and the frequency of using (number of ants). Whereas the quantity of pheromone laid on the floor pixel *ij* by the given ant k in the current iteration is denoted as, equation (2):

$$\Delta\tau_{ij}^{k} = \begin{cases} Q/L_k & case\,1 \\ 0 & case\,2 \end{cases} \quad (2)$$

where:
Q – constant determined for the given ant system,
L_k – route length of the given k^{th} ant.

The case 1 describes the situation when the k^{th} ant used the floor pixel *ij* during its return to the colony. The case 2 describes any other situation.
The presented algorithm represents the real behavior of ants. However its quality of optimization process was not satisfactory. So the trials were undertaken to solvetwo problems: to improve the performance of the algorithm and to investigate and better explain its behavior. As a result was proposed the Ant Colony System (ACS) algorithm. In ACS only the best solution established since the beginning of the computation is used to be globally updated (updating of the pheromone). It allows avoiding long convergence time by directly concentrate the search in a neighborhood of the best route. This rule leads to substitution, in the case of ACS, the final evaporation updating with a local one. During each move of an ant the pheromone is modified according to the equation (3):

$$\tau_{ij}(t) \leftarrow \rho\tau_{ij}(t-1) + (1-\rho)\tau_0 \quad (3)$$

where:
ρ – evaporation rate ($0 \leq \rho \leq 1$),
τ_0 – initial pheromone value.

This ACS corrections allow the algorithm to be more competitive with other optimization tools.

3. PROBLEM DESCRIPTION

The decision-making situation, which is considered in the paper, could be defined as a search of optimal route of a production process in a robotized workcell. The workcell is intended to be modeled as a multi-agent system (MAS). MAS are the solutions in the area of artificial intelligence including all applications in which a number of independent agent stream to obtain goals established for the. So, in MAS, at the lowest level, it could be distinguished a set of agents A (where an agent a∈ A). In the analyzed case it is a colony of ants. The agent is embedded in a certain environment E. Each agent (ant) is limited with a set of rules R (where a rule r ∈ R). This set creates an agent knowledge base. This base allows defining the behavior of agents in relation to other agents and in relation to the environment and obstacles.
The definition of an agent is not precise hence a lot of elements influence its structure and behavior. According to the literature an agent is a form of a virtual being. It is an abstract concept of an entity, prepared for the AI application and embedded in its environment. This being could utilize resources being available in its environment. It uses these resources to obtain the goals of the system. The characteristic features of an agent are [9, 10]:
- autonomy,
- reactivity,
- communicability.

An agent could cooperate with other agents to exchange information or to fulfill the task that is to complex for single agent.
It should be mentioned that agents, created any holarchy, do not possess the full knowledge concerning their whole environment. They possess only information related with their origin and gathered through their previous operation. Such assumption guarantees that the whole system (holarchy) could be treated as a decentralized one. It results in the fact that a single agent rarely has knowledge of how to solve a problem or has the ability to implement actions to solve this problem. It must cooperate both in the information sphere and in the realization one. This is why the mutual cooperation is the fundamental rule of MAS. The way of cooperation depends on the external conditions and it changes with the change of knowledge about the environment and its temporary configuration.
The presented approach could be implementation in the area of modeling the robotized production workcells. Such a system could be simply modeled as a multi-agent system in the form of interconnected components linking all workcell components with related to them agents. So the particular agent represents the individual element of the workcell, taking into consideration the hierarchy of workcells components. One should remember that every workcell component is an independent element which has its own control system and program. On the other

hand all components in a workcell cooperate to gain the common objective. This objective is described with particular schedules as well as the program of a supervising unit. In Figure 1 is presented a layout of a system of agents that reflect a flexible production workcell. The flexibility, as in an actual cell is provided thanks to the application of a computer control. It allows dynamic data exchanging.

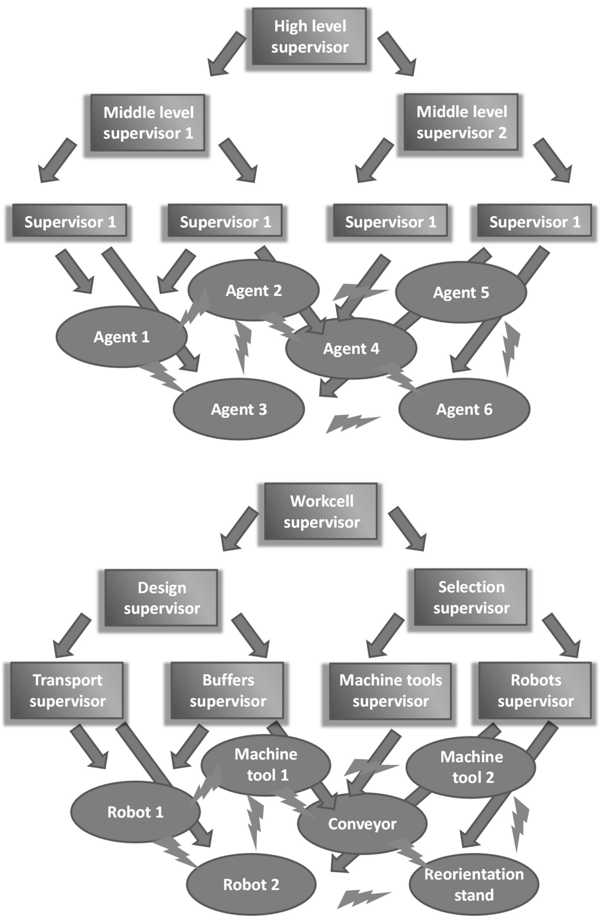

Fig. 1. Holarchy of MAS and of a workcell [11]

Generally the architecture of MAS is based on the assumption that robotized workcells are sets of rationally selected components being the optimal compromise in the analyzed period. It involves next assumption that selection of appropriate components of a workcell involves the designing or selection of agents representing these components. In the second case it is related with previous elaboration of bases of components (modules) of agents of workcell components, such as main components representing: agents of machine tools, agents of industrial robots, agents of inter-operational buffers, agents of technological tooling etc.

It should be emphasized that the fact that the design process of robotized workcells is a complex one. It involves a lot of decision making sub-processes. Some of them are related with the selection of the proper agents of chosen components. The selection criteria should correlate with the function fulfilled by this component in the workcell and the knowledge according the past experience about it. So additionally it is needed an appropriate advisory system to support this process.

In the analysis, described in this paper, it is proposed the other method of AI and namely the Case Base Reasoning (CBR) [12,13]. CBR bases on storing and processing the knowledge and experience gathered in previous decision making situations. So the idea of CBR bases on searching similar decisional situations in a knowledge base of previous cases [14,15]. This base also includes the description of a solution of each stored case. Such approach allows integrating dispersed knowledge concerning the past operation of the given production system and make it useful for future challenges. Such knowledge base is a very good extension to traditional MAS.

CBR is designed, basing on investigations concerning human intelligence, and the human learning process. On the other hand the reasoning module modifies its knowledge base basing on simply experience accumulation. In this element CBR resembles the agent intelligence module operation. But the base advantage of CBR is facilitating the process of acquiring and storing knowledge and experience of the system. This process runs in parallel with the currently conducted decisional one. In Figure 2 is presented a generalized conception of MAS architecture with additional knowledge bases.

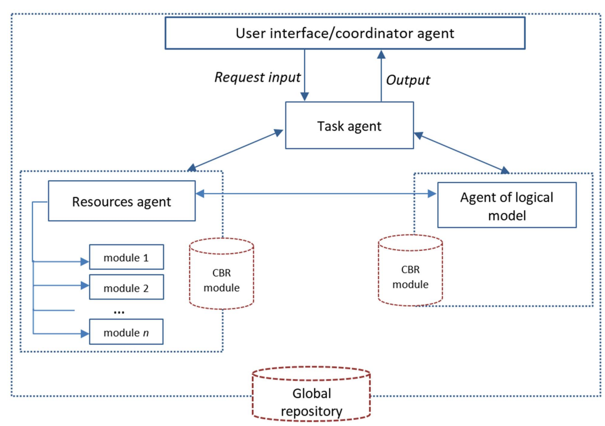

Fig. 2. Architecture of the system

One element in the process of functioning of a workcell is of highest importance. It is the autonomy of the decision making process during the designing phase. Each agent of this process has only the limited knowledge about this process, which is limited to its close environment. Moreover, the large number of requirements generates also decisional problems. The larger is the set of requirements the higher is the difficulty of the decisional process. These issues could be solved by linking the cooperation of agents in the

MAS optimizing approach that represent partial sub-sets of requirements and knowledge about the state of the design process. The optimal solution in this case is obtained as a result of MAS separate functioning. These remarks show the importance of the MAS application utilization in the analyzed case of workcell designing.
Basing on the presented above analysis it was proposed the structure of designed system of cooperating agents in the form of a holon [16]. So the holon is a system of relations and dependences between agents existing in the analyzed environment. It consists of small, decentralized and partially independent sub-sets of agents that are responsible only for the key goals related to them.
The analyzed structure of the system, as a virtual model of a robotized workcell, should consists of: a user interface, a system database and cooperating agents groups determined previous as holons. In the database is stored information about the process and the resources. This information is accessible to agents. They could receive and analyze the obtained data to influence on their environment. It allows them changing the environment structure being closer to the system objective. All components of the workcell could communicate with each other by signal links (information exchange). The signal bus allows receiving and sending binary information concerning the processes and programs conducted in the workcell.
Using the presented framework of MAS approach it was proposed the structure of the analyzed problem in the form presented in Figure 3.

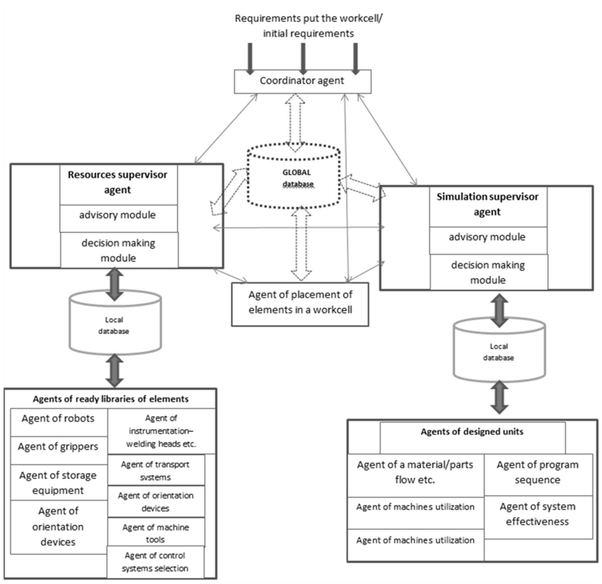

Fig. 3. Architecture of the system in a for of a holarchy of holons

Basing on the presented results it is planned to elaborate the method of modeling the workcell as a MAS system, including the issues of information managing and exchange.

4. MODELING THE PROBLEM

The NetLogo environment has been used to elaborate the multi-agent system of the analyzed manufacturing workcell. NetLogo is a multi-agent programming language and special pre-defined modeling environment. It allows simulating complex natural and social phenomena as well as systems. In NetLogo there are two forms of agents: working agents and layout agents. Working agents represents the changeable elements of the MAS environment. In this case the machined pieces. So the first group of agents could operate as ants in the ant colony optimization procedure. The second group of agents represents stable elements of the scene, so machine tools, transportation routes as well as obstacles.
Agents in NetLogo are operating concurrently. This type of cooperation allows them exploring micro-level behaviors of particular agents that lead to the macro-level patterns that emerge from their interactions between agents.
The proposed holarchy of a system being analyzed in the paper consist of mentioned previous elements that are placed in lines linked together. Each horizontal line represents one sub-system of the analyzed holarchy (Figure 4).

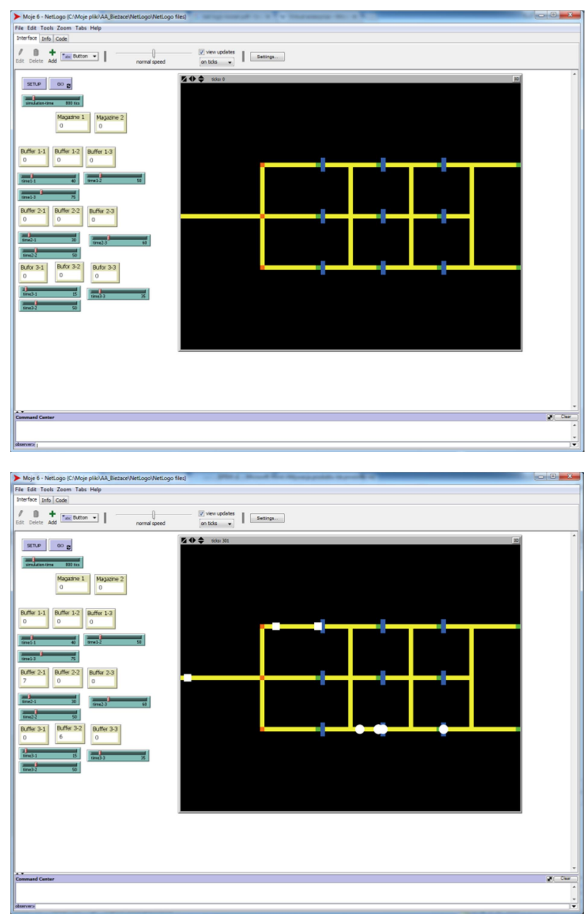

Fig. 4. Example of a simulation of the holarchy being analyzed

In the analyzed case the blue routes represents the possible routes of ants, representing the machined pieces. Each type of a workpiece is represented by other colony type, being settled in the input magazine. In the case two different processes are analyzed, which are represented by two different colonies (white squares represent ants of one colony and white circles represent ants of the second colony).

In Figure 4 is presented an example of simulation process being run. In this model the organization rule are represented by the set of possible decisions that could be made by a separate agent-ant concerning the chosen route. They could continue the manufacturing process (their food searching) at one manufacturer or change the next target point (manufacturer). The decision making process related with the route is made on the base of information of possible gains (food) in the particular points (machining stations). The change of the manufacturer is realized by taking the vertical lines linking one manufacturing line with others. The simulation was done at no limitations related with transportation lines.

5. CONCLUSIONS

Presently enterprises are searching for opportunities to maximize their manufacturing efficiency. One possibility is to use an AI approach like proposed an algorithm. It should be noted that scheduling the manufacturing processes for complex system configurations causes many difficulties. The paper presents results of exemplar analysis of utilization the multi-agent approach for manufacturing resources organizing. The exemplar solution is based on the application of MAS and ant colony algorithm in the NetLogo environment. The process of planning the manufacturing flow in complex structures of manufacturing systems requires effective utilization of specific AI tools. This can be achieved through utilization the specialized simulation environment to analyze and optimize the decision-making process related to planning of a manufacturing process and particularly to selecting routes that could be used by the workpieces being machined. This approach allows increasing the effectiveness of resources utilization in a production plant. The subject of further research will be related, in the area of MAC utilization, will be focused on creating more sophisticated MAS models. This particularly concerns the issues of optimization the transport units utilization.

Additionally one should state that in the contemporary enterprises the tendency to manufacture faster and more flexible is observed. It is related with the need to obtain higher productivity of the existing systems. One of ways to obtain that is making the production process more extensive. The other is to participate in complex production nets. These both solutions could be obtained by utilization, with higher effectiveness the achievements of contemporary AI methods and tools. It allows overcoming the problems associated with scheduling tasks in such systems that are time consuming and complicated and they could not be executed in real time what is frequently needed, especially in cases of unexpected disruptions [17]. The presented in the paper solution allows overcoming these problems. This is related with utilization the MAC approach in the complex MAS system, allowing modeling sophisticated rules of system behavior.

It should be stated that presented approach allows also increasing the quality of the system work what is strongly related with the appropriate organizational structure of the process being conducted [18, 19]. The optimization process is striving to obtain equilibrium between manufacturing costs and production time. Application of presented tools of artificial intelligence should increase the flexibility of the system on the planning stage. Results obtained on this initial stage of investigations show that the system allows to obtained balance and for less complicated cases of production system structure.

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