Multi-agent Systems in Industry: Current Trends & Future Challenges

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1 Introduction

The application of artificial intelligence (AI) mechanisms allows the development of intelligent machines/systems capable to solve very complex engineering problems. Multi-agent systems is one paradigm, derived from the distributed artificial intelligence and artificial life fields, that allows an alternative way to design distributed control systems based on autonomous and cooperative agents, exhibiting modularity, robustness, flexibility, adaptability and re-configurability.

This paper introduces the multi-agent systems paradigm and presents some industrial applications of this AI approach, namely in manufacturing, handling and logistics domains. The road-blockers for the current weak adoption of this technology in industry are also discussed, and finally the current trends and several future challenges are pointed out to increase the wider dissemination and acceptance of the multi-agent technology in industry.

2 Artificial intelligence and multi-agent systems

The management of complexity, currently found in systems ranging from washing machines to Airbus A380 aircrafts, requires the use of proper mechanisms and techniques. Artificial intelligence (AI), introduced by John McCarthy in 1956, is the science and engineering of making intelligent machines, especially intelligent computer programs mimicking the human though [1]. AI is becoming an essential part of the technology industry, providing solutions for several complex problems in engineering and computer science, namely:

- Game playing, e.g. machines beating human chess players.
- Optimization, e.g. optimizing logistics and production processes.
- Pattern recognition, e.g. detection of trends and patterns in medical or production diagnosis.
- Computer vision, e.g. the navigation of autonomous mobile robots and analysis of medical images.
- Speech recognition, e.g. supporting human-machine interfaces.

- Intelligent control, e.g. providing adaptive and intelligent behaviour to control processes.

When applying AI techniques, several topics should be considered, namely the perception, reasoning, knowledge, planning and learning, as well some philosophical issues about the ethics of creating artificial intelligent beings.

The multi-agent systems (MAS) [2;3] is a paradigm that takes inspiration from several disciplines, mainly from distributed artificial intelligence (DAI) and artificial life (that is related to study and model systems possessing life, i.e. capable of reproducing, surviving and adapting in hostile environments). Multi-agent systems are based on a society of distributed autonomous, cooperative entities, each one having a proper role, knowledge and skills, and a local view of the world, being its behaviour regulated by simple rules. Agent-based solutions replace the centralized, rigid and monolithic control by a distributed functioning where the interactions among individuals lead to the emergence of "intelligent" global behaviour (see Fig. 1). Note that such systems exhibit high degree of autonomy and re-configurability, without a fixed client-server structure.

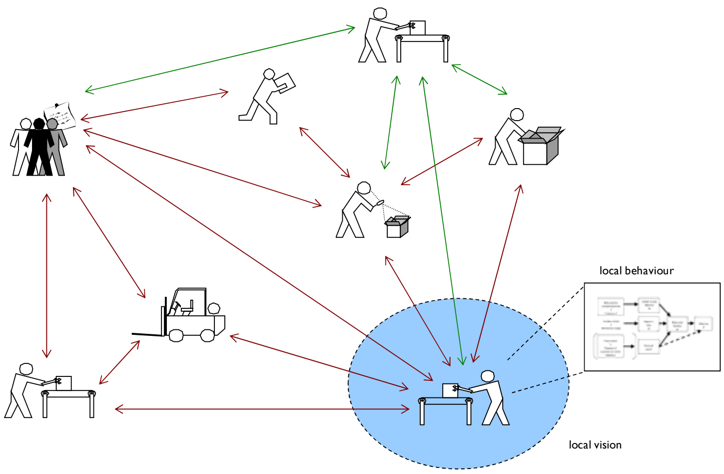

Fig. 1. MAS working in practice.

MAS is aligned with the current trend to build modular, intelligent and distributed control systems, which exhibit innovative features, like the agile response to the occurrence of disturbances and the dynamic re-configuration on the fly, i.e. without the need to stop, re-program and restart the process.

3 Applications of MAS in industry

The MAS approach is suitable to support the current requirements for modern control systems in industrial domains, providing flexibility, robustness, scalability, adaptability, re-configurability and productivity. MAS is being applied with success to a wide range of domains, namely electronic commerce, graphics (e.g., computer games and movies), transportation, logistics, robotics, manufacturing, telecommunications and energy. As examples, it is possible to refer the application of multi-agent systems solutions in the Daimler Chrysler factory of engines in Stuttgart [4], Tankers International that operates one of the largest oil tanker pools in the world [5], Air Liquide America to optimize the distribution of medical and industrial gases [6] and US Navy ships to control the heating, ventilation and air conditioned (HVAC) systems [7]. A deep analysis of industrial applications of MAS can be found in [8;9].

The analysis of the surveyed industrial applications of agent-based solutions allows extracting the following conclusions:

- Relatively small adoption of agents in industry, being the implemented applications limited in terms of functionality.
- The solutions address mainly the high-level control or the pure software systems (e.g. the electronic commerce).
- Little enthusiasm from both the technology providers and the industry companies.

The reasons for this weak adoption in industry were already widely discussed in the literature by several authors, namely [8;10]. Briefly, the main road-blockers are the required initial investment, the need to adopt the distributed thinking, the interoperability in distributed heterogeneous systems, the missing standardization, the real-time constraints and the missing technology maturity.

4 Current trends and future challenges

Lately, some promising perspectives for the adoption of the agent technology were provided by the development of multi-agent based solutions by several software developers companies, e.g. NuTech Solutions, Magenta Technology, Smart Solutions and Whitestein Technologies, and by several automation technology providers, e.g. Rockwell Automation and Schneider Electric. However, the main trend in the industrial application of multi-agent systems is to convince industry people of the benefits of using agents, e.g. by providing demonstrators running in industry that shows the maturity, flexibility and robustness of agent-based solutions. This will allow industrial companies to “believe” in the agent technology and its principles.

Additionally, several future challenges can be pointed out in industrial agents, namely:

- *Standardization*, which is pointed out by industry as a major challenge for the industrial acceptance of the agent technology, since standards may affect the development of industrial MAS solutions, namely the IEEE FIPA (Foundation for Intelligent Physical Agents), IEC 61131-3, IEC 61499, ISA 95 and semantics and ontologies standards.
- *Integration of other complementary technologies*, e.g. IEC61131-3 and IEC 61499 approaches to implement the low-level control that is not addressed by the agents, and Service Oriented Architectures (SOA) / Web services to solve the interoperability problems allowing the vertical and horizontal integration.
- *Mature engineering development methodologies, deployment and tools*, that simplifies the engineer of agent-based systems. For this purpose, simulation is a need to test the emergent behaviour before the real deployment.

- *Bio-inspired techniques*, to enhance the engineering of more robust, adaptive, reconfigurable and responsive systems. In particular, self-organization is mandatory to support re-configuration and evolution, being also important to consider other self-* properties, such as self-learning, self-adaptation, self-optimization and self-healing.

The fulfilment of these challenges leads to the development of more powerful agent-based systems that may be better accepted by industry.

6 Conclusions

As conclusions, AI provides a set of advantages to improve the performance of automatic complex systems, and the multi-agent systems, as a paradigm derived from AI, is suitable to address the current requirements imposed to industrial companies.

In spite of being already adopted in several industrial domains, the multi-agent technology still has a long and difficult path to be traversed for a wider acceptance of these AI concepts in industry.

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