MULTIAGENT SHOP FLOOR CONTROL

Przemysław Oborski

Summary

In spite of rapid development of Information Technology there is lack of proper, flexible and inexpensive solutions suitable for integration flow in manufacturing systems. From the beginning of last decade the research have been focused on development of multiagent technology, that allows to build distributed, easy to reconfigure systems based on intelligent modules. A short revive of the state of the art in multiagent systems for shop floor control is presented in the paper. There is presented the multiagent shop floor control system developed at Warsaw University of Technology as well. The system is based on multiagent platform JADE, on which operate specialised independent agents that communicate and plan their work according to flexible algorithms.

Keywords: multiagent systems, shop floor control, manufacturing

Wieloagentowe systemy sterowania produkcją

Streszczenie

Szybki rozwój technik informatycznych nie zwiększa bezpośrednio informatyzacji procesów produkcyjnych. Spowodowane jest to brakiem tanich, prostych w obsłudze i otwartych na zmiany konfiguracyjne systemów sterowania produkcją. Obiecującym kierunkiem badań w tym obszarze są systemy oparte na idei wieloagentowości. W pracy przedstawiono informację o stanie wiedzy w tym obszarze oraz zaprezentowano prototyp systemu sterowania bazujący na agentach niezależnych i negocjacyjnych algorytmach decyzyjnych.

Słowa kluczowe: systemy wieloagentowe, sterowanie produkcją, wytwarzanie

1. Introduction

Rapid development of computer and software technology changes all domains of our life and creates the so-called information society, as some researchers state. At the present time processing of the information becomes one of the fundamental domains of our economy, next to agriculture, mining, production and services. Some researchers write about new economy, they call it e-economy. Others say that economy is the same, but the information processing is going across the traditional economy domains. In both cases the IT development strongly influences traditional domains, also the production and in this manufacturing [1].

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The first approaches of integration of information flow, based on computer and software technology, were proposed in the early 70s – at that time it appeared to be overly futuristic [2]. In 1976, Lin stated that the future of manufacturing would strongly depend on the computer technology [3] – he suggested that the implementing of the advanced software technology would be the approach allowing to solve the problem of decreased productivity because of labour cost increasing. In the next years number of models of Computer Integrated Manufacturing (CIM) were proposed [4] and the idea of fully automated production facilities known as Flexible Manufacturing Systems (FMS) was introduced [5].

Computer technology and software possibilities have been developed rapidly since that time, most of systems are basing on client-server architecture. In the industrialised countries the work organisation methods, employee demands and the idea of making business in manufacturing developed as well [6]. Currently manufacturing systems have to be flexible, open for reconfiguration and must ensure the highest quality and low production cost [7]. However, commonly used computer systems based on client-server technology have problems to meet requirements of modern manufacturing systems, they are not enough open for reconfiguration changes. As a result of that, usually a dedicated and very expensive solutions have to be developed or there is a lack of information flow between shop floor and management level.

2. Requirements of shop floor control systems

Continuously growing international competition in the manufacturing sector forces companies to reduce costs, increasing at the same time complexity of products and quality requirements. To meet those requirements complex products require control at all levels of production process. Systems of direct control of the manufacturing system, manufacturing cells, machines and performance of orders should be used [7]. Such a system should allow monitoring of all steps of the production process according to requirements of Life Cycle Management (LCM) (Table 1).

The idea of LCM is currently implemented in airplane industry which is especially important due to strict security requirements. However, in following years it will be implemented also in other production sectors, that manufacture complex products, like car or computer industry. The main problem in implementation of Life Cycle Management is monitoring and control of manufacturing parameters at all steps of the production process. Large production companies, that use automated production lines for mass production can use special dedicated information systems for control and monitoring. Such dedicated systems are very complex and expensive. The problem is within their low flexibility – reorganisation of production lines requires reconfiguration

of whole control and monitoring system. In currently used information systems, based on client - server architecture, reconfiguration of production system usually requires very expensive and deep changes. In developed countries significant number of parts are produced by Small and Medium Enterprises (SME). Their financial and organisation potential usually does not allow for implementation of expensive, complex control and monitoring systems [8]. Moreover, most of those companies perform batch production, that often requires changes of produced assortment and very often is connected with reconfiguration of the manufacturing system [9]. The main advantage of SMEs is their flexibility, however it requires flexibility of all elements of production system. High flexibility in case of SME usually decides on low level of automation, also information systems – control and monitoring systems have to be very flexible and open. Such systems have to combine control and monitoring functions. Currently used control systems do not meet those requirements. They are not enough flexible, too expensive and too complex, especially for SME (Fig. 1) [10].

Table 1. Requirements on Shop Floor Control and Monitoring systems for manufacturing processes

No.	Requirement	Characteristics
1	Data acquisition	Data acquisition from monitored process
2	Monitoring of manufacturing process	Analysing of data from manufacturing process and combining with set values. Taking control decision in the case of deviation detection, if necessary.
3	Processes control	Taking and performing of control decisions that aim at realising production plan and disturbance elimination.
4	Data registration	Registration of data from process and orders monitoring.
5	Openness on configuration changes	Easy reconfiguration of system (changing functionality, adding new machines, changing structure of system, etc.) in the case of reconfiguration of manufacturing system.
6	Flexibility	Flexibility in different orders performing, also orders that need functionality that was not supervised during system development.
7	Resistance on disturbances	System stability and resistance on disturbance, ability of taking local decisions to eliminate influence of disturbance on system performance.
8	Easy to use	User friendly system with intuitive decision support, easy to reconfigure and adding new functionality.
9	Operating in distributed environment	Operating in distributed environment consisted of computers, controllers and mobiles terminals and equipment connected by various kinds of computer networks.
10	Independence on computer operating system	Ability of operation in various control equipment and on various computer operating systems.

Shop Floor Control system has to allow integration of information flow between manufacturing and management level of company. It should allow to plan and perform orders. Orders performing needs planning and execution of control decisions. During realisation of production process, the monitoring of the most important parameters should be done on line and archive for further analyse and for Life Cycle Management Systems that manage whole data describing the history of particular part production. Basing on the data from monitoring, a control decisions can be done, especially in the case of disturbance appearance. The most important functions that have to be performed by shop floor control systems are presented in table (Table 1).

3. Architecture of information systems

An architecture of information system decides about its properties. Architecture of IT system is characterised by two factors:

- Information structure – characterises the physical structure of the system, the place where the information is performed.
- Decision structure – characterises the logical way of decision taking process, when decisions are taken.

The information structure of the system can be divided into three kinds of systems:

- Centralised – an information system is working in one physical localisation, it is located for example in one single computer. The centralised system can also work in client-server architecture where number of client computers allow only for data entering and presenting, but whole logical structure of the system is located in one place on a server. Whole operations are performed on the server. There work algorithms and data is stored as well.
- Hybrid – structure partly centralised, but with parts that work according to idea P2P (peer to peer) – information is performed on single computers that are kind of small servers that cooperate with other computers and with the main server of the system.
- Decentralised – an information system is distributed into number of physical localisations, different parts of the system work on different computers that are like small servers connected together into one logical system. There is not one main server, it is a clear P2P architecture. In that way multiagent systems work, in which equal, distributed agents perform in cooperation the separated tasks, but logically create one system.

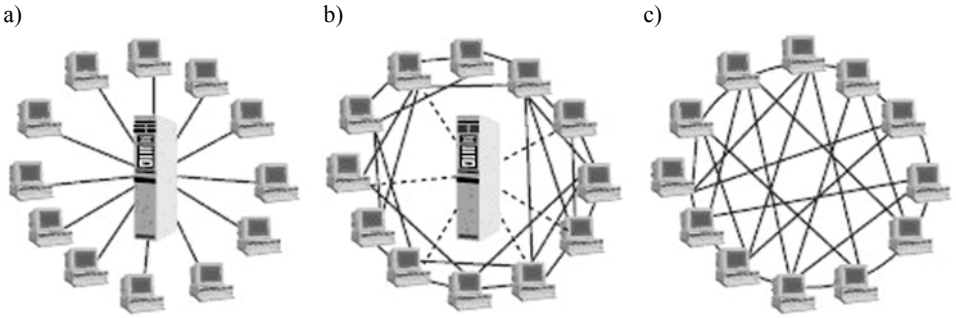

Fig. 1. Different architectures of decentralised information systems:
a) client-server, b) hybrid P2P, c) clear P2P [11]

The system can be also characterised from the decision process point of view. The decision structure depends on a control algorithm according to which system operates. It can be divided into:

- One decision unit – all decisions are taken in one place. Most of client-server information systems work in this way. In that system it is easy to perform global optimisation, but the system is very sensitive on unexpected disturbances.
- Hierarchical – local decisions are taken in different places, but all of them depend on central decision unit. Complex control systems and IT system based on client-server architecture are built in this way.
- Decentralised hierarchical – general decisions are taken centrally, however local decision units are able to perform local optimisations of controlled parts of the system. This kind of systems combine ability of global optimisation and high robustness on appearing small local disturbances.
- Heterarchical – fully decentralised architecture, all decisions are taken locally by independent, cooperating agents. In this way multiagent systems work. Such a system is not able to perform global optimisation, but it is very robust on unexpected disturbances.

4. Multiagent systems

Information systems based on an idea of agents seem to be very well suited to complex systems with high ratio of disturbances. An agent approach combines the idea of autonomy and the problem of complexity management. An autonomous agent is able to suite to local changes and disturbances. Philosophy of multiagent systems is based on similar systems that function in nature. Free market economy is organized in a similar way, agents are independent companies that compete to fulfil clients demands. They are autonomous, very often have to cooperate and are able to perform local optimisation [12].

Multiagent systems are distributed, particular agents can operate on different physical localisations (Table 2). Multiagent can be treated as an information platform that allows to implement different kinds of systems. Usually in such systems there are implemented heterarchical decision structures, that are based on various kinds of cooperation between independent agents. However, in cases where some kind of global optimisation can be useful, decentralised hierarchical algorithms or hierarchical algorithms can be implemented. Properly built multiagent platform should allow to implement different kinds of algorithms [13].

Table 2. Characteristic features of multiagent systems

No.	Characteristic feature	Description
1	Decentralised architecture	System based on agents that are software objects. They can operate in various places and communicate through computer network or Internet.
2	IT platform enabling implementation of various systems.	Agent based system enable implementation of various functionality and various control algorithms.
3	Various algorithms on different levels of system	Particular agents can have implemented various intelligent control algorithms.
4	Robustness on disturbances	High robustness on disturbances is a result of applying decentralised control algorithms and decentralisation of physical structure of system. Local disturbances and problems do not influence the whole system
5	Object orientation	Agent based systems are object oriented. There is possible development of types of agents, that can be replicated to perform tasks the require similar functionality.
6	Flexibility	Multiagent system can be easily suited to changing tasks. Modification of system functionality requires modification of selected agents, the reconstruction of the whole system is not needed.
7	Easy reconfiguration	Reconfiguration of system requires adding new agents or removing existing agents. It does not require rebuilding of the whole system and can be done during its work, even if new machines, orders or resources are added
8	Agent mobility	Agents have potential ability to move between various computers to perform requested tasks.

Research on information systems for manufacturing carried in last years are focused more and more often on implementation of multiagent philosophy into shop floor control. It seams that it should be the best solution for solving problems of complexity, flexibility, openness for reconfiguration and disturbance management that are the most important factors in present manufacturing systems. Those factors decide that traditional systems based on

client-server architecture are not suitable for shop floor control, especially in SME companies.

The most important features of agents operating in clearly separated environment are [14]:

- agent can observe its environment,
- agent has its own knowledge and opinion about environment,
- agent has its preferable reactions and opinion about environment,
- agent initialises and performs activities that change its environment.

5. Research on multiagent systems

Research on multiagent systems are carried from late 80-ties – the firms' ideas of such a system were formed at that time. One of the first publications from that time is written by Lin Solberg [15] in 1992. He proposed information system structure based on intelligent agent performing control tasks in manufacturing system. An interesting review paper from that time is article written by Sen [16]. Francisco and Douglas [17] in 1998 proposed a system based on independent agents planning its tasks with help of agent coordinator. At that time there were also developed ideas similar to multiagent philosophy, like [5] holonic [18], fractal and bionic systems [19].

Development of research focused on particular implementation of multiagent systems can be observed at the end of 90-ties. The main problem at that time was the necessity of development the own communication platform for each developed system. Since last years rapid development of research on multiagent systems can be observed. It is a result of development of universal environments for building a multiagent system. The most popular is JADE platform [20]. JADE allows to built prototypes of multiagent systems on the base of a ready communication platform and useful a set of tools. Standards supporting such systems have been developed by FIPA [21].

The latest achievements of research are presented by Morel [10] in a review of trends in Integration in Manufacturing. A survey of applications of multiagent systems (MAS) is presented by Shen [22], there is as well a survey of projects that have been realised in last years in the area of multiagent systems (Table 3). An interesting analyse of problems occurring in development of MAS systems for control and monitoring of manufacturing has been done by Morell [10]. Particular problems limiting practical use of multiagens systems are discussed and supervision of system based on MAS further development is presented. Information about research on the most interesting multiagent systems developed for control and monitoring of manufacturing systems can be found in following papers:

- multiagent system for control assembly cell, the particular stress if put on tasks planning, scheduling and disturbance management [23],

- control of manufacturing cell implemented in the didactic system [24],
- comparison of two multiagent systems applied in the real manufacturing environment [25],
- multiagent ERP (Enterprise Resource Planning) system [26],
- MAS system dedicated for monitoring and supervision of production processes [27].

Table 3. Projects based on multiagent idea performed in last years [22]

No.	Fields on which the project is focused	Number of projects
1	Cooperation in the frame of supply chain	25
2	Process planning and scheduling	32
3	Shop Floor Control	24

Review of research activity shows that mutiagent technology is very promising for systems that have to manage complex systems, with high number of disturbances and required high flexibility. Currently implementations of multiagent systems are the most advanced in telecommunication. There is still only few implementations in real manufacturing systems.

6. Prototype of shop floor contorl system based on multiagent idea

Since more then 10 years research on intelligent distributed shop floor control systems are carried at Institute of Manufacturing Techniques of Warsaw University of Technology. The survey of research in this area can be found in following papers [5, 6, 8, 28-33].

The first developed system was the implementation of the holonic idea. The prototype based on universal communication core and specialised modules – holons [33].

Current research are focused on development of multiagent shop floor control system based on universal JADE platform. System is based on three main types of agents:

- order agent – responsible for managing particular order, when a new order is accepted to manufacture, a new order agent is added. The order agent negotiates with machine agents a way and cost of machining (Fig. 2),
- machine agent – an agent responsible for control and representing particular machines, offers particular functionality for order agents, negotiates to receive optimal conditions of order performing (Fig. 3),
- process agent – an agent that keeps information about process – order and machine agents use stored information to perform order.

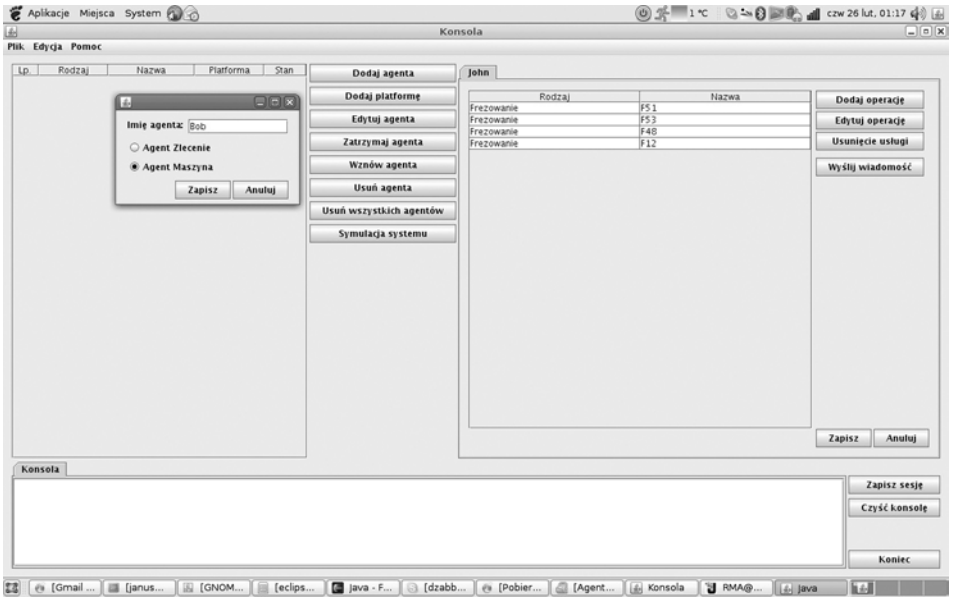

Fig. 2. Screens view of the system prototype

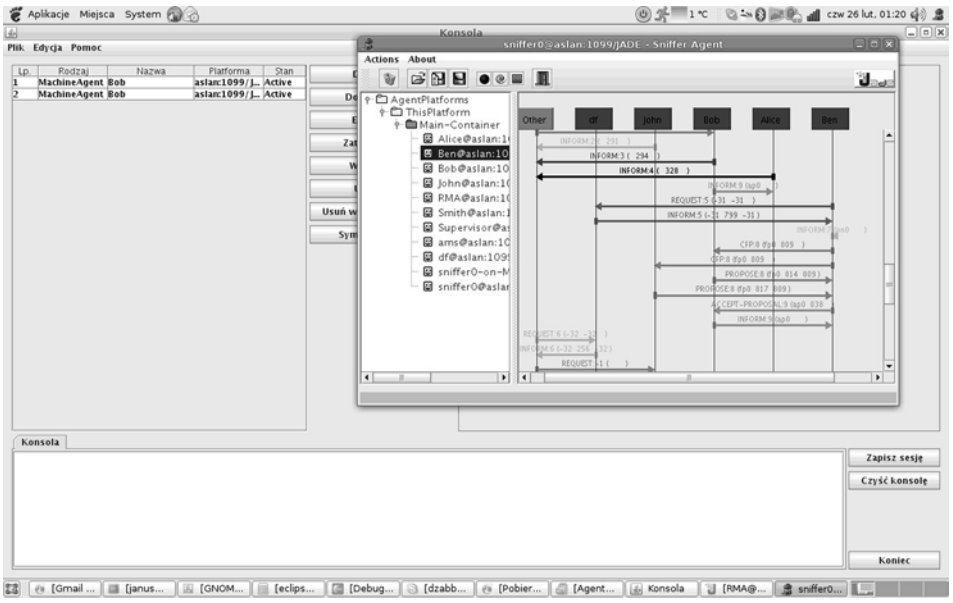

Fig. 3. Screens view of the system prototype

Moreover, a number of tool agents were developed as well. They are algorithm agent, agents responsible for system visualisation, system monitoring and data analysing agent.

Two kinds of algorithms are implemented in the system: the first one is based on time, the second one is based on cost optimisation. Actual algorithm can be easly changed into the other one. Both algorithms are fully decentralised, based on negotiations similar to free market. A system can operate in distributed environment on several computers connected by Internet. Special tools supporting system operation have been developed. There is an application that allows to observe communication between agents. It is important for analysing a negotiation process. Application for data analysing and presenting was developed, as well. It allows for easy performing tests of the systems, data analysing and presenting it in the form of charts and reports.

During tests developed system was compared to real control systems based on centralised client-server architecture. Tests show that prototype of the multiagent system with negotiation algorithms works properly and it can be further developed.

7. Conclusions

Trends in manufacturing systems development require a new approach for shop floor control systems. Present solutions based on client-server architecture are not enough flexible, not enough opened for reconfiguration changes and are too expensive, especially for Small and Medium Enterprises. It seams, that solutions based on multiagent technology will be the most suited for requirements of future manufacturing systems. They are flexible, open for changes, has decentralised physical structure and distributed decision process. Moreover, they allow for implementation of various control algorithms and reconfiguration of the system without switching off. In the past, main problems in development of such systems were lack of standards and lack of universal communication platform. Recent research projects focus mostly on developing practical solution of control systems on the base of JADE platform or similar solutions. Presented in the paper short review of state of the art in shop floor control systems based on multiagent technology shows rapid development in this field. The research done in this area at the Warsaw University of Technology has been presented in the paper. The prototype of shop floor control system based on multiagent idea was developed.

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